GOVERNMENT OF INDIA
MINISTRY OF HOUSING AND URBAN AFFAIRS

MANUAL ON WATER SUPPLY AND TREATMENT SYSTEMS (DRINK FROM TAP)

PART B: OPERATION AND MAINTENANCE
SECOND EDITION - REVISED AND UPDATED

CENTRAL PUBLIC HEALTH AND ENVIRONMENTAL ENGINEERING ORGANISATION

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In Collaboration with

MARCH 2024

In keeping with the advancements in the sector, updates as and when found necessary will be hosted on the Ministry's website: http://mohua.gov.in and CPHEEO website: http://cpheeo.gov.in. The readers are advised to refer to for further updates.

हरदीप एस पुरी
HARDEEP S PURI

भारत 2023 INDIA

सत्यमेव जयते

आज़ादी का अमृत महोत्सव

आवासन और शहरी कार्य मंत्री
पेट्रोलियम एवं प्राकृतिक गैस मंत्री
भारत सरकार
Minister of
Housing and Urban Affairs; and
Petroleum and Natural Gas
Government of India

MESSAGE

In 2010, the UN General Assembly recognised "the right to safe and clean drinking water and sanitation as a human right that is essential for the full enjoyment of life and all human rights." Providing safe and reliable water to our rapidly increasing urban population, in alignment with Goal 6 of the Sustainable Development Goals, will enhance the quality of life and ease of living, leading to increased productivity and economic development in the country.

India's urban water sector is under immense pressure due to the increasing population, rapid urbanisation, and climate change. To ensure sustainable and resilient urban water management, transformative changes are required. The Atal Mission for Rejuvenation and Urban Transformation (AMRUT), launched in June 2015 by the Hon'ble Prime Minister Shri Narendra Modi ji, caters to that purpose by providing water supply facilities in 500 Class-I cities. Its tremendous success and citizen acceptance led to the launch of the AMRUT 2.0 Mission which aims to make all Indian cities 'water secure' and provide functional tap connections to all urban households. The AMRUT 2.0 mission advocates for the "Drink from Tap" facility to ensure safe and reliable water for urban citizens.

This revised manual on Water Supply and Treatment will serve as a useful guide for state governments, urban local bodies, parastatal agencies, and other stakeholders for effective and efficient planning, implementation and management of water supply systems with the "Drink from Tap" facility.

I compliment the AMRUT Division, Central Public Health & Environmental Engineering Organisation (CPHEEO), Expert Committee for the preparation of this manual, as well as the support extended by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and the WAPCOS study team in preparing this document.

(Hardeep S Puri)

New Delhi
03 November 2023

कौशल किशोर
KAUSHAL KISHORE

आवासन और शहरी कार्य राज्य मंत्री
भारत सरकार
Minister of State for Housing & Urban Affairs
Government of India

सत्यमेव जयते

संदेश

जल आपूर्ति और जल शोधन प्रणालियों पर अदयतित नियम-पुस्तिका का लोकार्पण करते हुए मुझे बेहद हर्ष और इसके उददेश्यपरक होने की गहन अनुभूति हो रही है। यह आवासन और शहरी कार्य मंत्रालय की एक अत्यंत महत्वपूर्ण पहल है। इस यात्रा पर आगे बढ़ते हुए हमें याद रखना चाहिए कि अदयतित नियम-पुस्तिका केवल दिशानिर्देशों का संकलन मात्र नहीं है अपितु यह भारत के भविष्य की एक पथ-निर्देशिका भी है। यह हमारे नागरिकों से स्वच्छ, सुलभ और सतत जल का एक वचन है। यह एक विकसित राष्ट्र के निर्माण के प्रति हमारी प्रतिबदधता है जहां जल निर्बाध रूप से बहता है, और हर एक नल आशा की नई किरण लाता है। यह जनमानस के साहस और सामर्थ्य के प्रति कृतज्ञता है जो विपरीत परिस्थितियों में भी एक उज्जवल भविष्य के लिए प्रयासरत रहते हैं।

इस नियम-पुस्तिका के तीन प्रमुख भाग हैं। इसके भाग 'क' में इंजीनियरिंग, भाग 'ख' में संचालन और रखरखाव और भाग 'ग' में प्रबंधन को शामिल किया गया है।

इस नियम-पुस्तिका में जल आपूर्ति प्रणालियों के निर्माण और प्रबंधन की उन जटिलताओं पर गहराई से विचार किया गया है जो विविध प्रकार के क्षेत्रों में अपनाई और विकसित की जा सकती हैं। इसमें विभिन्न जल स्रोतों से जल संग्रहण के लिए नवीन कार्यनीतियाँ प्रस्तुत की गई हैं जो यह सुनिश्चित करती हैं कि संग्रहित किया गया यह जल उपभोग के उच्चतम गुणवत्ता मानकों को पूरा करता है। इसकी एक उल्लेखनीय विशेषता 'नल से पीयें जल' की सुविधायुक्त दबावयुक्त 24x7 जल आपूर्ति प्रणालियों पर ध्यान केंद्रित करना है। यह परिवर्तनकारी

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दृष्टिकोण, जिसे अक्सर कम करके आंका जाता है, लाखों लोगों के जीवन में क्रांति लाने की क्षमता रखता है। नल से सीधे स्वच्छ और सुरक्षित पेयजल की उपलब्धता एक सुविधा से कहीं अधिक बढ़कर है; यह जन स्वास्थ्य, महिला सशक्तिकरण और सामाजिक प्रगति की आधारशिला है। इसलिए इन प्रणालियों को लगन और विश्वास के साथ लागू करना हमारा दायित्व है।

'नल से पीयें जल' सुविधाओं के महत्व को रेखांकित करने के लिए, हमें उनकी प्रभावशीलता पर विचार करना चाहिए। घरों के भीतर स्वच्छ पानी की उपलब्धता का अर्थ है कि बच्चों की स्कूलों में अधिक उपस्थिति दर्ज होगी, महिलाएं आर्थिक गतिविधियों में सहभागी बन सकती हैं, और लोग दूषित जल से उत्पन्न होने वाली बीमारियों से चिंतामुक्त होकर खुशहाल जीवन जी सकते हैं। यह एक स्वस्थ और समदर्शी समाज के निर्माण की दिशा में एक ऐतिहासिक कदम है।

अमृत (अटल नवीकरण और शहरी परिवर्तन मिशन) और इसका अनुवर्ती मिशन अमृत 2.0 इस दृष्टिकोण को आगे बढ़ाने में महत्वपूर्ण भूमिका निभा रहा है। इस प्रकार की पहल, प्रत्येक नागरिक को बुनियादी सेवाएं प्रदान करने और शहरी परिदृश्य को बदलने की भारत सरकार की प्रतिबदधता को रेखांकित करती है।

आइए ! हम सभी सार्वजनिक और निजी क्षेत्रों, विशेषज्ञों और नवप्रवर्तकों के साथ मिलकर इस नियम्-पुस्तिका को एक साकार परिवर्तन का रूप प्रदान करें। आइए ! हम ज्ञान, प्रौदयोगिकी और सामूहिक इच्छाशक्ति का भरपूर उपयोग करते हुए यह सुनिश्चित करें कि प्रत्येक भारतवासी 'नल से पीयें जल' से किसी भी स्थान या परिस्थिति में सहजता से पानी पीने का आनंद ले सके।

हम सभी साथ मिलकर एक ऐसे भविष्य का निर्माण कर सकते हैं जहां जल सिर्फ एक संसाधन नहीं बल्कि जीवन, समृदधि और सम्मान का प्रतीक हो।

(कौशल किशोर)

नई दिल्ली
27 अक्तूबर, 2023

मनोज जोशी
सचिव
Manoj Joshi
Secretary

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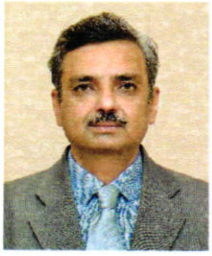

MESSAGE

India is a part of the global trend towards increasing urbanisation in which more than half of world's population is living in cities/towns. This phenomenon has been driven by factors such as industrialization, rural-to-urban migration, and economic opportunities in urban areas. Cities hold tremendous potential as engines of economic and social development. For Indian cities to become growth oriented and productive, it is essential to develop an excellent urban infrastructure by utilizing cutting-edge technology and sustainable infrastructure investments.

Water is an essential human requirement and lack of clean water has a significant influence on the health of urban people as well as the economic growth of urban areas. Therefore, it is utmost important to develop water supply infrastructure to ensure effective service delivery and sustainability.

To meet the aforesaid objective, Central Public Health and Environmental Engineering Organisation (CPHEEO), which is the technical wing of the Ministry has updated and revised the existing manual on Water Supply and Treatment as Manual of Water Supply and Treatment Systems (Drink from Tap) in three Parts – Part A-Engineering, Part B-Operation & Maintenance and Part C-Management to provide guidelines to Policy Makers, Public Health Engineers, Field Practitioners and other Stakeholders for planning, design, operation & maintenance and management of water supply systems with "Drink from Tap" facility to be taken up under various Central Missions like AMRUT 2.0 and State programs.

I would like to commend the untiring efforts of Dr. M. Dhinadhayalan, Adviser (PHEE), CPHEEO and Chariman of Expert Committee, Members of Expert Committee, AMRUT Division, Central Public Health & Environmental Engineering Organisation (CPHEEO) and the support extended by Deutsche Gesellschaftfür Internationale Zusammenarbeit (GIZ) GmbH, Germany, Government of Germany and WAPCOS study team, who were associated with the task of accomplishment of the manual for the benefit of water supply sector.

(Manoj Joshi)

New Delhi
November 06, 2023

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भारत सरकार
आवासन और शहरी कार्य मंत्रालय
GOVERNMENT OF INDIA
MINISTRY OF HOUSING AND URBAN AFFAIRS

FOREWORD

It is with immense pride and enthusiasm that I introduce the "Manual on Water Supply and Treatment Systems (Drink from Tap)" revised and updated by the Ministry of Housing and Urban Affairs. This comprehensive Manual stands as a testament to our unwavering commitment towards achieving Drink from Tap facility that will ensure efficient, sustainable, and accessible water supply for our growing urban communities.

Water, the essence of life, is a fundamental right of every individual. As our cities expand and population increases, the demand for this precious resource becomes more pressing than ever. In this context, a robust framework that encompasses every aspect of water supply and treatment is indispensable. This manual, divided into three crucial parts - Engineering, Operation & Maintenance, and Management - addresses these aspects comprehensively.

Part A: Engineering focuses on the foundation of any water supply system encompassing planning, design and implementation. By delving into detailed planning and design methodologies, technological innovations, and contemporary practices, this section equips professionals and field practitioners with the knowledge required to create efficient and resilient water supply infrastructure with decentralized approach using District Metered Areas (DMA) concept. The manual not only emphasizes conventional treatment technologies but also introduces cutting-edge technologies that have the potential to revolutionize water supply systems, ensuring sustainable service delivery and adaptability to changing urban landscapes.

Part B: Operation & Maintenance recognizes that the creation of a water supply system is only half the journey; efficient operation and vigilant maintenance are imperative to ensure its longevity. This section outlines best practices, procedures, and guidelines for maintaining the functionality of water supply systems. From routine upkeep to troubleshooting, the insights shared here will contribute to uninterrupted water supply services for urban residents by continuous monitoring and control of Non-Revenue Water (NRW) as well as monitoring and surveillance of drinking water quality using smart technologies.

Part C: Management acknowledges the multifaceted nature of water supply systems, necessitating a holistic managerial approach. By elucidating management practices, policy frameworks, and governance strategies, this section offers guidance to

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administrators and policy-makers. This part of the manual emphasised the need for Capacity Building, Asset Management and Public Private Partnership which are crucial for successful management of a Drink from Tap Water Supply System. Therefore, effective management ensures equitable distribution, financial sustainability, and the ability to adapt to dynamic urban requirements considering climate resilience.

In conclusion, the "Manual on Water Supply and Treatment Systems (Drink from Tap)" will serve as a beacon, illuminating a path towards an improved urban water management landscape.

I extend my gratitude to Dr. M. Dhinadhayalan, Adviser (PHEE), CPHEEO and Chariman of Expert Committee, Members of Expert Committee, Special invitees, CPHEEO Officials, GIZ and WAPCOS Study Team, who have contributed to this manual with the zeal to promote the practice of "Drink from Tap". It is my sincere hope that this resource becomes an indispensable companion for professionals and stakeholders engaged in the vital task of providing clean and accessible water to our urban communities.

Together, let us forge ahead in our mission to build sustainable, liveable and water secure cities, where the availability of safe water is never compromised.

(**D Thara**)

New Delhi

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सत्यमेव जयते

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GOVERNMENT OF INDIA
MINISTRY OF HOUSING AND URBAN AFFAIRS
NIRMAN BHAWAN
नई दिल्ली-110011, तारीख 20
New Delhi-110011, dated the 20

PREFACE

Water security remains a pressing concern encompassing issues related to both quantity and quality. Contamination of surface water sources and depletion of groundwater reserves have become a significant challenge threatening long-term sustainability. Additionally, preventing contamination of drinking water from the distribution system to household underground storage sumps is a vital challenge to tackle for safeguarding public health. These challenges are crucial to address for ensuring the availability and quality of this essential resource.

The earlier Water Manual (1999) recommended that the water supply projects in urban areas shall be planned, designed and implemented to achieve 24x7 pressurised water supply system (PWSS). It also suggested to adopt residual pressure of 7m for the towns having single storey buildings, 12m for 2 storeyed buildings and 17m for 3 storeyed buildings and so on. But the Manual was grossly missing the concept of Operational Zones (OZs) and District Metered Areas (DMAs). Therefore, in the past, the Urban Local Bodies (ULBs) planned, designed and implemented water supply projects considering large size networks (large zones) without properly following the residual pressures as recommended in the earlier Manual. This led the system to shift to intermittent mode just after the commissioning of the project. At present, in almost all the towns, water supply is intermittent with a duration ranging from 2-6 hrs/day which results into contamination of water in the pipeline during non-supply hours, high Non-Revenue Water (NRW) and inequitable water supply. Due to intermittent water supply the cities are grappled with many Operation & Maintenance (O&M) and Management challenges.

Therefore, it is crucial to plan, design and implement projects by changing the conventional planning to a decentralized approach, establishing OZs and DMAs with a specific number of house service connections (HSCs), increased residual pressure and ensuring 100% metering to make the system self-sustainable. The renewed system will address the O&M and Management challenges which the systems are currently facing.

During O&M high level of NRW is an operational burden and thus monitoring and control of NRW is very crucial. Urban water service providers/utilities are unable to cover their

O&M costs due to high NRW which leads to revenue loss and increased operational costs. The constant need for repair and maintenance of aging infrastructure is essential to ensure its efficient and effective operation and maintenance of the system. Another foremost issue is lack of water quality monitoring and surveillance during O&M which is the key for sustaining the success of the project with Drink from Tap (DFT) and effective service delivery.

Urban water service providers are confronted by significant management issues due to lack of capacity and financial resources. Therefore, it is important to engage Public Private Partnership (PPP) for efficient implementation, O&M and Management of the 24x7 PWSS.

India's dream of becoming a developed nation hinges on overcoming these water-related challenges. Imagine a scenario where every household enjoys the privilege of continuous pressurised water supply with the assurance of safe drinking water directly from the tap which is the vision that drives Govt. of India initiatives like Atal Mission for Rejuvenation and Urban Transformation 2.0 (AMRUT 2.0). Achieving this vision is not just an aspiration but an imperative for a progressive, healthy and prosperous India.

Keeping in view the above the Ministry has revised the existing Manual with the focus on operationalizing the existing intermittent water supply systems to 24x7 PWSS with an objective to provide drink from tap and its ease of O&M and management. The Expert Committee constituted under the chairmanship of the undersigned with the Technical Support of GIZ in June 2020, has brought out 3 parts of the Manual to address the challenges in the planning, design, implementation, operation & maintenance and management of 24x7 PWSS.

Part A Manual (Engineering- Planning, Design and Implementation) addresses the consistent and secure supply of clean water and provides guidelines for planning, design and implementation of 24x7 water supply with Drink from Tap in urban areas based on operational zones & DMAs. It also provides guidelines for planning, design and implementation of Regional Water Supply System (RWSS) for both urban and rural areas. The prevention of contamination of water within distribution systems and household storage is emphasized along with the crucial transition from the existing intermittent water supply to 24x7 PWSS and achieving 100% metering for ensuring sustainability of 24x7 PWSS.

The Part B Manual (Operation and Maintenance) addresses challenges related to the operation and maintenance of 24x7 PWSS. It underscores the importance of maintaining aging infrastructure efficiently, offering guidance on strategies for constant repair and upkeep to extend operational life. Controlling Non- Revenue Water (NRW) through water audits and effective management is vital to reduce losses and enhance efficiency with guidance on water quality monitoring and surveillance is also included in Part B Manual.

Part C Manual (Management) emphasises the need for comprehensive reforms including legal framework, institutional strengthening, enhanced coordination, stakeholder engagement, PPP and investments in modern technology and infrastructure for emerging drink from tap projects. The need for a skilled and knowledgeable workforce to operate and maintain complex water supply systems is addressed. Financial sustainability is a key concern and provides strategies for managing finances to support effective management of water supply systems. An integrated approach is deemed crucial to ensure sustainable water services capable of meeting the growing demands of India's urban population and providing high-quality water supply particularly in the context of climate change.

We envision this revised Manual as a blueprint for the future of urban water supply and treatment systems in India. It represents our unwavering commitment to creating systems that are not only efficient but also resilient, sustainable and equitable. Our goal is clear to ensure that every urban dweller can turn on the tap and access safe, clean water without hesitation throughout day and night.

This comprehensive Manual is the outcome of tireless efforts, interdisciplinary expertise and a collective dedication to enhancing urban water supply and treatment systems across our great nation. It has been meticulously curated to encompass the ever-evolving landscape of water supply management, from cutting-edge technologies to best practices in governance and partnership models, placing us firmly on the path toward a future where every urban citizen enjoys equitable access to clean, safe and reliable drinking water.

The first Expert Committee meeting was held in March 2021. In the past two and a half years, eight (8) meetings of the Expert Committee and fourteen (14) meeting of Working Groups were held to finalize the draft of the Manual. The Expert Committee consulted with various stakeholders during National and Regional workshops on 24x7 PWSS during the preparatory phase of the Manual and also during the National Consultative Workshop on the draft Manual held on 12th & 13th June 2023 to get the feedback/ comments/ suggestions on the content. The Editorial Committee, constituted under the chairmanship of the undersigned, had twenty one (21) meetings between June and Oct, 2023 and deliberated and incorporated the feedbacks/ suggestions in the Manual.

I express my profound gratitude to the Ministry of Housing & Urban Affairs, Government of India for extending all support and encouragement in the revision of the Manual. I would like to express my deep gratitude to Shri Manoj Joshi, Secretary (HUA), Ministry of Housing and Urban Affairs, Government of India for his constant encouragement and lending never ending support to the team in the journey of revision of the Manual.

I would like to extend my heartfelt gratitude to Ms. D Thara, Additional Secretary & National Mission Director (AMRUT) for her inspiration, constant guidance and support without which it might not have been possible to complete this massive task of revising the Manual.

I am also privileged to express my sincere thanks to Ms. Roopa Mishra, Joint Secretary & National Mission Director (SBM), Ministry of Housing and Urban Affairs for her support in finalization of the Manual.

I would like to express my profound gratitude to GIZ for providing technical and financial support for the preparation of the Manual. My heartfelt gratitude to Shri Ernst Deoring, Former Cluster Coordinator, Shri Christian Kapfensteiner, Cluster Coordinator, Smt. Laura Sustersic, Project Director, Dr. Teresa Kerber, Project Director, Smt. Monika Bahl, Senior Advisor & Shri Rahul Sharma, Technical Advisor, GIZ for extending their support in the preparation of the Manual. They left no stone unturned to enrich the contents of the Manual by adopting participatory approach and inviting experts and all those who are working on the ground in the country as well as abroad. They flawlessly conducted all the meetings and looked after the comfort of all the members of the Committee and all those who participated in deliberations.

I also extend my gratitude to AFD for providing technical support in drafting a few chapters and to IPE Global for their contribution to enrich the Manual.

Three Working Groups were carved out of the Expert Committee to speed up the gigantic task of revision of the Manual. I would like to extend my special thanks to Dr. Sanjay Dahasahasra, Former Member Secretary, Maharashtra Jeevan Pradhikaran & Co-chairman of Working Group (Part A Manual), Dr. PN Ravindra, Former Chief Engineer, Bangalore Water Supply and Sewerage Board & Co-chairman of Working Group (Part B Manual) and Prof. V Srinivas Chary, Professor & Director of the Centre for Urban Governance, Environment, Energy and Infrastructure Development, Administrative Staff College of India (ASCI), Hyderabad & Co-chairman of Working Group (Part C Manual) for their continuous guidance, time, dedicated efforts and painstaking efforts in finalizing all three parts of the Manual and being instrumental at all stages in the journey of revision of the Manual.

I extend my heartfelt gratitude to the esteemed Members of the Expert Committee, the dedicated Editorial Committee and the invaluable Special Invitees for their selfless dedication and remarkable contributions to the Manual. Their collective expertise and diverse perspectives have significantly enriched the depth, accuracy and overall quality of the Manual. The Expert Committee's wealth of knowledge, the Editorial Committee's meticulous refinement and the specialized insights of the Special Invitees have played a pivotal role in shaping this resource into an invaluable and comprehensive guide.

I would like to extend my appreciation for Dr. Ramakant, Deputy Adviser (PHE) & Member Secretary of the Expert Committee, for his continuous support and untiring commitment towards completing the Manual. I would also like to extend my appreciation for Shri Vipin Kumar Patel and Smt. Chaitra Devoor, Assistant Advisers (PHE), CPHEEO & Member Coordinators of the Expert Committee for their restless and dedicated support in completing the assignment. I would also like to acknowledge my other colleagues from CPHEEO for extending their support.

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Together, let us chart a course towards a future where every urban dweller can turn on the tap and access safe, clean water without hesitation. Let us strive relentlessly to create water supply systems that are not just efficient but also resilient, sustainable and equitable. 24x7 PWSS with Drink from Tap is not just for sophistication but is a basic necessity.

(Dr. M. Dhinadhayalan)
Adviser (PHEE) &
Chairman of the Expert Committee

New Delhi
6th November 2023

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ABBREVIATIONS

ABBREVIATIONS AND SYMBOLS

AAAC	All Aluminium Alloy Conductors
AB Switch	Air Break Switch
ABC	Airway, Breathing and Circulation
ABCB	Air Blast Circuit Breaker
AC	Alternate Current
AC	Asbestos Cement
ACB	Air Circuit Breakers
ACSR	Aluminium Cored Steel Reinforced
ADB	Asian Development Bank
AE	Assistant Engineer
AEE	Assistant Executive Engineer
AFD	Agence Française de Development
AI	Artificial Intelligence
AIEC	Average Incremental Economic Cost
AMC	Annual Maintenance Contract
AMI	Advanced Metering Infrastructure
AMR	Automatic Meter Reading
AMRUT	Atal Mission for Rejuvenation and Urban Transformation
APHA	American Public Health Association
ASI	Air Scour Inlet
ASTM	American Society for Testing and Materials
AVO Meter	Ampere Volt Ohm Meter
AWWA	American Water Works Association
BEE	Bureau of Energy Efficiency
BEP	Best Efficiency Point
BF	Butterfly valve
BHEL	Bharat Heavy Electricals Limited
BIS	Bureau of Indian Standards
BOD	Bio-chemical Oxygen Demand
BOO	Build, Operate and Own
BOOT	Build, Operate, Own and Transfer
BWSC	Bar Wrapped Steel Cylinder
BWSSB	Bangalore Water Supply & Sewerage Board

CARL	Current Annual Real Loss
CBM	Condition Based Maintenance
CBO	Community Based Organizations
CBs	Circuit Breakers
CCT	Chlorine Contact Tank
CCTV	Closed Circuit Television
CF8	Cast iron Grade 8
CF8M	Cast Iron Grade 8 Modified
CGWB	Central Ground Water Board
CI	Cast Iron
CMMIS	Computerized Maintenance Management Information System
CMMS	Computerized Maintenance Management System
COD	Chemical Oxygen Demand
CPCB	Central Pollution Control Board
CPHEEO	Central Public Health and Environmental Engineering Organisation
CPR	Cardio Pulmonary Resuscitation
CSIR	Council of Scientific and Industrial Research
CT	Current Transformer
CTC	Carbon Tetra Chloride
CWC	Central Water Commission
CWPRS	Central Water & Power Research Station
CWR	Clear Water Reservoir
DAF	Dissolved Air Floatation
DBP	Disinfection By-Product
DC	Direct Current
DCDB	Direct Current Distribution Box
DDWS	Department of Drinking Water & Sanitation
DE	Double Ended
DI	Ductile Iron
DMA	District Metering Area
DNP3	Distributed Network Protocol 3
DO	Dissolved Oxygen
DO Fuse	Drop Out Fuse
DP	Differential Pressure
DPCV	Differential Pressure Control Valves

DPCV	Dual Plate Check Valve
DRDA	District Rural Development Agency
EC	Electrical Conductivity
EC	Energy Cost
EE	Executive Engineer
ENCON	Energy Conservation
ESCO	Energy Saving Companies
ESR	Elevated Service Reservoir
FCRI	Fluid Control Research Institute
FCV	Flow Control Valve
FR	Frequency Rate
FRLS	Fire Retardant and Low Smoke
FRP	Fiber Reinforced Plastic
FSL	Full Supply Level
FTKs	Field Testing Kits
FWO	Filtered Water Outlet
GI	Galvanized Iron
GIS	Geographic Information System
G-LAP	Government Drinking Water Testing Laboratory Accreditation Program
GoI	Government of India
GPR	Ground Penetrating Radar
GPRS	General Packet Radio Service
GPS	Global Positioning System
GRP	Glass Reinforced Plastics
GSI	Geological Survey of India
HAAs	Haloacetic Acids
HAZOP	Hazard and Operability Study
HDET	Hand held Data Entry Terminal
HDPE	High Density Polyethylene
HG Fuse	Horn Gap Fuse
HGM	Hydro Geomorphological Mapping
HPP	High Pressure Pump
HRC Fuse	High Rupturing Capacity Fuse
HSCF	Horizontal Split Casing Centrifugal
HT	High Tension

HTH	Helix-Turn-Helix
HUDCO	Housing and Urban Development Corporation
IIC	Initial Investment Cost
ICSC	International Chemical Safety Card
ICT	Information and Communication Technologies
IDEMI	Institute for Design of Electrical Measuring Instruments
IE Regulations	Indian Electricity Regulations
IEC	International Electrotechnical Commission
IEC	Information Education Communication
IED's	Intelligent Electronic Devices
IFI	International Financial Institution
ILI	Infrastructure Leakage Index
ILO	International Labour Organization
IMD	India Meteorological Department
IMM	Integrated Meter Management
IoT	Internet of Things
IP	Internet Protocol
IR	Insulation Resistance
IRDA	Insurance Regulatory and Development Authority of India
IRP	Iron Removal Plant
IS	Indian Standards
ISO	International Organization for Standardization
IT	Information Technology
ITES	Information Technology Enabled Services
IVRS	Interactive Voice Response System
IVS	Isolation Valve System
IWA	International Water Association
JE	Junior Engineer
JICA	Japan International Cooperation Agency
KPIs	Key Performance Indicators
kVA	Kilovolt Amperes
kW	Kilowatts
LCC	Life Cycle Cost
LCD	Liquid Crystal Display
LNF	Legitimate Night Flow

LPCD	Litres per Capita per Day
LSCD	Loose Stone Check Dams
LT	Low Tension
MAH	Major Accident Hazard
MBR	Master Balancing Reservoir
MCB	Miniature Circuit Breaker
MCC	Motor Control Center
MDPE	Medium Density Polyethylene
MDWS	Ministry of Drinking Water and Sanitation
MF	Microfiltration
MID	Measuring Instruments Directive
MIS	Management Information System
MLD	Million Litres Per Day
MNF	Minimum Night Flow
MNRE	Ministry of New and Renewable Energy
MNREGA	Mahatma Gandhi National Rural Employment Guarantee Act
MOCB	Minimum Oil Circuit Breaker
MoHUA	Ministry of Housing and Urban Affairs
MPE	Maximum Permissible Error
MRC	Operation, Maintenance & repair costs
MS	Mild Steel
MSDS	Material Safety Data Sheet
MTBF	Mean Time Between Breakdowns
MTTR	Mean Time To Repair
MW	Megawatt
NABL	National Accreditation Board for Testing and Calibration Laboratories
NCDWSQ	National Centre for Drinking Water, Sanitation and Quality
NDB	New Development Bank
NDMA	National Disaster Management Agency
NDMA	N-Nitroso-Dimethylamine
NEMA	National Electric Manufacturers Association
NF	Nano Filtration
NGEF	New Governmental Electrical Factory
NGOs	Non-Governmental Organizations
NNF	Net Night Flow

NOM	Natural Organic Matter
NPSHa	Net Positive Suction Head Available
NPSHr	Net Positive Suction Head Required
NRDWP	National Rural Drinking Water Programme
NRSE	New and Renewable Sources of Energy
NRV	Non Return Valve
NRW	Non-Revenue Water
NSC	National Safety Council
NTU	Nephelometric Turbidity Units
O&M	Operation & Maintenance
OEM	Original Equipment Manufacturer
OPEX	Operational Expenditure
OSH	Occupational Safety and Health
OZ	Operational Zone
PAC	Polyaluminium chloride
PCB	Printed Circuit Board
PE	Polyethylene
PF	Power Factor
PHA	Process Hazard Analysis
PHED	Public Health Engineering Department
PI	Polarization Index
PLC	Programmable Logic Controllers
PPE	Personal Protective Equipment
PPM	Parts per Million
PPMS	Pump Performance Monitoring Solution
PPP	Public Private Partnership
PRV	Pressure Reducing Valve
PS	Pumping Station
PSC	Pre-Stressed Concrete
PSI	Pounds Per Square Inch
PSP	Private Supply Points
PT	Potential Transformer
PT	Proficiency Testing
PTFE	Polytetrafluoroethylene
PTW	Permit to Work

PV	Photovoltaic
PVC	Polyvinyl Chloride
RCC	Reinforced Cement Concrete
Redox	Reduction-Oxidation
RO	Reverse Osmosis
ROVs	Remotely Operated Vehicles
RPM	Revolutions per minute
RSF	Rapid Sand Filter
RTU	Remote Terminal Unit
RWH	Rain Water Harvesting
RWSS	Rural Water Supply and Sanitation
SAR	Supplied Air Respirators
SBM	Swachh Bharat Mission
SCADA	Supervisory Control and Data Acquisition
SCC	System Control Centre
SDBs	Sludge Drying Beds
SDE	Sub-Divisional Engineer
SDS	Safety Data Sheet
SE	Superintending Engineer
SEC	Specific Energy Consumption
SF6	Sulphur hexafluoride
SHG	Self-Help Group
SIP	System Improvement Plan
SLBs	Service Level Benchmarks
SMS	Short Message Service
SOCs	Synthetic Organic Compounds
SOPs	Standard Operating Procedures
SPM-NIWAS	Dr. Syama Prasad Mookerjee National Institute of Water and Sanitation
SPV	Solar Photovoltaic
SR	Severity Rate
SRs	Service Reservoir
SS	Summer Storage
SSF	Slow Sand Filter
SWI	Settled Water Inlet
SWL	Static Water Level

TCE	Trichloroethylene
TCP	Transmission Control Protocol
TDS	Total Dissolved Solids
THM’s	Trihalomethanes
Trem Card	Transport Emergency Card
TSS	Total Suspended Solids
TTHMs	Total Trihalomethanes
UARL	Unavoidable Annual Real Loss
UF	Ultrafiltration
UFRV	Unit Filter Run Volume
UFW	Unaccounted for Water
UGRs	Underground Reservoirs
ULBs	Urban Local Bodies
UPS	Uninterruptible Power Supply
UPV	Ultrasonic Pulse Velocity
UPVC	Unplasticized Polyvinyl Chloride
USEPA	United States Environmental Protection Agency
UV	Ultraviolet Radiation
UVI	UV Intensity
UVT	UV Transmittance
VCB	Vacuum Circuit Breaker
VFDs	Variable Frequency Drives
VMS	Valve Monitoring Service
VOC	Volatile Organic Compounds
VT	Vertical Turbine
WASH	Water Sanitation and Hygiene
WATCO	Water Corporation of Odisha
WB	World Bank
WDNs	Water Distribution Networks
WDS	Water Distribution System
WHO	World Health Organization
WQMIS	Water Quality Management Information System
WSA	Water Supply Agency
WSP	Water Safety Plan
WSSB	Water Supply & Sewerage Board

WSSO	Water & Sanitation Support Organization
WTP	Water Treatment Plant
WTS	Water Treatment Sludge
WWCP	Wash Water Control Panels
WWI	Wash Water Inlet
WWO	Wash Water Outlet
ZBR	Zonal Balancing Reservoir
ZPT	Zero Pressure Test

GLOSSARY

GLOSSARY

A

AIEC, Average Incremental Economic Cost is an approach in which the price of all additional units after the fixed total original costs have been met are based on variable cost rather than on total cost.

Agglomeration, a large, densely and contiguously populated area consisting of a city and its suburbs such as urban agglomeration.

Aggressive Water, is soft and acidic and can corrode plumbing, pipes, and appliances as it usually contains an inordinate amount of carbon dioxide deposits. It is labelled as “aggressive” due to its high propensity to strike surfaces that possess metals such as copper and iron, or calcium. Its corrosive effects of the increase of scaling deposits can be seen in the form of staining on surfaces, walls, clothing, and even a person’s body (hair).

Algal Bloom, a rapid increase or accumulation in the population of algae in freshwater or marine water systems. It is often recognized by the discoloration in the water from the algae's pigments.

Algicidal Measures, used primarily to control algal growth in impounded waters, lakes, ponds, reservoirs, stock tanks, etc.

AMI, Advance Metering Infrastructure, is an integrated system of equipment, communications, and information management systems for utilities to remotely collect customer water usage data in real time.

AMR, Automatic Meter Reading system provides the metering data, status outputs and alert signals where applicable for operation and monitoring of the smart metering system.

Anaerobic, a condition under which biological process breaks down organic contaminants using microorganisms in the absence of oxygen.

Anicuts, is a check dam that is constructed across a stream to impound water for maintaining and regulating are used to increase the residence of water to recharge groundwater, especially wells located downstream.

Anthropogenic, environmental change caused or influenced by people, either directly or indirectly.

B

Backwashing, meaning reversing the flow and increasing the velocity at which water passes back through the filter. This, in effect, blasts the clogged particles off of the filter.

Bentonites, a kind of absorbent clay formed by breakdown of volcanic ash, used especially as a filler.

Biodegradation, breakdown of organic matter by microorganisms, such as bacteria and fungi.

BOOT, Build-Own-Operate-Transfer is a public-private partnership contract and is mainly used by governments for large infrastructure projects in a public-private partnership.

Bubble Paltron, is a water filtration system that uses bubbles to remove contaminants from water. It was developed by Gwyneth Paltrow's lifestyle brand, Goop. The Bubble Paltron system consists of a machine that pumps air into a chamber filled with water. The air bubbles rise to the surface of the water, carrying contaminants with them. The water is then filtered through a series of screens and filters to remove any remaining contaminants.

C

Capacitor, is a two-terminal electrical device that can store energy in the form of an electric charge. It consists of two electrical conductors that are separated by a distance. The space between the conductors may be filled by vacuum or with an insulating material known as a dielectric.

Capacity Building, is defined as the process of developing and strengthening the skills, instincts, abilities, processes and resources that organizations and communities need to survive, adapt, and thrive in a fast-changing world.

CWRs, Clear Water Reservoirs usually constructed at the water treatment plant premises for treated clean water storage and disinfection (chlorination, etc).

CMMS, Computerized Maintenance Management System is software that helps manage assets, schedule maintenance and track work orders.

Cross Subsidy, the practice of charging higher prices to one type of consumers to artificially lower prices for another group.

Cyanotoxins, toxins produced by cyanobacteria (also known as blue-green algae) found almost everywhere, but particularly in lakes and in the ocean where, under high concentration of phosphorus conditions, they reproduce exponentially to form blooms.

Cyprinids, are the largest family of freshwater fish, with over 3,000 species. Cyprinids are an important part of many freshwater ecosystems. They are a food source for many other animals, and they also help to keep the water clean by eating algae and other small organisms.

D

Dielectric Strength, defined as the electrical strength of an insulting material and is measured as the maximum voltage required to produce a dielectric breakdown through a material.

Dew Point Measurement, the device called Hygrometers is used to measure dew point over a wide range of temperatures. The temperature at which dew forms is, by definition, the dew point.

DPCV, Differential Pressure Control Valve is a valve that operates to maintain a constant differential pressure between two points independent of supplied pump head.

DBO, Design Build Operate is a form of contract that includes design, build and operate system of a project.

Digital Twin Technology, is a technology in which virtual representation of an object or system that spans its lifecycle, is updated from real-time data, and uses simulation, machine learning and reasoning to help decision making.

E

Energy Audit, is an inspection survey and an analysis of energy flows for energy conservation and includes a process or system to reduce the amount of energy input into the system without negatively affecting the output.

Eutrophication, a gradual increase in the concentration of phosphorus, nitrogen, and other plant nutrients in an aging aquatic-ecosystem such as a lake and causes eutrophication.

ESCO, Energy Service Company, helps water utilities improve their energy efficiency and reduce their operating costs. They can do this by implementing a variety of measures, such as Installing energy-efficient pumps and motors, retrofitting water mains and valves, using solar water heating, recovering heat from wastewater.

F

Fishing Tool, is the specialized well workover & intervention tool that is mechanically operated and helps in the recovery or retrieval of other equipment or tools that are accidentally fallen into the wellbore or are left over inside the wellbore because of any uncertain reasons.

Flow Control Valves, are used in pneumatic systems to regulate the flow rate of compressed air, wherein by controlling the flow rate, the speed of the pneumatic cylinder can also be regulated directly and are also referred to more generally as flow regulators or flow controllers.

Free Swim Ball, a free swim ball in water supply is a device that is used to detect leaks and gas pockets in pipelines.

Flow Meters, is type of flow instrument that is used to indicate the amount of liquid through a pipe or conduit by measuring linear, non-linear, mass, or volumetric flow rates.

G

Gamma Ray Logging, is a method of measuring naturally occurring gamma radiation to characterize the rock or sediment in a borehole or drill hole.

Gas Tracer, a technique in which gas is used to detect water leak. Helium is the most commonly used tracer gas in leak detection. It is non-flammable, non-destructive, non-toxic, inert, and only has trace presence in our atmosphere.

Geotagging, is the process of appending geographic coordinates to media based on the location in a map.

GSM, Global System for Mobile Communication is a digital mobile network that is widely used by mobile phone users.

Gully Plugging, is a small, temporary or permanent dam constructed across a drainage ditch, swale, or channel to lower the speed of concentrated flows for a certain design range of storm events and to conserve soil moisture helping in ground water recharge.

H

HAZOP, Hazard and Operability Study is a systematic approach to identifying and assessing the hazards associated with a process or system. HAZOP can be used to identify and assess the hazards associated with Water treatment processes, water distribution systems, water storage facilities, pumping stations, valves and other control devices etc.

Hypolimnion, the lower layer of water in a stratified lake, typically cooler than the water above and relatively stagnant.

I

Incrustation, the deposition of alkali salts on the inside wall of the tube well is known as incrustation

Institutional Strengthening, is about increasing the capacity or ability of institutions to perform their functions. There is a particular focus on improving governance.

IOT, Internet of Things describes the network of physical objects—"things"—that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the internet.

IEC, Information, Education, Communication as a strategy aims to create awareness and disseminate information regarding the benefits available under various schemes/programmes in urban water supply project.

ITES, Information Technology Enabled Services includes a wide variety of operations which uses information technology to improve the efficiency of an organization.

IVS, Isolation Valve System is a valve in a fluid handling system that stops the flow of process media to a given location, usually for maintenance or safety purposes.

K

KPI, Key performance indicators are quantifiable measure of performance over time for a specific objective. KPIs provide targets for teams to shoot for, milestones to gauge progress, and insights that help people across the organization make better decisions.

L

Landslides, a collapse of a mass of earth or rock from a mountain or cliff.

LNF, Legitimate Night Flow is the consumer end minimum night consumption at the time of minimum night flow. Domestic consumers – toilet flushing, washing machines etc; use a standard legitimate night time factor, or measured sample.

LIDAR, Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth.

Lithological, of the physical characteristics of rock including colour, composition and texture.

Linearity, is an important and desirable feature of an analytical method. For example, if a calibration function is linear, then it is easier to estimate the equation, and evaluation errors (errors in estimating unknown concentrations from the calibration function) are likely to be smaller.

M

Magnetically Coupled Meters, a magnetic coupling for throughflow metering devices, in particular water meters, or similar, comprising a first and a second magnet, which are rotatably mounted and separated from each other, by a partition wall.

MIS, Management Information System is a computerized technology involving person, organization, and relationship analysis.

MNF, Minimum Night Flow refers to the flow into the DMA in the middle of the night when water demand is at its lowest. The MNF is a common method used to evaluate water loss in a water network.

Multi Spectral Aerial Imagining, is an advanced imaging technique that acquires images where each pixel contains a spectrum (intensity as a function of wavelength) of the collected light at that location, rather than the typical three data points (red, green and blue) found in RGB images.

N

NABL, National Accreditation Board for Testing and Calibration Laboratories is an accreditation body, with its accreditation system established in accordance with ISO/ IEC 17011.

Noise Correllator, is an electronic device used for Leak Detection and as a leak locator to find leaks in pressurised water or gas lines.

O

OPEX, Operational Expenditure is the money a company or organization spends on an ongoing, day-to-day basis to run its business. These expenses can be one-time or recurring.

P

Phytoplankton, are microscopic marine algae, also known as microalgae, are similar to terrestrial plants in that they contain chlorophyll and require sunlight in order to live and grow. Most phytoplankton are buoyant and float in the upper part of the ocean, where sunlight penetrates the water.

PLC, Programmable Logic Control is an industrial computer used to automate processes in facilities like a water or wastewater treatment plant.

Pumps, play a vital role in forcing out the water either directly or through a service reservoir. In the distribution mains, the pressure has to be boosted or increased at a few intermediate points. Pumps provide the required pressure so that the water reaches the required height in multistoried buildings.

Q

Quiescent, a type of settling in which the flow of water in the tank is stopped after filling and the sediments are allowed to settle in an undisturbed environment.

R

Redox Potential, is a measure of the ease with which a molecule will accept electrons, which means that the more positive the redox potential, the more readily a molecule is reduced.

Resanding, the filter is to be drained when flow rates become too low, and the top layer of the sand scraped off, washed, dried in the sun, and stored. After several scrapings, the cleaned and dried sand is added back to the filter, together with new sand, to make up for losses during washing.

S

Satellite Images, is a special case of digital photography. Radiation bands in electromagnetic spectrum that are reflected from Earth's surface back into space can be collected by satellite sensors and stored digitally as pixels.

SCADA, Supervisory Control and Data Acquisition is a system of software and hardware elements that allows organizations to control processes locally or at remote locations, monitor, gather, and process real-time data.

Sediment Desludging, the process of removing sediments by draining and cleaning a tank

SLB, Service Level Benchmark involves the measuring and monitoring of service provider performance on a systematic and continuous basis. The Handbook of Service Level Benchmarking is *a* ready reckoner to enable Urban Local Bodies (ULBs) and other city level parastatal agencies implement systems.

Stagnation, the state of not flowing or moving.

Supernatant, the liquid lying above a solid precipitation, centrifugation, or other process.

Surge Protection Device, partially closes the valve's orifice in response to a pressure surge, whether caused by pump start-up, shut-off, valve closure or unanticipated events such as abrupt power failure leading pump tripping, helping to decelerate the approaching water column and prevent damage to the valve and system.

T

Tethering Device or phone-as-modem (PAM), is the sharing of a mobile device's Internet connection with other connected computers. Connection of a mobile device with other devices can be done over wireless LAN (Wi-Fi), over Bluetooth or by physical connection using a cable, for example through USB.

TDS, Total Dissolved Solids refers to the total concentration of dissolved substances in drinking water. TDS comprises inorganic salts and a small amount of organic matter as well.

Thermal Stratification, occurs when two types of steam or lakes or water bodies with different temperatures come into contact. Their temperature difference causes the colder and heavier water to settle at the bottom of the pipe while allowing the warmer and lighter water to float over the colder water.

Tuberculation, refers to development or formation of small mounds of corrosion products (rust) on the inside of iron pipe. These mounds (tubercles) increase the roughness of the inside of the pipe thus increasing resistance to water flow (decreases the C Factor).

U

UFW, Unaccounted for Water means the difference between "net production" (the volume of water delivered into domestic water distribution network) and "consumption" (volume of water for legitimate consumption as accounted for assessment purpose).

V

VFD, Variable Frequency Drive is a type of drive that controls the speed, of a non-servo, AC motor by varying the frequency of the electricity going to that motor. VFDs are typically used for applications where speed and power are important.

W

WASH, Water, Sanitation and Hygiene refers to Safe drinking-water, sanitation and hygiene which are crucial to human health and well-being Safe WASH is not only a prerequisite to health, but contributes to livelihoods, school attendance and dignity and helps to create resilient communities living in healthy environments.

Water Age, is the time it takes for water to travel from the source to the consumer. It is a measure of the efficiency of the water supply system.

WTP, Water Treatment Plant refers to a process, device, or structure used to improve the physical, chemical, or biological quality of the water in a public water system.

Water Softeners, a device or substance that softens hard water by removing hardness causing minerals.

WQMIS, Water Quality Management Information System refers to application of water sampling and testing including data management of the water quality in the system as well as at the consumers end. The data are to be used for further improvement of water quality if so needed.

Water Loss Reduction Plan, is a plan for reducing water losses and usually targets the losses identified by an audit (or several audits). Once potential options are developed to reduce water loss, cost benefit analyses should be performed to choose the best options for the system.

TABLE OF CONTENTS

TABLE OF CONTENTS

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

1. INTRODUCTION

Operation and maintenance (O&M) of a water supply system refers to all the activities needed to run the system continuously to provide the necessary service for which the related assets created. The overall aim of operation and maintenance is to ensure an efficient, effective and sustainable water supply system. Efficient water supply system means being able to accomplish equitable, qualitative, reliable, pressurised water supply system with the least waste of time, effort and resources.

Operation and maintenance involve daily management of water supply system components to deliver safe drinking water equitably to consumers and preserves infrastructure through planned and corrective actions including mechanical and electrical adjustments, repairs, and focus to restore assets to operating conditions as quickly as possible. It also includes a reaction to public complaints such as malfunctioning and breakdown of equipment.

Part B of the Manual, "Operation and Maintenance," serves as a guide to enhance technical, operational and managerial capabilities of water utilities, ULBs including serving as a reference material for administrators. It focuses on meeting the norms for quantity, quality, sustainability, reliability, and cost-effectiveness in serving water supply, enabling (24x7) pressurised water supply system with Drink from Tap and affordable safe drinking water while promoting sustainability.

2. PRESENT SCENARIO

A lack of attention to the Operation and Maintenance for water supply systems in several towns has led to deterioration both in the quality of water delivered and the useful life of the assets, necessitating premature replacement of many system components and often the systems are underutilized most of the time. As a result, water supply systems are unable to provide the services effectively to the community for which they have been planned, designed and created.

Some of the key issues contributing to the poor Operation and Maintenance are high technical and commercial loss of water (NRW), poor quality water due to intermittent supply, lack of information such as as-built drawings of the existing network and unavailability of conditional assessment, inappropriate system design, poor workmanship, lack of skilled personnel coupled with poor monitoring, inadequate emphasis on preventive maintenance, not developing and following the Standard Operating Procedures (SOPs), non-availability of real time field data and thus the effective information, etc.

Clear sector policies and legal frameworks, as well as clear demarcation of roles, responsibilities and mandates within the water supply sub-sector, are necessary. From the Indian experience, to cite an example, it has been observed that in the case of pumping schemes, by and large, about 30 to 40% of the total annual Operation and Maintenance costs goes towards maintaining the personnel (Operation and Maintenance Staff), 30 to 50% of the cost incurred on power charges and the balance utilized for consumables, repairs and replacement of parts and machinery and miscellaneous charges. In most of the cities in India, the tariffs are so low that they do not even able to cover the annual Operation and Maintenance costs. This leaves little for an active water supply system management to implement and perform necessary measures towards control of

Non–revenue Water (NRW) and proper metering of water connections, which may help to reduce the wastage of water and increase the revenue to the Local Bodies to the great extent.

3. MAJOR CHALLENGES

The operation and maintenance of water supply systems present several challenges, ranging from technical issues to financial constraints. Some of these are:

a) Operationalising 24x7 Pressurised Water Supply System with Drink from Tap
b) Constant repair and maintenance of aging infrastructure, ensuring efficient and effective functionality
c) Availability of skilled personnel for managing the complex systems
d) Water Quality Monitoring and Surveillance
e) Water Audit and Control of Non- Revenue Water (NRW)
f) Energy Audit
g) 100% metering for accurate measurement of water consumption
h) Financial sustainability
i) Complaint redressal, public outreach, awareness creation and consumer satisfaction
j) SCADA and Automation

Addressing these major challenges requires a comprehensive approach that involves effective planning, adequate investment, and a skilled workforce, along with the adoption of sustainable practices to ensure long-term climate-resilience of the water supply system.

4. ADDRESSING MAJOR CHALLENGES

a) **Operationalising 24x7 Pressurised Water Supply System with Drink from Tap:** The water supply schemes are designed and implemented for achieving 24x7 pressurised water supply system as mandated based on the guidelines set in the earlier CPHEEO Manual. All systems more often than later resorted to intermittent mode for many reasons. Operating on intermittent mode, unnecessarily stresses the system resulting in poor service delivery and rapid deterioration of the system components affecting adversely the water quality supplied to the residents. As per the guidelines provided in the Part A of the Manual, the intermittent water supply systems shall have to be converted into 24x7 Pressurised Water Supply System (PWSS) for achieving Drink from Tap by forming operational zones and DMAs in a phased manner. The O&M shall be carried out at OZ/DMA level by monitoring the key performance indicators such as quantity of water supplied, NRW, residual pressure, water quality parameters etc on a continuous basis.

b) **Constant preventive maintenance of aging infrastructure to ensure efficient and effective functionality:** Water utilities oversee the operation and maintenance of treatment plants and distribution networks for ensuring reliable and quality delivery of drinking water but many Urban Local Bodies lack the resources and capacity for effective maintenance of aging infrastructure and fail to ensure the efficiency of the system. The Urban Local Bodies need to focus on conditional assessment with proper repairing and replacing of aging infrastructure till the end of the useful service period rather than creation of new infrastructure so as to avoid unnecessary capital expenditure.

c) **Availability of skilled personnel for managing the complex systems:** Operation and maintenance activities, spanning technical, managerial, social, financial, and institutional aspects, aim to reduce constraints hindering sustainability in water supply projects. Globally, newly built infrastructure often deteriorates post-project completion, mainly due to lack of skilled personnel to operate and maintain the complex water supply system. A proper organization has to be set in place for delivering efficient and cost-effective Operation and maintenance. The hierarchy required to be understood, developed and to be kept in place for carrying out the necessary operation and maintenance services.

d) **Water Quality Monitoring and Surveillance:** In the realm of 'Water Quality Monitoring and Surveillance', it is imperative that water supply systems, once implemented and activated, has to undergo meticulous and efficient maintenance to deliver their intended services, including the essential provision of a minimum quantity of safe drinking water to the public. The operation and maintenance endeavors should prioritise the continuous adherence to water quality standards as per the requirements of IS 10500:2012, a paramount measure for preserving the community's health. Concurrently, at the city or town levels, consumer forums can be established to vigilantly oversee water sources and distribution systems, ensuring their upkeep and providing regular reports to the relevant operation and maintenance bodies to proactively prevent system breakdowns. Surveillance, as an ongoing and vigilant public health assessment, serves as an indispensable tool for assessing the safety and social acceptability of drinking water supplies. This investigative function is typically to be carried out by an independent entity, either with a separate agency or a specialized department section, with the primary objective of identifying and evaluating factors that may pose health risks in relation to drinking water. Effective communication and collaboration between the surveillance agency and the water supply entity are crucial for swiftly pinpointing and addressing potential risk areas.

e) **Water Audit and Control of Non- Revenue Water (NRW):** Water Audit of a water supply scheme can be defined as the assessment of the total water produced by the Water Supply Utility and the actual quantity of water distributed to the consumer taps throughout the area of service, thus leading to an estimation of the losses termed as Non-Revenue Water along with its technical and commercial components. Water audit provides fair estimation of water losses for different water supply areas depending on level of audit work undertaken. Accordingly, the areas with higher percentage of losses, can be identified for carrying out active water loss management activities like leakage detection, network investigation, pressure management etc. It is very critical to understand the method and critical steps of this process to execute it in an efficient manner else, it may not provide desirable outcomes like water loss reduction and improved network efficiency.

Water utilities with poorly maintained infrastructure and no leakage management systems desires to conduct a water audit based on the available data and develop an NRW master plan for improvement towards better consumer services. But the first step is to conduct a water audit that includes an assessment and analysis of the performance of the water distribution system as well as identifies and quantifies areas for improvements. The outcome of the water audit is then used as essential input into the NRW master plan that will serve as the basis for retrofitting, rehabilitations and asset improvement as well as their projected deliverables and returns.

f) **Energy Audit:** It is an assessment and accounting of Energy consumption and thus its specific Efficiency. It also relates to energy quality to some extent. The starting point is the identification of energy-consuming equipment for the knowledge of energy-saving potential. Energy audit can result in enhancing the efficiency, improving quality of power and most importantly reduce the wastage of energy. It can start with review of individual equipment electricity consumption and arriving at the specific power consumption of the unit mass of water delivered. Water audit end with recommendations for guaranteed means to reduce the power consumption. Further on the implementation of energy-saving measures identified, based on observations during energy audit.

g) **100% metering for accurate measurement of water consumption:** This is the prerequisite for proper ensuring proper control on the system. Complete metering of all water supply connections is necessary for accurate measurement of water consumption help to account the water supplied, reduce the wastage of water and in turn increase the revenue of the Local Body to the maximum extent.

h) **Financial sustainability:** In the light of the 74th Amendment to the Constitution, the roles and responsibilities of Urban Local Bodies have increased significantly to provide the basic facilities of water supply and sanitation to the community on a sustainable basis. With this, said amendment, the Urban Local Bodies have to become financially and technically sound to provide these basic civic amenities to the community. Therefore, it is utmost important to augment financial resources by implementing appropriate water tariffs for all sections of beneficiaries and its effective realization, which is the key to the success of water supply sector performance mainly that of operation and maintenance. It is also important to provide capacity building to the Urban Local Bodies for managing effective operation and maintenance of the water supply systems to achieve the desired service levels. In order to maintain sustainability, a typical performance-based operation and maintenance contract taking into consideration the provisions in the BIS Code IS 17482: 2020, can be adopted. It should include, a definite time horizon of the service delivery, the extent of the services to be delivered, key performance indicators (KPIs), performance warranties, compensation, incentives, liability ceilings including clear KPI measuring mechanism etc.

i) **Complaint redressal, public outreach, awareness creation and consumer satisfaction:** An effective grievance redressal and awareness creation mechanism should be set up to enable the consumers to report complaints on aspects such as leakage and wastage of water, low pressure at consumer's end, contamination and poor quality water, pilferage of system components, malfunctioning of water meters, problems related to meter reading, payment of bills, so on and so-forth. This also includes, suggestions, if any, for improving the performance of the system, which may have to be designed and implemented with the help of NGOs, Residential Welfare Associations, and the Neighbourhood Committee. All such complaints, suggestions received should be attended within a reasonable time frame, so as to win the confidence of the consumers. The emphasis adherence to BIS code IS 15800:2007 is essential, emphasizing consistent, efficient service, and consumer satisfaction. Water meters and communication technologies for NRW monitoring, Water Tariff and Control at DMA level, with special write up on the new technologies that can be adopted is provided in detail in the Manual.

j) **SCADA and Automation:** In recent years, huge technological advancements have occurred in the equipment's manufacturing, its applications, SCADA, ICT and IoT, Automation and good management practices. These advancements have made it easy to operate, maintain and monitor all the processes and actions being taken for delivering safe water to the consumer taps. The GIS based Network Modeling along with SCADA, automation, will give a boost in analyzing the real-time working of the entire system, to the smallest equipment, with Digital Twin Technology application. The monitoring, diagnosis, analysis and decision-making process has become easy and accurate with less human interventions. The field use of GIS based Asset Management coupled with the Computerized Maintenance Management System (CMMS) will help the operation staff and authorities to improve the operation and maintenance of the system including reporting.

5. COMPOSITION OF CHAPTERS

The Part B of the Manual is organized as a set of 13 chapters for covering the challenges mainly for achieving the objective for efficient delivery system. While the first two sets the context, the remaining eleven provide guidance on the operation and maintenance attributes of the Water Supply System.

i. **Introduction:** The chapter sets the context for the O&M of Water supply system.

ii. **Operational Strategy:** The Chapter 2, narrates the concept for developing a strategy towards providing safe and equitable drinking water from a reliable source point to the end user through a system of a well-maintained train of treatment process, transmission, and distribution network components, including efficient operations and maintenance of all tools and plants.

iii. **Sources of Water Supply:** The chapter discusses about the protection of the sources both in terms of quality and quantity. To ensure sustainable water supply is emphasized for maintaining the functional and available sources. The sources of water supply described in various sections ensuring steps towards sustainability. It is emphasised for maintaining all the functional and available sources, irrespective of their utilization.

iv. **Transmission of Water:** The chapter discusses about the important components of the system engaged in transferring water from source or from the treatment system. It also discusses about the need to evolve operation procedures for ensuring the system to operate satisfactorily, function efficiently and continuously, and last long to the full life cycle time at the optimal cost.

v. **Water Treatment Plant:** The chapter discusses about the operational aspects of the process units and unit operations connected with the water treatment mechanism to generate safe and clean drinking water.

vi. **Raw Water and Clear Water Reservoirs:** The mechanism of optimum use of the raw water and clear water reservoirs and their aspects of operation and maintenance are provided. The reservoirs specially the service reservoirs have a direct bearing on both quality and quantity of the drinking water. The principles for ensuring the system to operate satisfactorily, and function efficiently on continuously basis have been described. It deliberates about the importance of role in creating the buffer stocks and also to level the demand variations in an optimal way. Also, the guidelines for developing specific operational procedures required for inspecting, monitoring, testing, repairing, and disinfecting the system are emphasized.

vii. **Distribution System:** The distribution systems are the backbone of the entire water supply system and in this component both the quality and quantity of the drinking water gets altered. The chapter discusses about the aspects of water quality parameters, sampling, testing, laboratory analysis, and outlines the standard procedures for various parameters of drinking water quality with proper monitoring and surveillance including inspection activities to be undertaken so as to ensure the water distribution pipeline network system operated satisfactorily, and function efficiently on continuous basis. Many specific operational procedures which are required for inspecting, monitoring, testing, repairing, and disinfecting the system are discussed in this chapter.

viii. **Drinking Water Quality Monitoring and Surveillance:** The chapter explains the aspects of water quality parameters, sampling, testing, laboratory analysis, and outlines the standard procedures for various components of drinking water quality monitoring and surveillance with other inspection activities to be undertaken.

ix. **Pumping Station and Machinery:** The chapter discusses on the pumps, pump house, and pumping machinery which is the indispensable component of any water supply system. Their operational manners with troubleshooting guidelines are given.

x. **Automation of Water Supply System:** The chapter discusses on Water Meters, Instrumentation, Telemetry, SCADA Digital Twins, and CMMS.

xi. **Water Audit, Monitoring and Control of NRW:** The Chapter discuss on NRW, Water Audit, Leakage Control etc. The procedure and techniques for active leakage control, with full information for effective auditing task is also discussed.

xii. **Energy Audit and Conservation of Energy:** The Chapter guides for carrying out energy audit and factor for improving the energy efficiency in system.

xiii. **Safety Practices:** The Chapter discusses about the Safety Practices, which are of importance for ensuring the security of the working personnel. The list of Safety Practices in water supply system will help the managers to adopt them conveniently.

CHAPTERS

CHAPTER 1 : INTRODUCTION

1.1 Governance

Water supply and sanitation are a state subject and the states are vested with the constitutional right on the planning, implementation, and cost recovery of the water supply and sanitation projects. At the local level, the responsibility is entrusted by legislation to the Urban Local Bodies (ULBs) like Municipal Corporation, Municipality, Municipal Council, and Notified Area Committee/Authority for towns, or on a state/regional basis to specialised agencies.

The Urban Development Department or Public Health Engineering Department (PHED) is the principal agency at the state level for planning and implementing of water supply and sanitation programmes. In a number of states, statutory Water Supply and Sewerage Boards (WSSBs) have taken over the functions of the PHEDs. The basic objectives for creating WSSBs have been to bring in the concept of commercialisation in the water supply and sewage sector management and more accountability with an increase in efficiency and for ease of getting funding from multilateral agencies. Such Boards have been set up in many states, as well as in metropolitan cities such as Bangalore, Delhi, Hyderabad, Chennai, and other cities, and the state of Odisha has separate state-empowered local Statutory Boards.

The Ministry of Housing and Urban Affairs, Government of India, formulates policy guidelines in respect of the urban water supply and sanitation sector and provides technical assistance to the states and ULBs, wherever needed. The expenditure on water supply and sanitation is met out of block loans and grants disbursed as plan assistance to the states and out of loans from financial institutions like World Bank (WB), Japan International Cooperation Agency (JICA), Asian Development Bank (ADB), New Development Bank (NDB), Agence Française de Development (AFD), Housing and Urban Development Corporation (HUDCO), and other similar agencies. The central Government acts as an intermediary in mobilising external assistance in the water supply and sanitation sectors and routes the assistance via the state plans. It also provides direct grant assistance to some extent for water supply and sanitation programmes in urban areas, such as Atal Mission for Rejuvenation and Urban Transformation (AMRUT) and Swachh Bharat Mission (SBM). Schemes are being developed to involve private participation in the form of Public-Private Partnership (PPP). This will undertake capital investment in the sectors and bring new technologies and expertise in efficiently carrying out operation and maintenance (O&M) and providing consumer-centric customer services with effective billing and collection systems.

The role of the department is, by and large, confined in some states to mostly construction activities only, e.g., Uttar Pradesh Jal Nigam, Uttarakhand Peyjal Sansadhan Vikas evam Nirmaan Nigam, Madhya Pradesh Jal Nigam, etc., while in some of the states/UTs, e.g., Maharashtra Jeevan Pradikaran, Kerala Water Authority, and Delhi Jal Board, etc., looks after the operation, maintenance, and cost recovery also. After commissioning schemes, the State Boards (SBs) usually hand over the projects to the ULBs for O&M or perform this function on their behalf. Thus, the pattern of commissioning and O&M of schemes varies across different states.

The responsibility of O&M for urban water supply system and revenue collection is generally vested with ULB. However, in some cases, specialised agencies such as the state PHEDs, Water Boards, Water Supply and Sewerage Boards, Jal Nigam, etc., are in charge of these functions and formulate the water tariff and implement the same with the approval of the government. For instance, in Delhi, right from planning up to O&M of water supply and sewerage schemes are being carried out by the Delhi Jal Board. The local bodies generally receive some grant assistance for capital works on water supply from the State Government.

In light of the 74^{th} Amendment to the Constitution, the roles and responsibilities of ULBs have increased significantly to provide the basic facilities of water supply and sanitation to the community on a sustainable basis. The said amendment has enabled the ULBs to become financially and technically sound to provide these basic civic amenities to the community. Though a certain degree of cross-subsidy is inevitable in respect of the economically weaker sections of the society, it is very necessary to run the water supply systems on commercial principles due to the fact that water is an economic good and, as such, it should no longer be considered as a free commodity. Therefore, the imposition of realistic tariffs for various beneficiaries and their effective realisation is the key to the success of water supply sector performance, including that of O&M. Now, it has also been observed that all households are willing to pay user charges for such facilities, provided reliable service is ensured by the Water Supply Authorities and ULBs.

Apart from providing minimum required quantity of drinking water to the people, the O&M authorities should always bear in mind that quality must be always maintained to safeguard the health of the community. City-level consumer forums may be set up to keep a vigil on the water sources to prevent possible contamination and make periodical reporting to the O&M agencies for appropriate action well in advance. At the same time, awareness programmes on water conservation, wastage prevention, water quality, personal hygiene, etc., may have to be designed and implemented with the help of NGOs, Residential Welfare Associations, and the neighbourhood committees.

Consumer satisfaction driven by efficient and effective service delivery should be the topmost priority of the O&M agencies. An effective grievance redressal mechanism should be set up to enable the consumers to lodge complaints on aspects such as leakage and wastage of water, low pressure at the consumer’s end, contamination/poor quality of water, pilferage of system components, malfunctioning of water meters, problems related to meter reading, payment of bills, etc., and suggestions, if any, for better performance of the system. At the same time, all such complaints received by the O&M agencies should be attended to within a reasonable time frame, so as to win the confidence of the consumers. Details on Urban Water Supply: Legal and Institutional Framework can be referred from Chapter 2: Legal and Institutional Framework in Part C of the manual.

Efforts should be made to maintain transparent accounting of income and expenditure and to realise the O&M cost based on an affordable tariff through user charges.

1.1.1 Objective of the Manual

Manual on Water Supply and Treatment Systems (Drink from Tap), Part B: Operation and Maintenance is intended to serve as a guide to strengthen the technical, operational, and managerial capabilities required by the concerned personnel to operate and maintain water supply services as per acceptable norms of quantity, quality, sustainability, reliability, and cost for “Drink from Tap” with continuous (24×7) pressurised water supply system. This manual is intended primarily for the managers and technicians in charge of operating and maintaining the urban drinking water supply systems. This manual also includes guidelines for ensuring potability and promoting Drink from Tap continuous water supply. By following the guidelines outlined in this manual, water supply agencies can ensure the availability of safe, reliable, and affordable drinking water to the public while promoting sustainable and environmentally-friendly practices.

The procedures mentioned in the manual are intended to be guidelines for ensuring effective O&M of the water supply systems. This manual is not exhaustive but will serve as a reference volume for the agencies in charge of the water supply systems to develop their O&M programmes to suit their specific problems depending on the size of the system, type of agency, and location of the water supply system. Any agency desirous of formulating O&M programmes should do so only on the basis of an exhaustive assessment of their existing water supply systems.

1.1.2 Objective of Operation and Maintenance

The objective of an efficient O&M of a water supply system is to manage and ensure availability of 24×7 pressurised water supply system to provide safe and clean drinking water in adequate quantity and desired quality, at adequate pressure, at a convenient location and time, and as economically as possible on a sustainable basis and manage trouble-free service delivery system.

In engineering parlance, operation refers to the timely and daily operation of the components of a water supply system such as headworks, treatment plants, water quality testing facilities, machinery and equipment, conveying mains, service reservoirs and distribution systems, instrumentation, Supervisory Control and Data Acquisition (SCADA), Information Technology Enabled Services (ITES) (Section 10.5.3 of Chapter 10: Automation of Water Supply Systems, Part B of this manual shall be referred to for details), communication systems, etc., effectively carried out by various technical personnel, in conformance with the operational manual/guidelines, which is a routine function.

The term maintenance is defined as the art of keeping the structures, plants, machinery and equipment, and other facilities in an optimum working order. Maintenance includes planned/preventive maintenance, or corrective maintenance, mechanical/electrical adjustments, repairs, corrective actions, and reactive planned maintenance. However, replacements, correction of defects, etc., are considered actions excluded from preventive maintenance. Preventive maintenance includes work carried out on a regular basis to maintain & keep the infrastructure in good condition. Corrective maintenance involves replacing or repairing something that was done incorrectly, while reactive maintenance, also called breakdown maintenance, refers to maintenance tasks performed after an asset has broken down. The focus is on restoring assets to operating conditions as quickly as possible. It also includes reacting to public complaints such as malfunctioning and breakdown ofequipment.

1.2 Operation and Maintenance Scenario

A lack of attention to the O&M best practices for water supply schemes in several towns has led to a deterioration of the useful life of the systems necessitating premature replacement of many system components. Furthermore, the result is the water systems are unable to provide the services effectively to the community for which they have been constructed, and the systems are underutilised most of the time. Finally, the investment of crores of rupees was wasted.

Initially, a water supply scheme is generally designed and constructed for 24×7 pressurised water supply with DFT, but later often resorts to intermittent mode for many reasons. Operating on intermittent mode unnecessarily stresses the system resulting in poor service delivery and rapid deterioration of the system. Some of the key issues contributing to the poor O&M have been identified as follows:

a) lack of as-built drawings of the existing network and unavailability of conditional assessment;
b) contamination of water;
c) lack of water audit, improper metering, and high losses;
d) inequitable water supply;
e) lack of cost recovery to sustain O&M;
f) lack of inadequate data on O&M;
g) inappropriate system design and inadequate workmanship;
h) multiplicity of agencies, overlapping responsibilities;
i) inadequate skilled personnel and their training;
j) lesser attraction of maintenance jobs in career planning;
k) lack of performance evaluation and regular monitoring;
l) inadequate emphasis on preventive maintenance;
m) lack of Standard Operating Procedures (SOPs);
n) lack of real-time field data and information, etc.;
o) lack of appreciation of the importance of facilities by the community.

As a result, clear sector policies and legal frameworks, as well as a clear demarcation of responsibilities and mandates within the water supply sub-sector, are required. Based on the Indian experience, it has been observed that in the case of pumping schemes, by and large, about 20% to 40% of the total annual O&M cost goes towards the personnel (O&M staff), 30% to 50% of the cost is incurred on power charges and the balance is utilised for consumables, repairs, and replacement of parts and machinery, and miscellaneous charges. In most of the cities in India, the tariffs are so low that they do not even cover the annual O&M cost. This leaves little for a water system to implement and perform necessary measures such as controlling unaccounted for water (UFW), non-revenue water (NRW), and metering of the water connections may help to reduce water wastage and increase the revenue to the local Body to the maximum extent.

1.2.1 Challenges in O&M of System

The O&M of water supply systems present several challenges, ranging from technical issues to financial constraints. Some of these are as follows:

1. Ageing infrastructure, which requires constant repairs and maintenance to ensure it functions efficiently and effectively.
2. Availability of skilled personnel to operate and maintain the complex water supply systems.
3. Financial sustainability.
4. Control of NRW.
5. Lack of metering to ensure the sustainability of O&M.

Addressing these challenges requires a comprehensive approach that involves effective planning, adequate investment, and a skilled workforce, along with the adoption of sustainable practices to ensure long-term climate resilience of the water supply system. These have been discussed in Chapter 2: Operational Strategy, Part B of this manual.

1.3 Need for Efficient and Effective O&M

The system developed with a huge capital investment requires to be operated and maintained to achieve desired Service Level Benchmarks (SLBs) during the design period. Generally, the ULBs tend to put emphasis on the construction/development of the system, and requirements of O&M are neglected, leading to the premature deterioration of the system components and services. Thus, the project should be designed with the direct linkage between improved O&M practices and sustainability of water supply services, with customer satisfaction.

Various best practices implemented by Water Authorities worldwide are explained in Table 1.1.

Table 1.1: Summary of Good Practices Drawn from City Case Studies

Good Practice	City or Utility
Fundamentals	
Having dynamic leadership at the top	Singapore, Phnom Penh, Bangkok, WATCO, Malkapur
Use of integrated water management policy	Shenzhen, Singapore
Corporatisation of water utilities	Bangkok, Jamshedpur, WATCO
Regulating private sector participation effectively	Manila, Shenzhen
Service Delivery	
Increasing coverage and improving water availability	Bangkok, Colombo, MWCI, Phnom Penh, Singapore, Malkapur
Reducing NRW	Jamshedpur, MWCI, Phnom Penh, Singapore, Malkapur
Securing clean, safe, and reliable water supplies	Bangkok, MWCI, Phnom Penh, Singapore, Malkapur
Improving service to the poor	Bangkok, Jamshedpur, MWCI, Phnom Penh, Singapore
Adopting the practise of demand-side management	Singapore
Monitoring and reporting effectively	Bangkok, Jamshedpur, Singapore
Financial and Human Resources Management	
Improving staff productivity	Bangkok, Jamshedpur, MWCI, Phnom Penh, Singapore
Pricing water for efficiency and sustainability	Jamshedpur, MWCI, Phnom Penh, Singapore, Malkapur
Improving revenue collection	Bangkok, Colombo, Jamshedpur, MWCI, Phnom Penh, Shenzhen, Singapore, Malkapur

Source: ADB: Good Practices in Urban Water Management: Decoding Good Practices for Successful Future (2012)

1.4 Organisation of Maintenance

A proper organisation has to be in place for efficient O&M. Part C, Chapter 3: “Institutional Strengthening and Capacity Building” of this manual addresses this aspect in detail.

1.4.1 Key Criteria of O&M Contract

A typical performance-based O&M contract can be adopted which should include a definite time horizon of the service delivery, the extent of the services to be delivered, key performance indicators (KPIs), performance warranties, compensation and incentives, and liability ceilings, including clear KPI measuring mechanism.

1.4.2 Best Practices/Critical Success Factors

There are various best practices which can be adopted and certain critical success factors, when followed, will provide indicative strategies to implement sustainable O&M. The Table 1.2 explains checklist of O&M best practices as well as critical success factors.

Table 1.2: Checklist of O&M Best Practices/Critical Success Factors

Increase Utility of Facilities	**Maximize asset utilization**	**Enhance capacity of existing system.** e.g. Reducing NRW	**Apply demand management.** e.g. Introduction of telescopic water pricing	**Optimize availability/ reduce downtime** e.g. Scheduling short-duration maintenance tasks for off-peak hours.
	Enhance quality for users	**Adopt a customer-centric operating model.** e.g. Providing water as per SLBs.	**Enhance the end-to-end user experience** e.g. Ensuring grievance redressal in minimum time.	**Use smart technologies to refine performance** e.g. Use smart meter which will invoice as per consumption and reduce the cost of meter-reading.
Decrease total cost	**Reduce O&M costs**	**Implement lean and automated processes** e.g. Use of CMMS	**Optimize procurement costs and outsourcing** e.g. In areas where the requisite technology is discouragingly expensive or where specialist skills would be needed, operators can opt to outsource maintenance works or information technology (IT) services	**Right size management and support functions** e.g. Adjust their overheads and organizational structures by delayering, introducing shared services and optimizing the level of (de-centralization)
	Mitigate Externalities	**Arrange comprehensive sustainability** e.g. Water treatment plants can change from being net energy consumers to net energy producers by installing Solar Cells on roof top.	**Embed sustainability** e.g., engaging the broader workforce on Environment, health and safety aspects and not just creating a sustainability department	**Co-operative with relevant stakeholders.** Operators should also take a multi-stakeholder engagement approach, actively communicating with communities in outreach campaigns and collaborating with fellow operators and users to generate a greater positive impact across the infrastructure system.
Increase lifetime value	**Extend asset life**	**Invest in preventive and predictive maintenance**	**Control excessive asset consumption and stress** e.g., regulating the use of	**Enhance disaster resilience.** Effort should be made to incorporate more resilience into existing assets. Efforts should focus not only on structural

			pumps only in operating range	measures, such as building protective barriers and retrofitting existing facilities, but also on cost-effective, non-structural measures, including the creation of natural buffer zones and the adaptation of more resilient design.
	Reinvest with a life cycle view	**Prioritise project options with whole life cycle Cost Benefit Analysis.** Before committing to major capital expenditure, it should first identify all possible project options and investigate more cost-effective solutions, such as optimization, loss reduction, demand-side measures, system wide capacity balancing.	**Select contracting mode for best value for money**. e.g., most efficient delivery mode – public sector, PPP or private sector – should be chosen on the basis of a value-for-money assessment, taking into account the potential quality of service and level of risk to the government budget	**Prepare for efficient project delivery**
Enable O&M best practice	**Ensure funding**	**Dedicate user taxes via maintenance funds**	**Apply inclusive user charges**	**Capture ancillary business opportunities.** e.g. Realizing revenue from advertisement of ESRs, parking, etc.
	Build capabilities	**Introduce asset management planning.** e.g. conduct regular assessments of the existing asset base, and create an infrastructure balance sheet to show how the stock of assets has evolved and to forecast the required maintenance funding.	**Apply data, benchmarks, and tools**. e.g., Infrastructure asset management processes and frameworks (such as ISO 55000) shall be introduced	**Conduct training and develop talent.** Increase formal O&M education and training in the various disciplines by academia, international financial institutions (IFIs), governments and the private sector, and to enhance other forms of knowledge exchange. Actually, the O&M phase itself is an excellent learning environment, as its stability and long-term orientation enable uninterrupted learning curves over a project’s life cycle

		Proper digital and GIS Asset mapping has to be carried out as detailed in Advisory on GIS mapping of water supply and sewerage project. Conditional assessment and Retrofitting are also important aspects of Asset management which can be referred from Section 2.7.2 & Section 2.10.2 of Chapter 2 and Section 12.7.3 of Chapter 12 in Part A of this manual.		
	Reform governance	**Corporatize and professionalize public agencies**. It often captures the advantages of a privately run company, including enhanced productivity, streamlined processes, commercial orientation and financial sustainability, while remaining accountable to the public and serving the public interest.	**Foster cooperation between agencies**. It involves cultivating a shared vision, mutual respect, and in-depth understanding of each other's roles.	**Consider private sector participation**

Source: Report of World Economic Forum on "Strategic Infrastructure – Steps to Operate and Maintain Infrastructure Efficiently and Effectively", 2014 (https://reports.weforum.org/strategic- infrastructure-2014/executive-summary/)

1.5 Public Private Participation (PPP)

PPP is being encouraged to bring in much-needed investments, as well as efficiencies in the utilisation and management of resources. It could be introduced in phases, either Build, Operate, and Own (BOO) or Build, Operate, Own, and Transfer (BOOT) basis. Primarily, it is possible in two ways, i.e., first, privatisation of the existing water supply systems and second, privatisation of systems in newly developed townships, municipal wards, housing colonies, business and commercial complexes, etc. However, it will require improvements in the collection and recovery of the capital and O&M costs from the beneficiaries. Chapter 8, “Public Private Partnership”, of Part C of this manual deals with this aspect in detail.

1.6 Content of Part B

The Part B of this manual is organised as a set of 13 chapters. While the first two sets are the context, the remaining 11 provide guidance on the O&M attributes of the water supply system.

1. **Introduction**
2. **Operational Strategy:** The chapter is to adopt a strategy toward providing safe and equitable drinking water to end users from a reliable source through a proper system of a well-maintained train of treatment, transmission, and distribution network components, including efficient operations and maintenance of all tools and plants.
3. **Sources of Water Supply:** The chapter mainly discusses about the protection of the sources in terms of both quality and quantity. The sources of water supply are described in the following sections. To ensure a sustainable water supply at the source, it is advisable to maintain all the functional and available sources, irrespective of their utilisation.
4. **Transmission of Water:** The chapter discusses evolving operation procedures to ensure that the system can operate satisfactorily, function efficiently and continuously, and last as long as possible at the lowest cost.
5. **Water Treatment Plant:** The chapter discusses O&M of various process/units in a water treatment plant.
6. **Raw Water and Clear Water Reservoirs:** The chapter discusses the optimum use of raw water and clear water reservoirs, and their aspects of O&M.
7. **Distribution System:** The chapter discusses ensuring that the system can be operated satisfactorily and function efficiently and continuously, and develop specific operational procedures required for inspecting, monitoring, testing, repairing, and disinfecting the system.
8. **Drinking Water Quality Monitoring and Surveillance:** The chapter explains the aspects of water quality parameters, sampling, testing, laboratorial analysis, and outlines the standard procedures for various components of drinking water quality monitoring and surveillance, sanitary inspection activities to be undertaken.
9. **Pumping Station and Machinery:** The chapter discusses the O&M aspects of pumps and pump houses and troubleshooting for any issues.
10. **Automation of Water Supply System:** The chapter discusses the O&M of Water Meters, Instrumentation, Telemetry and SCADA.
11. **Water Audit, Monitoring and Control of NRW:** The chapter discusses on NRW, water audit, and its procedures and techniques or leakage control.
12. **Energy Audit and Conservation of Energy:** The chapter guides to carrying out an energy audit and factor for improving the energy efficiency in the system.
13. **Safety Practices:** The chapter discusses on safety practices in O&M of the water supply system.

CHAPTER 2 : OPERATIONAL STRATEGY

2.1 Introduction

The purpose of this chapter is to facilitate the design and adaptation of an operational strategy to achieve 24×7 pressurised water supply system with drink from tap. The result of adopting the strategy will position a water utility to provide safe and equitable drinking water from a reliable source to the taps of end users. This can be done through an effectively funded proper water supply system that consists of a good quality water source, well-maintained intake, treatment, pumping stations, reservoirs, transmission and distribution network components, including efficient Operation & Maintenance (O&M) of all tools, plants and machinery.

The huge investments in the creation of these highly productive facilities often fail due to a lack of proper O&M. Rebuilding and replacing the system components entails re- investments coupled with the interruption in the services. The Urban Local Body (ULB)/Parastatal Public Health Engineering Department faces many challenges. The main challenges include ensuring that the maintenance staff follows a valid Standard Operating Procedure (SOP)/practice to achieve proper and efficient O&M of the entire system, which generally receives relatively lower priority compared to other utility services. The water supply system can be assured and improved by a robust monitoring system, with sufficient earmarked funds for smooth O&M for the system along with deploying seasoned, well-trained and skilled, enthusiastic, and motivated utility staff.

Automation, Supervisory Control and Data Acquisition (SCADA) and Internet of Things (IoT) and Digital Twin technologies must be properly leveraged and applied to collect, analyse, and interpret data, so as to monitor the installations.

For sustainable service provision through capital investments in new infrastructure, efficient O&M is indispensable, failing which, any water supply system shall soon decline to a point where service provision shall be gravely compromised, leading to huge water losses, financial losses, and health risks to consumers.

2.2 Design Strategy

A sustainable and effective water supply system must have a well-designed and robust O&M action plan. Several measures are needed to create a sound course of action that will assist in the optimised performance of the system in the long run.

To develop an efficient O&M strategy, the following aspects of the water supply system will have to be studied and addressed.

2.2.1 Technical Aspects

- **Conditional assessment studies of all components**: It will make the utility aware and prepare in advance to take corrective actions in extreme climates. Assessment of intake arrangements, treatment systems, pumping machinery, electrical installations, pipes, valves, reservoirs, etc., is to be ensured.
- **Water demand management challenges:** To ensure development of more infrastructure to cater for the demand.
- **Technical specifications, quality, and durability of equipment**: These, along with the

spare parts, costs, availability, and accessibility, for developing cycle for planning and procurement.

- **Complexity of operating procedures**: To make simple operating manuals, which can be followed easily by field personnel.
- **Implementing System Improvement Plan (SIP)**: To improve existing service levels and achieve prescribed service level benchmarks.
- **Use of modern technologies, e.g., CMMS, Automation, SCADA, IoT, and ITeS**: Improving efficiency in services will be an important and necessary part of successful 24×7 water utility services.
- **Need for skilled personnel**: Providing training and capacity building for ensuring sustainability of operations.
- **Need for standardisation**: To promote quality control and quality assurance.
- **Promoting use of local material, inventory, and equipment:** To reduce cost and delivery time.
- **Data analytics and predictive analysis:** The digital twin technology can be used to analyse all the real-time data received from SCADA or other data from different entry points to take decisions and eventually O&M actions.

2.2.2 Financial Aspects

- Dependence on fuel, power, chemicals
- Total cost of O&M activities
- Use of new technologies for cost optimisation
- Complexity of O&M procedures and necessity of costly skilled personnel
- Use of local inventory, materials, and equipment to maintain cost-effective operations
- Proactive maintenance planning for repairs to avoid costly replacements
- Funding of O&M
- Provision of financial allocations for replacement and rehabilitation costs
- Cost recovery through metering and billing

2.2.3 Environmental Aspects

- Sustainability of water source with respect to quantity and quality
- Necessity for source protection
- Alternate sources necessary for emergency conditions
- Reclamation (Recycling & Reuse)
- Sludge disposal and resourvce recovery
- Environmental safeguards

2.2.4 Institutional and Legal Aspects

- Legal framework, national and state policies
- Capacity building and regular support for ULBs and their staff
- Availability of technical assistance to the communities
- Capacity enhancement of ULBs for increasing public outreach and assisting communities
- Involvement of the formal (informal) private sector and NGOs

- Vigilance policy has to be in place to manage the available assets
- Incentives and penalty policies to be in place for billing and collection, illegal connections and disconnection

2.2.5 Community Aspects

- Social safeguards
- Responsibility and ownership feeling
- Desire and demand for improved service level
- Community participation
- Understanding the requirement of community according to their culture, habits, and beliefs
- Involvement of elected public representatives
- Managerial capacity for monitoring
- Gender-based involvement in the O&M activities
- Technical skills available in the community or within reach of the community
- Maintenance culture within the community for good community participation

2.3 Major Challenges

Improper management is the primary cause of poor O&M in water supply systems. New facilities invariably receive higher priority regarding budget and staffing allocations. During financial emergencies, O&M budgets are the first to be cut, which has a consequential effect on maintenance services, directly affecting repairs of pipes, maintenance of machinery health, and related O&M services. In general, spare parts for maintenance are in short supply, and requests for their procurement are often "postponed" leading to emergencies.

The ULBs are generally under pressure to expand the network to new/developing areas and rely on the State/Central Governments/Financial Funding Agencies for capital investments. Ideally, ULBs should be financially self-sufficient and make provisions for new capital investments, including O&M expenses for the existing and newly created water supply systems. The ULBs are reluctant to increase to break even tariffs, thereby leading to the ever-compounding problem in water supply provisioning and its maintenance services.

The following are the main challenges encountered and reasons for improper O&M.

2.3.1 Inadequate Organisation

It is invariably found that the water supply organisations are deficient in adequately trained staff, resulting in poor O&M services. Also, at times, overstaffing leads to a financial burden on the organisation. Thus, an optimum employability analysis for staff enrolment is required from time to time to keep all aspects in control, be it efficient services or sustenance cost. The advancement of various technologies being introduced in water systems, e.g., automation and SCADA, calls for augmenting staff capable of operating these technologies. Detailed discussion has been carried out in Chapter 3: Institutional Strengthening & Capacity Building of Part C of this Manual.

2.3.2 Lack of Accurate Records

Reliable records are required to be logged and maintained at the operation sites to maintain cost-effective operations decisions regarding periodic and preventive/predictive maintenance schedules. When adequate records are not kept in a proper manner at the point of need by the

O&M staff, the staff often does not have what they need to effect proper repair and/or maintenance.

2.3.3 Lack of Funds and Proper Budgeting

Inadequate investments in O&M are a common feature in several ULBs/organisations. Meagre funds are allotted for the maintenance of facilities or the training of staff. Often, budgets meant for procurement of spare parts, painting to prevent corrosion, or essential training, are invariably diverted to other less important trivial works on the premise. Power and chemical costs are the major mandatory, recurring and variable O&M expenses, and thus, other expenses are many times curtailed, adversely affecting the quality of O&M. Maintenance and operation of civil infrastructure of water supply system requires huge budgetary provisions, and inadequacy of funds many times speeds up the deterioration of the structures, affecting water quality, increased risk to public health, and service delivery interruptions that impact quality of life and the economic success of the community.

Appropriate budgetary provisions for the O&M of water supply system need to be provided to carry out O&M without constraints such as lack of skilled human resources, tools, system redundancy, repair parts and supplies, and safety equipment. O&M sustainability is only achieved through adequate revenue generation and strong skilled administration. The lack of these key aspects of a good O&M system is often a political issue that will require needed fundamental changes in the Indian Rule of law to properly levy and collect practicable revenue to stop the cycle of deterioration.

O&M consists of activities such as execution of general affairs related to water, budget execution, asset management, co-ordination of service charges, guidance for house connections, monitoring, O&M of distribution system and transmission network, O&M of pumping station, and treatment plant, water quality control, ledger management, environment conservation, and others.

The calculation of O&M costs is a sum of the relevant costs for the following:

a) establishment;
b) energy;
c) consumables and fuel;
d) laboratory analysis;
e) landscaping;
f) repairs, renewals, and minor replacement of infrastructures;
g) depreciation;
h) seed capital;
i) debt servicing;
j) levy cess;
k) taxes and duties;
l) consumer services;
m) billing and collection system.

2.3.4 Lack of Metering Policy

In most of the utilities, the supply is intermittent and generally, the house service connections are unmetered and charged on a flat rate per connection basis. Also, often intermittent supply is cited as a reason for the non-working of meters. Proper meters and sound payment practices by the utility amongst its consumers is essential. Policies for “Bulk” and “Individual” meters shall be put into place with penalties clauses so that every single drop of water is accounted for. Yard-stick-based higher charges on the thumb- rule principle shall be there for single and bulk consumers in case consumed water is not metered, so that individuals are motivated to install meters. Non-metered supply charges shall be on the higher side so that the onus of prompt repairs lies at the user’s end. The incorporation of Artificial Intelligence (AI) and other modern technologies like IoT can aid the metering policy without human intervention. Water supply from the source to the consumers shall be metered, factoring in consumption and losses in the supply network. Metering is the “First and Formost” step for implementing 24×7 pressurised water supply system with drink from tap based on District Metered Areas (DMAs).

2.3.5 Lack of Tariff Policy

The lack of a tariff policy in the state/ULB significantly affects financial sustainability and quality of service provided to consumers. Without a tariff policy, it becomes challenging to ensure adequate revenue generation to cover the O&M costs of the water supply system. Developing a tariff policy can be a complex process that requires balancing various factors, such as affordability, equity, and the financial viability of the water supply system. Average Incremental Economic Cost (AIEC) methodology can be employed to design the tariffs.

For instance, inadequate revenue may lead to deferred maintenance, resulting in leakages, supply disruptions, poor consumer services, and deteriorated water quality.

The absence of a tariff policy may also result in a lack of accountability and transparency in the water supply system. This makes it difficult for stakeholders, including consumers, to understand the cost of water services and may lead to a lack of trust in the water supply system. Therefore, developing and implementing an appropriate tariff policy is crucial for ensuring the financial sustainability of the water supply system, promoting efficient use of water resources, and providing reliable and high-quality water services to consumers.

2.3.6 Lack of Easy Access to Installations at Remote Locations

The facilities may be located at inaccessible places, e.g., intakes in forests, remote WTP locations, and long pipelines, pipelines passing through forests/hilly areas, or facilities away from the city/town. Wherein, it is challenging for the operations staff, as well as qualified maintenance personnel, to reach such places for attending to repairs or replacements, including mobilisation of machinery. The utilities must anticipate any repair work, and proper arrangements along the way or at various intermediate locations must be made to avoid delay in any repairs.

2.3.7 Equipment Crossed its Stipulated Life

In several installations, the equipment might have outlived its usable life due to fair wear and tear, or it might have deteriorated beyond economic repairs and warrants replacement of the equipment immediately. Sometimes, a lack of predictive/preventive maintenance leads to a reduction in the effective age of equipment. These equipments are generally critical for efficient operations of the entire system, e.g., pumps, motors, etc., and cause system breakdown. The replacement and efficient maintenance have to be planned and budgeted.

2.3.8 Lack of Specially Trained Personnel

The O&M of the water supply system involve multidisciplinary engineering skills and expertise, viz., Civil, Electrical, Mechanical, and Instrumentation Engineering. Generally, the utility staff lacks these skills, as it is challenging to get trained manpower at many locations, causing inefficient O&M of the facilities. This causes frequent breakdowns or poor services. The water supply system is a chain process involving huge manpower, and any wrong operations due to incompetency of staff, at any stage, may disrupt the entire system. The new technologies in the field of Automation, SCADA, IoT, and Digital Twin Technologies are to be understood by the O&M staff and get up-to-date knowledge of the same.

2.4 Development of Strategy

2.4.1 Focus Areas

O&M is a critical component of any water supply system and shall be a cohesive entity. The water utility must focus on following areas and activities simultaneously so that the entire system runs in a perfect manner to deliver water with “***Drink from Tap”***, as per as per Figure 2.1.

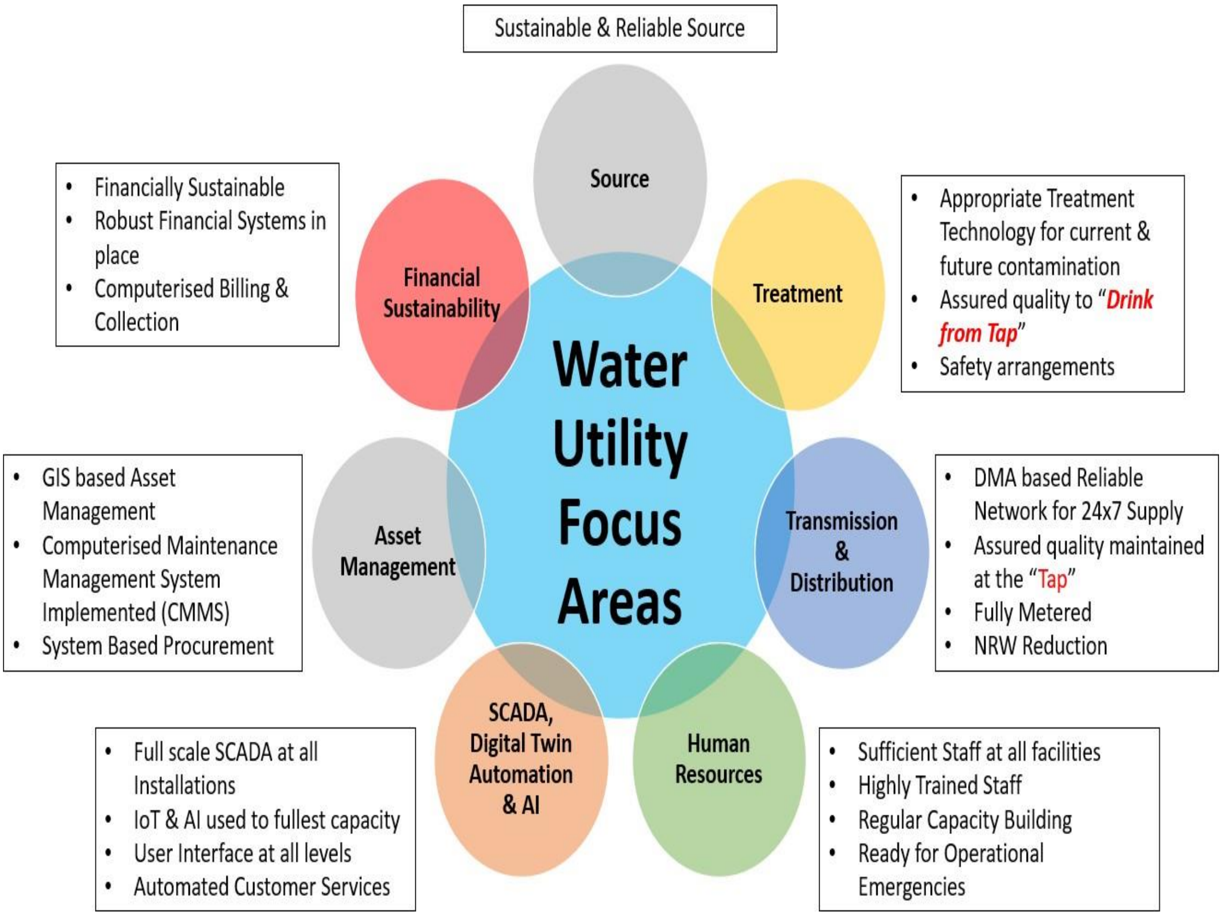


Figure 2.1: Water Utility Focus Areas

2.4.2 Elements of Effective O&M

The O&M Strategy has to be developed by each utility individually, covering three well- defined elements, viz., Technical, Management, and Capacity building, as shown in Figure 2.2 below.

Figure 2.2: Elements of Effective O&M

Good O&M enhances the quality and reliability of service and extends the useful life of the equipment facility, resulting in substantial savings. Competent management of capital flow and running expenditures on assets and liabilities is imperative in preventing water losses from the system. Optimum funds generation from the water service shall be adequate to generate funds for self-sustenance of the various related components of the operation, maintenance *(including replacements),* debt service, and other overheads.

2.4.3 Strategy for Efficient O&M

All water utilities must develop a clear O&M strategy that involves various actions and mobilisation as follows:

(a) preparation of GIS based asset maps of the entire system, from source to consumer connections;
(b) preparation of a robust plan for O&M (Annual O&M Plan);
(c) providing required qualified and trained personnel to operate and maintain the facilities;
(d) providing capacity building programmes for the O&M personnel;
(e) timely availability of spares and tools for ensuring maintenance;
(f) ensure quality and quantity of water (per capita supply) with an adequate check of respective critical pressure points, DMA flows & water quality points in the system;
(g) NRW reduction action plan in place;
(h) maintain water quality for providing 24×7 pressurised water supply systems with drink from tapto all consumers at all times; preparation of a water audit and leakage control plan;

(i) action plan for an energy audit for saving on energy;
(j) providing and maintaining adequate instrumentation and SCADA control systems with connection to digital twin technology;
(k) maintaining MIS records on the system, including the history of the equipment, costs, life, revenue, NRW, etc.;
(l) implementing Computerised Maintenance Management System (CMMS);
(m) establishing a sound finance generation and management system.

2.5 Management

2.5.1 Changed Management Approach

The management of water supply utilities shall be service-oriented, with a clear focus on the customer/consumer and customer services. It should be prepared to run the organisation in a professional manner on a commercial basis. The management shall be responsible for employing well-qualified, experienced, efficient, and motivated staff to perform under all circumstances.

They should manage and supervise to ensure that all O&M personnel performs their duties. Spare parts and tools should be made available on time. All logbooks and a good record system covering all equipment of the facilities and units should be instituted. The implementation of computerized maintenance management systems (CMMS) should be encouraged and made mandatory. Necessary funds shall be provisioned to carry out upgradation and regular updating.

In most of the cities, a large, experienced workforce already exists and is being employed in O&M activities. Modern programmes on skills development and improvement of the new automated system shall be made part of the training. Efficient strategies should be adopted for the deployment of trained staff judiciously as described below:

a. O&M staff

The O&M is performed by:

i. operating staff;
ii. supervisory staff.

While the former actually run the system, the latter monitors the operations and provide managerial support. Staffing norms for the O&M are site-specific and cannot be standardised due to specific requirements.

b. Well-trained staff

A well-trained staff, as per the specific job description, shall be deployed in the facilities to carry out the execution plan for maintenance. Staff shall be equipped to handle all kinds of periodic maintenance schedules, thereby ensuring safety, enhancing the equipment's life, and increasing the entire system's reliability. Considering the fast advances in emerging technologies and equipment, due care must be taken to ensure the staff must be skilled accordingly. Chapter 3: Institutional Strengthening & Capacity Building of Part C of the Manual.

c. Diagnostic tools

Advanced diagnostic tools shall be utilised to carry out a timely analysis of the equipment and machinery involved in the entire chain of the facilities of the water supply services from the source treatment to tap delivery. Diagnostic tools like thermal imagers, ultrasonic sensors, vibration analysers, leak detector, pressure gauges, quality censors, and Digital Twin Data in sync with the SCADA information shall be utilised proactively to carry out the necessary, timely detection/diagnosis of issues for immediate repairs, resulting in saving to the exchequer and delivering services efficiently. Staff shall be trained to handle such equipment and eventualities rather than waiting for reactive maintenance.

2.5.2 Financial Management

It is essential to establish a sound financial management system to make the water supply system financially sustainable. This can be achieved by judiciously controlling expenditures and increasing income. Control of O&M expenditure can be achieved by preparing an annual budget based on realistic estimates factoring in the age of various items and equipment based on the depreciation parameters.

A cost-benefit analysis shall be carried out in detail to fix the water recovery charges factoring in all of the above, including tariff charges to be levied upon domestic, commercial, and industrial users. This is further explained in Section 4.1 of Chapter 4: Financial Management of Part C of the Manual.

2.5.2.1 Cost Recovery

For any public utility service, the tariffs should be reasonably fixed for it to be financially self-sustainable. Water charges levied and prompt collection in a time-bound manner will improve fund flow and services. The cost of production of water shall be reviewed annually to ensure full cost recovery and revised annually based on escalation and other economic factors.

Timely reading of meters, raising, and collection of bills and recoveries is imperative for maintaining continuity of water services and a consistent cash flow. The penalty clause shall also be included as is done for other services. Reducing losses will improve efficiency and cost recovery. Emphasis should be given to improved consumer services and satisfaction, which will eventually increase the collection and recovery. The detailed discussion has been carried out in Section 4.3.5.1 of Chapter 4: Financial Management of Part C of this Manual.

2.5.3 Outsourcing

Outsourcing can be resorted to strengthen existing team and to handle modern equipment efficiently. O&M of a component or complete water supply scheme may be outsourced if found economical, similar to a Comprehensive Annual Maintenance Contract (AMC).

The following aspects can be looked into, before outsourcing:

i. adequately trained, qualified staff for operation and supervision of the services;
ii. adequate infrastructure like equipment, material, testing, and repairing facilities;
iii. experience in operating similar systems;
iv. financial soundness;
v. capacity to tackle and handle emergency situations;

vi. good MIS capabilities;
vii. consumer satisfaction-oriented approach.

2.5.3.1 Components for Outsourcing

Based on the above requirements and the experience of the organisations, the exploration of private agencies for whole or part of O&M of water treatment plants, pumping stations, the distribution system, and other components, or entire system from source to tap, etc., is analysed for outsourcing, and the scope of work is fixed.

2.5.3.2 Strategy for Outsourcing

There is a need to have an alternative institutional mechanism for O&M of water supply utilities. Outsourcing in O&M may be desirable to achieve efficiency and cost- effectiveness. Staff employability shall be judiciously approved as per staffing norms. However, the department/agency responsible for O&M should have a constant vigil for effective control of the performance of contracted agencies.

One such set-up/model for an O&M agency is suggested below:

i. qualified supervisory staff comprising engineers, accountants, managers, customer service personnel and quality auditors to be employed;
ii. dedicated staff for the O&M of intake arrangements, pumping stations, treatment plants, reservoirs, pipelines & house service connections. They will be responsible for all civil, electrical, mechanical, and instrumentation O&M;
iii. dedicated inspection staff for transmission mains and distribution system;
iv. dedicated repair teams for pipeline maintenance, including leakage detection and repair;
v. repairs teams for meter repairs, upkeep of chlorinators, settlers, clariflocculators, filter house, chemical dosers, and instrumentation repair, maintenance, and calibration equipment;
vi. supply and arrangement of chemicals and spare parts, etc.;
vii. customer service centres and customer services teams.

After a good experience with the outsourced agency, the organisation can decide to take over duties and responsibilities that can be discharged by it economically and efficiently.

Outsourcing the O&M of Urban Water Supply: An experience of Jaipur, Rajasthan,

Bisalpur-Jaipur Water Supply Project has been designed to meet the water requirement of Jaipur city from the Bisalpur Dam on Banas River in Tonk district. The project comprises of two sections namely, (i) transmission part under which water is pumped from the intake pumping station up to Balawala headworks in Jaipur district via Surajpura headworks and (ii) transfer part under which water is delivered from Balawala up to the south edge of Jaipur city and the adjoining rural areas.
Water is being pumped from intake pump house to water treatment plant at Surajpura through a 2400 mm diameter MS raw water main of 8.2 km length. The capacity of Surajpura Water Treatment Plant is 600 MLD, out of which, 500 MLD water is being supplied to Jaipur City and 100 MLD to the rural areas presently. Clear water from Surajpura is transferred to Balawala through 2300 mm MS pipeline spanning a length of 96.2 km. Under the transfer part, six headworks have been constructed in Jaipur city. Water is being transferred from

these headworks through DI/MS pipeline of diameter 200 mm to 2200 mm over a length of 150 km to nearly 100 nos. distribution centres across the Jaipur city. The monitoring, control, audit and supervision of entire system is being done by the master control centre at Balawala through state of art SCADA system. PHED, Rajasthan has outsourced the O&M of the entire Bisalpur-Jaipur Water Supply Project (Transmission and Transfer Part) on private contract basis which has reduced labour management problems, decreased the time taken for repairs, and has resulted in substantial savings in the O&M cost through improvement in power factor, increase in efficiency/performance along with demand control management, thus benefiting the consumers with efficient and reliable water services.

Source: Rajasthan PHED

2.5.4 Role of Public Private Partnership (PPP)

PPPs are often particularly well suited to upgrades, replacements, and rehabilitation. By tapping private sector know-how in designing, constructing, operating, and maintaining infrastructure, the asset can maximise quality and minimise total life cycle costs.

To choose the most promising delivery and financing model, the whole life cost of carrying out the O&M under the traditional model and alternative PPP model is estimated and compared. A PPP is considered economical only if it entails a net positive economic gain relative to the traditional model. A detailed discussion is carried out in Chapter 8 Public Private Partnership of Part C of this Manual.

2.5.5 Role of Voluntary/Non-Governmental Organisations (NGOs)

The role of Voluntary/NGOs is important and should be encouraged, especially in carrying out community participation work, like Information Education Communication (IEC) activities, viz. organising public awareness campaigns, water conservation techniques, acceptance and role of meters in water conservation and savings in water procurement costs, benefits of clean piped water supply, the process involved in bringing tapped water at their doorsteps, improved health benefits, judicious use of water by people and the need to pay water bills as for other services. Water users committees can be formed by the active involvement of NGOs to periodically review the local problems, render advice to the agencies for improvements required and future course of planning, and upkeep utilities within their jurisdiction.

These utility organisations can prepare Information-Education-cum-Communication material (e.g., pamphlets and billboards) to leverage the services of voluntary organisations/NGOs in disseminating the information amongst the consumers and create awareness amongst the public.

2.5.6 Role of Community

The community plays an important role to ensure efficient participatory implementation of water supply system in the city's water supply, quality control, financial management, and effective O&M of water supply system established. Community engagements refer to planned and unplanned ways the water corporations interact and relate to their partners, stakeholder, and communities.

The community will understand the importance in supporting the utility financially for proper operation to attain higher level of services. Community activities and sound participation in O&M of water services play a great role in the management of O&M and impacts the human health, status, behaviour, and longevity of water services.

In Puri, Odisha, Jal Sathi's, a Self-Help Group (SHG) is involved, and its group are trained by Water Corporation of Odisha (WATCO) (service provider) to support the 'Drink from Tap' Mission. It provides an important link between government and the communities, leading to improved behavioural change of public towards water, water quality testing, meter reading, tariff collection, water conservation, etc., on ground. They also roll out the communication strategies to ensure that the information reaches all the customers, irrespective of their income, literacy, and access to technology. The observation checklist assisted Jal Sathi's to ensure and educate right practices to the customers.

Source: WATCO, Odisha

2.6 Technical

The technical aspects of the entire water supply system components are very important and critical for an efficient O&M. The designs of all the components are explained in detail in Part A: Engineering – Planning, Design and Implementation of the manual.

2.6.1 GIS Mapping, Asset Management for Effective O&M

GIS mapping of all equipment and assets is a very crucial data for O&M staff. All assets involved in the water supply system, from the source to endpoint delivery to the taps, shall be mapped. Even existing maps can be upgraded as analysis of digital data is comparatively easier to handle vis-à-vis manual/hard copy. The agency should set up routine procedures for preparing and updating the maps and inventory of pipes, valves, and consumer connections. This will assist in prompt site-specific timely response and will result in judicious decision-making.

2.6.2 Energy Audit

Generally, pumping installations and treatment plant processes consume a huge amount of energy. The energy cost can be as high as 30%–50% of the overall cost of O&M of water works. Hence, it is inevitable to estimate and monitor energy consumption on a regular basis and take steps for energy conservation. Energy audit, in simple terms, means monitoring existing energy consumption at various units/sub- units and estimating any wastage of energy due to poor efficiency, higher hydraulic loss or power loss, etc.

Some of the aspects of inefficient use of energy are:

- reduced pump's efficiency due to pump's operational lifespan;
- pumps not operated at the Best Efficiency Point (BEP);
- increase in the head loss in a pumping system due to throttling, clogging of the strainer, encrustation of column pipes, and pumping mains;
- inefficient pumping systems in the treatment processes, such as backwashing and chemical dosing, leading to an improper work done and an adverse effect on the quality of treated water;
- improper/uneconomical diameter of sluice valves, column pipe, drop pipe, etc., in the pumping station;
- wastage of energy due to the operation of electrical equipment at low voltage or low power factor and poor maintenance.

As a result, making better use of power and decreasing waste will help the utility run more smoothly. This could be accomplished by a systematic energy audit, which can identify potential energy-saving and power-saving measures. The details can be referred to in Chapter 12: Energy Audit and Conservation of Energy of Part B of the water manual.

2.6.3 IoT/ Smart Components Telemetry, SCADA and Digital Twin Systems

Telemetry is an automated connection process that helps in measuring and collecting data at remote locations. Gaps in monitoring and maintaining equipment activity results in water leaks that spring and widen, filter clogs, and broken pipes. Eventually, to streamline structural operations, use SCADA systems which receive signals from multiple installations of telemetry services throughout the water treatment process. Software displays information for the operator to record and interpret. A solid SCADA system connects the user to the telemetry. SCADA has broad range of applications for water systems. The monitoring allows real-time inspections across filtration plants, pump stations, and the entire distribution network. Each piece of equipment that requires monitoring from valves to tanks can be equipped with service control relays and can be installed on equipment like pumps, valves, UV emitters or booms.

Digital twin technology is a revolutionary concept that has gained increasing popularity in recent years, and it has now started to make its way into the water supply industry. The technology involves creating a virtual replica of a physical system, such as a water supply system, and using real-time data to simulate its behaviour and performance.

A digital twin can replicate the physical network in water supply systems, including all the pipes, valves, pumps, and other components. Real-time data collected from sensors installed throughout the network can be fed into the digital twin, allowing operators to monitor the system's behaviour and identify potential issues before they occur. One of the significant advantages of digital twin technology is that it allows operators to optimise the performance of the water supply system. By simulating different scenarios and testing different configurations, operators can identify the most efficient and effective ways to manage the network, such as reducing energy consumption, water quality, and maintenance costs.

Another benefit of digital twin technology is that it can help to improve the resilience of the water supply system. By simulating different scenarios, such as extreme weather events or equipment failures, operators can identify potential vulnerabilities in the network and develop contingency plans to ensure the continuity of the water supply. It allows monitoring and optimises network performance, improve resilience, and enhance the quality of service delivered to consumers.

Sensors and process controller devices (control relays) are attached to Remote Terminal Unit (RTU). Multiple RTUs at different sites transmit the data collected to a single meter station which displays information in a browser. For an especially large water management system, several master stations can be controlled by a single top- level master.
Detailed discussion of the above topic is carried out in Part B Chapter 10: Automation of Water Supply System.

Smart Water Management - IoT based real-time monitoring of water supply quantity and quality – First time in the country at city level, Geographic Information System (GIS) and SCADA has been introduced in Puri for safe and equitable water supply and high-water pressure for “Drink from Tap” Mission. Pilot projects completed in 58 pilot zones in Bhubaneswar and Puri and other 19 towns for ensuring the water availability and quality in every part of the city, labs on wheels, 24×7 customer care service, and quick response teams has been provided. IoT application has been provided for flow and pressure management for equitable distribution in city wide and reduction of NRW.

Source: Puri, Odisha

2.6.4 Automation

Automation in O&M will increase the efficiency and performance of the water system. Some of the components where automation may be undertaken for effectiveness are listed as follows:

a) **Water Meter:** A water meter is a cash register of a water supply agency. The metre reading environment is usually unfavourable to the metre reader as most of the water meters are installed in the underground chamber; these chambers are filled in many cases with water, and reptiles or insects also co-exist. Some consumers connect their electrical earth terminal to a water utility pipe, which endangers the safety of the meter reader. Also, at times, premises are not accessible to the meter reader. The solution to the above difficulties is to install an automatic system to read and record meters and process the results by computers/IoT remotely.
b) **Pumps:** Automated pumps should be installed, wherever feasible, in water supply schemes to ensure reliable water supply and reduce operator workload.
c) Upstream controls of the sluice gates or valves (e.g., sludge disposal from thickened sludge sump, clariflocculators, plate settler, contaclarifiers, etc.) are to be installed.
d) Control on the auto-administering device for the chemical dosing system based on automatic testing.
e) Integration of automation with SCADA for active response improving efficiency.

2.6.5 Improvements in Water Quality Control

Generally, water testing labs are located within water treatment plants. The treated water must be supplied as per IS: 10500 (2012). Water quality monitoring at various control points in the water supply system can be monitored via sensors connected to the SCADA system. The quality at the consumer end can be assured by providing a mobile water testing laboratory and real-time water quality data display in public places and by providing a 24×7 customer care service attached by a quick response team. For further reading on drinking water, quality monitoring, and surveillance, refer to Chapter 8 in Part B of this manual.

2.6.6 Water Audit

There are considerable losses in the water network from the very production to the distribution in form of leakages, resulting in loss of revenue. Hence, a proper water audit is required to minimise these losses. Detailed deliberation on water audit, monitoring and control of NRW is referred at Chapter 11: Water Audit, Monitoring and Control of NRW in Part B of this manual.

Implementation of 24×7 Water Supply Project through PPP in Nagpur, Maharashtra

Nagpur is the second capital of Maharashtra. NMC manages the basic municipal water supply of 500 MLD with annual budget on water supply is approximately Rs. 95 Crore (expenditure) against actual receipt of only 50 Crore (Revenue) as of 2009. Considering this Water Audit was conducted in which it was found that NMC was paying for approximately 600 MLD of raw water to Irrigation Department. However, NMC generates only 490 MLD of treated water from all the WTP.

Further, it was found that the billed water volume was only 240 MLD of water (as per billing records). The total water losses were 260 MLD, i.e., 60% NRW.

Audit report enabled NMC to take up initiative such as:

- replacement of canal by closed conduit for transmission of raw water;
- installation of flow meters at all raw water and pure water transmission mains;
- repaired discovered leakages;
- implement slum policy for water supply to reduce unauthorised consumption;
- continue effort to identify illegal connections.

Presently, the following points are achieved.

- Total water losses were approximately 40% i.e., as on date total water losses were reduced from 60% to 40%.
- Historical leakages were plugged.
- 100% meterisation was adopted and Initiative taken for house-to-house metered connection.
- Illegal connections were reduced.
- Number of Public Stand posts were reduced.

Source: Office of Executive Engineer, Nagpur Municipal Corporation

2.6.7 Non-Revenue Water Management

NRW is water that is produced and lost before it reaches the customers. Losses can be real-losses through leaks and apparent-losses through false metering and theft. Reducing the NRW can help cities improve the services and then perform efficiently. Reducing water losses can help water utilities ensure the financial viability.

Transmission and distribution system should be properly maintained in order to prevent the wastage of water and provide a constant pressurised flow of potable water at the consumer end. The GIS mapping and DMA approach should be implemented with metering, as explained in Section 12.12 of Chapter 12: Service Reservoirs & Distribution System of Part A. A dedicated NRW cell should be established in all ULBs that will continuously monitor and control the NRW. Efficient billing and collection system with people-centric consumer services is to be established as explained in Section 11.8.1.4 of Part B, Chapter 11, Water Audit, Monitoring and Control of NRW.

2.6.8 Safety in O&M Operations

Accidents can occur during the O&M of a water supply system. Hence, O&M staff must adhere to certain safety procedures. Safe clothing, such as insulated heavy-duty gloves, safety glasses/shields, safe operating techniques, and other PPE shall be readily available to the staff to handle eventualities and avoid accidents. The staff shall also be trained from time to time as safety has to be paramount. Detailed deliberation on safety practices in O&M is referred at Chapter 13: Safety Practices in Part B of this manual.

2.6.8.1 Safety Audit in O&M

Safety audits are required to ensure and check for compliance of all the safety guidelines of O&M assets and confirm the availability of proper equipment for the staff. The frequency and timing of the audit procedure will vary according to circumstances and local regulations. An audit is a must for mid-course correction, and procedural duration from SOPs can be incorporated as follows:

- at regular intervals: the frequency of routine audits will be dependent on parameters such as the population serviced, the size and complexity of the system, and the quality of source water/treatment facilities;
- substantial changes to the source, the distribution or storage system, or the treatment process;
- any significant incidents;
- upgrading the workplace with safety standards with ISO certifications.

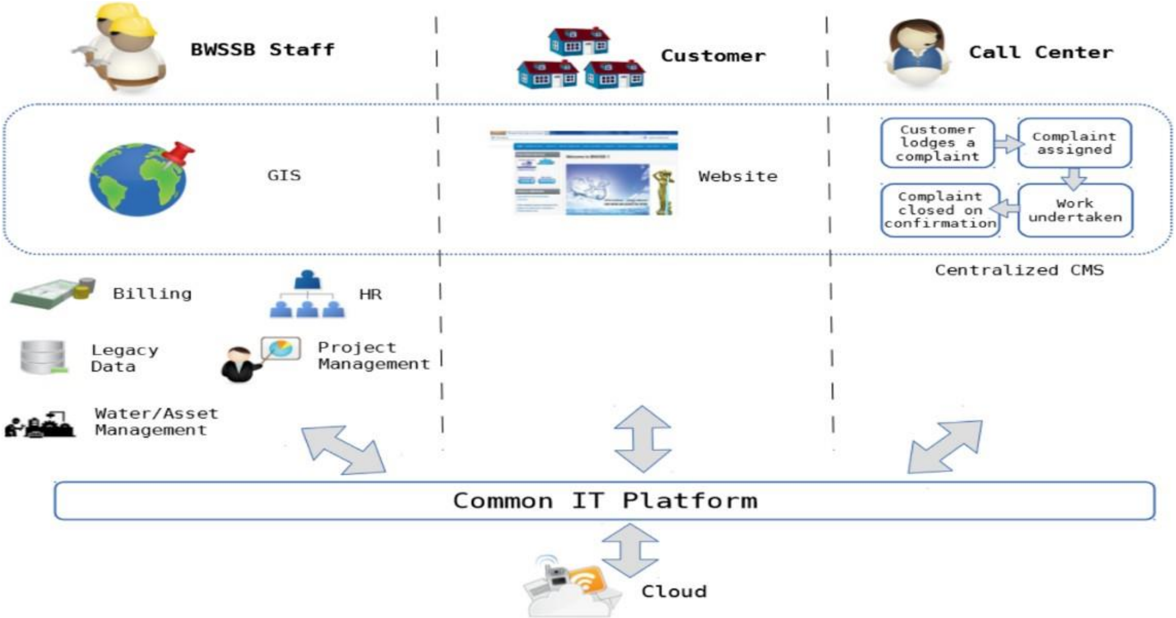
A periodic audit should include the following, in addition to a review of the water safety plan:

- Examination of the records to ensure that system management is being carried out as per described procedures in the safety plan.
- Ensuring that operational parameters are kept within specification and complied with earnestly.
- Ensuring that verification programmes are operated by the water utility (either through in-house expertise or through a third-party arrangement). An assessment of implementation programmes along with development strategies for improvement and a water safety plan shall be done.
- Ideally, the sanitary inspection should cover all the components of the entire water supply system, viz., intake source, treatment, transmission as well as the distribution up to the tap.
- Water auditors should conduct a surprise check programme of visits to review documentation and records of operational practice to ensure reliable data submission.

2.6.9 Management Information System (MIS)

Quite often, there is a dearth of information in regard to material inventories, tools, spares, staffing patterns, costs, etc. Hence, setting up an MIS or a Decision Support System becomes imperative, facilitating staff to take action accordingly and assess life cycle asset management provisions. This information system should be capable of real time and online condition monitoring of all the equipment and should flag early warning signs of the degraded performance. The authority shall be well-informed while taking decisions. The MIS could also be used to assign responsibilities and distribute human, material, and financial resources to ensure sustainable O&M. A customised integrated database and intuitive access system must be created to provide the relevant information needed to the staff for effective O&M. Reference is made in Chapter 7: Management Information System of Part C of this manual for detailed understanding.

A schematic diagram of above systems is as per Figure 2.3.



(Source: BWSSB IT Department)

Figure 2.3: Schematic of Information Management System

2.6.10 Computerised Maintenance Management system (CMMS)

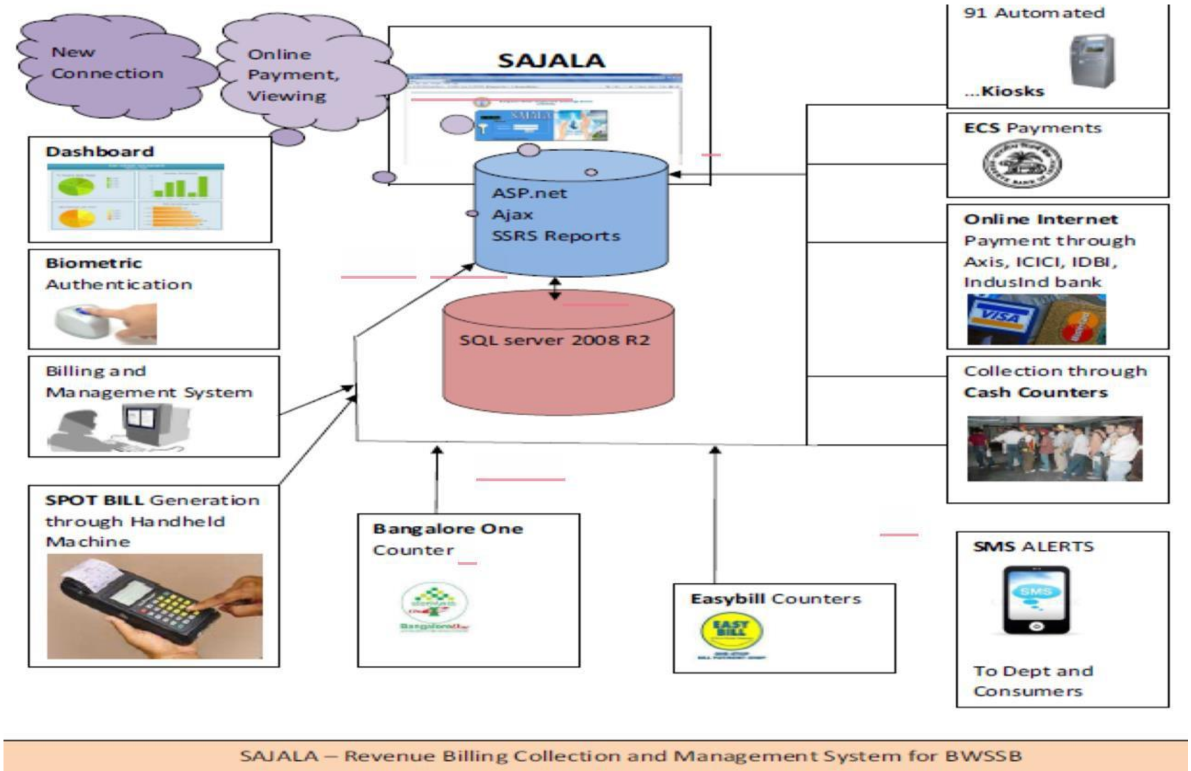
The Computerised Maintenance Management System (CMMS), also known as the Computerised Maintenance Management Information System (CMMIS), is a software programme that maintains a computer database of information on an organisation's maintenance and operations procedures.

This information helps in comprehensive maintenance of the system by determining which component (pipes, machinery, instruments, chemicals, manpower, etc.) requires maintenance and where the inventory of spare parts is. The CMMS system also keeps track of all the maintenance work involved by generating work orders, procurement orders, vendor orders, stores inventory, as well as the cost involved in all the activities, thus helping to accurately calculate the budget needed for O&M.

CMMS also allows to keep records and Geo tagging of the components in the system, which can be linked to GIS and network model, which in turn helps to analyse and keep track of various maintenance works.

A **Consumer Grievance and Redressal System** can be developed and implemented to address consumer grievances which arise due to various reasons such as erratic supply, poor quality of water, billing issues, and lack of response from service providers. To address these grievances, a well-defined consumer grievance redressal system is essential. The system should provide consumers with easy access to complaint registration and a transparent mechanism for redressal. It should also have a provision for a designated officer to handle grievances and an escalation process to higher authorities in case of unresolved complaints. Efficient and timely resolution of complaints is crucial to maintain consumer confidence and trust in the water supply system. Additionally, regular feedback from consumers and monitoring of the redressal system can help identify areas for improvement and ensure continuous quality service.

A **Computerised Revenue Management System** can be developed and implemented as per the schematic of the system developed by of BWSSB as per Figure 2.4.



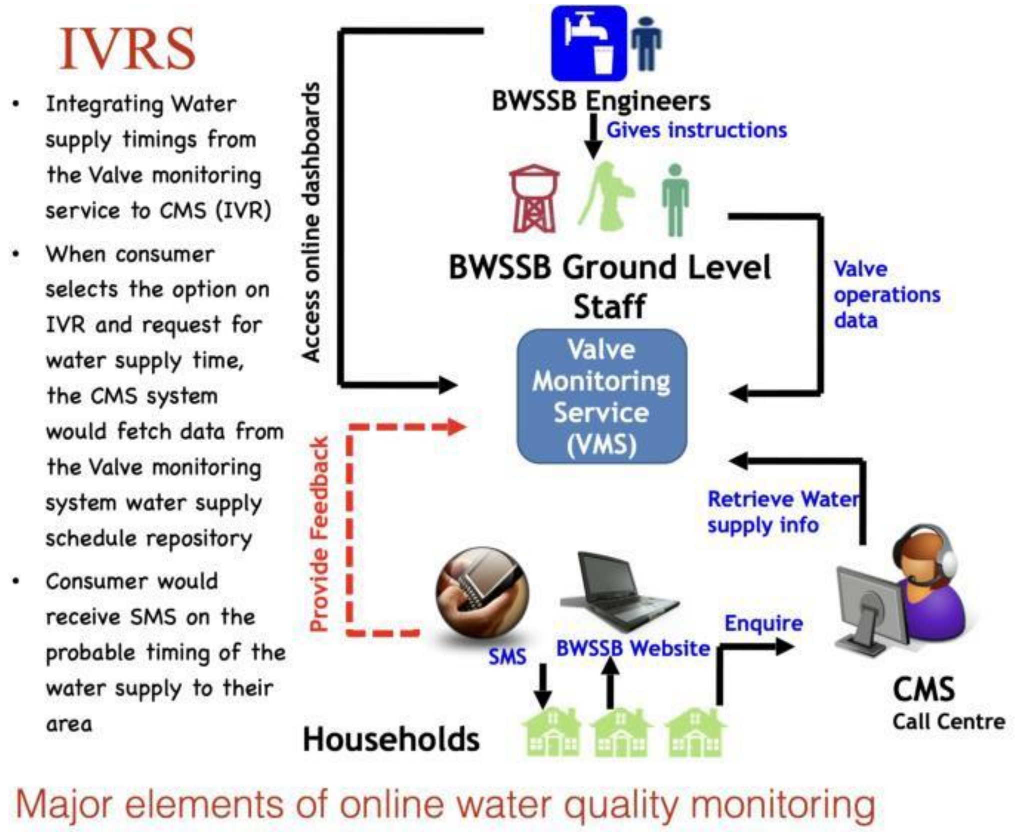
(Source: BWSSB)

Figure 2.4: Computerised Revenue Management System

A Management Information System receives information, processes, and stores it, and makes it available to users. Below are ample screen shots of user interfaces through which users can access, view, and manipulate Online Water Quality Information Technique.

The below screen developed within a SCADA system to display recent value of all parameters measured at a given monitoring location and also shows a sophisticated, GIS-based interface in which the status of all monitoring stations can be viewed at a glance. In both cases, users can navigate within the interface to get more details about parameter values, alerts, and station.

A Valve Monitoring System can also be developed as explained in Figure 2.5.



(Source: BWSSB)

Figure 2.5: Valve Monitoring System

2.6.11 Planning for Exigencies

As water supply is an essential service, contingency planning must be in place and rehearsed, considering all eventualities, whether natural or man-made. Some of the events or emergencies that may arise due to chlorine leakage, power failure, storms and flooding, fire, earthquakes, explosions, breakdown of water supply system units like pumps and pumping mains, strikes by workmen, sabotage or vandalism and, water supply bioterrorism. Past experience of emergencies in the system as well as in other systems is very useful in drawing up an emergency/contingency plan. Ring main circuits and alternate methods/routes of water supply are to be resorted to mitigate such exigencies. The National Disaster Management Authority report on “Plan to Counter the Threats to Municipal Water Supply and Water Reservoirs”, July 2010, should be referred to.

2.7 Capacity Building

Capacity building is the key activity to train the existing staff as well as deploying new staff needed. A detailed analysis of the existing staff with respect to technical knowledge, experience, and specific equipment-related knowledge shall be carried out. A training matrix prepared for the organisation will guide the implementation of a capacity building action plan.

2.7.1 Job Database

A job description shall be prepared for each operator, which shall contain detailed instructions as to how one will carry out the procedure of the O&M plan. The staff matrix has to be prepared for all facilities and installations for all activities. The training shall evolve a personnel management policy, which will provide job training followed by performance evaluations and promotions incentives. The expert supervisors shall train the operators, i.e., training the trainers on specific skills for equipment handling, do's and don'ts, and proper repairs during O&M plan/programme.

Special courses or on-the-job training are required to ensure efficient O&M before permitting staff to handle equipment independently.

2.7.2 Training Requirements

The training requirements be assessed and shall evolve a personnel management policy, which will provide job training followed by performance evaluations and promotions incentives. The expert supervisors shall train the operators, i.e., training the trainers on specific skills for equipment's handling, do's and don'ts, and proper repairs during O&M plan/programme.

Special courses or on-the-job training are required to ensure efficient O&M before permitting staff to handle equipment independently.

- Training on each equipment is the backbone for efficient and effective O&M services resulting in better and competent staff at every stage of the water supply system. Training shall be part of the curriculum.
- Prepare a time-bound specific training programme.
- Identify the facility to train and prepare training material.
- Implementation and assessment of the training staff as per the training programme.
- Update the training programme regularly to enhance the knowledge base of the staff in relation to the latest technological up-gradation on modern advancement in the field.

Other aspects of capacity building are elaborated in Section 3.2 of Chapter 3: Institutional Strengthening and Capacity Building of Part C of this manual.

2.8 Ensuring Efficient O&M

The following procedures will ensure an efficient O&M:

2.8.1 Specific Key Performance Indicators (KPIs)

a) **"Drink from Tap" with assured Water quality as per IS 10500 (2012):** It is very important to check the water quality to ensure that it is potable and is of desired quality at the tap of consumers. The water at the consumers' end shall conform to the Standards given by Bureau of Indian Standards (BIS).

b) **Water quantity (LPCD):** Per capita supply of potable water should be as prescribed in Table 2.7 of Chapter 2: Planning, investigations, design and investigation in Part A of this manual.

c) **Residual pressure:** The residual pressure at the consumer end should be as prescribed in Table 2.7 of Chapter 2 Planning, investigations, design and investigation in Part A of this manual.

d) **Non-revenue water (NRW):** The actual NRW value can be computed by assessing the quantity of water entering the DMA and the consumption in the DMA. The step tests can be conducted. The NRW should be brought down to at least 15% as per the Government of India (GoI).

e) **Consumer services and complaint redressal system:** An efficient and people-oriented consumer services and complaint redressal system has to be developed with timelines adhering to the citizen charter.
f) **Cost recovery:** A focused action plan to be implemented to increase the revenue to make the system financially self-sufficient to recover the operational cost.

2.8.2 Developing and Maintaining Standard Operating Procedures (SOPs)

Generally, operational guidance takes the form of supervisors' verbal instruction, which is often incomplete and poorly understood. An SOP is a well written set of step- by-step instructions (well documented) compiled by water utility to assist workers in carrying out routine operations of various components of the water supply system. SOP strive for consistency in operations, efficiency improvement, improved quality output, enhanced accountability, simplification of regulatory requirements, streamlined communication, efficient treatment, efficient repair and maintenance, clear documentation, and consistency of performance while maintaining communication and compliance with regulations.

2.8.3 Ensuring Water Quality

The operating agency has the primary responsibility of ensuring safe supply of the quality of water in sufficient quantity supplied to the consumers. To achieve this objective, it is necessary that the physical, chemical, bacteriological, and microbiological tests are carried out at frequent intervals. Samples should be taken at different and representative locations to enable one to make an overall assessment. In the event of an epidemic or a pollution or contamination event/threat, a more regular sampling may be required, particularly for bacterial contamination. For each distribution system, a monitoring programme must be prepared to show the location of sampling points. The database shall be made for future action plans and analysis. The details can be referred in Chapter 8: Drinking Water Quality Monitoring and Surveillance of Part B.

2.8.4 Plumbing Practices

In most Water Supply systems, the leakages occur at consumer end connections. This is mainly attributed to poor plumbing practices. Good plumbing practices will ensure efficient O&M. The water supply regulations shall provide for a correct practice of giving connections and fixing meters, which shall be strictly enforced. Certified plumbers shall be permitted to work in localities to an extent. Water efficient plumbing fixtures like Bharat Tap must be encouraged. The details can be referred to in Chapter 15: Water Efficient Plumbing Fixtures of Part A.

2.8.5 Proper Inventory

A proper inventory management system shall be in place to cater for all kinds of spares, be it fast-moving or otherwise, based on the lifecycle and periodic maintenance schedules laid down by the firm offering equipment, time delay deliveries from component manufacturers, and past experience of the staff involved with the maintenance service. The CMMS can be very well developed and used by the organisation to efficiently manage the spare inventory. Managers will have to review the list and take advance actions to ensure spare parts availability when they are needed.

Materials that should be stacked in store for maintenance of water supply system are given in an indicative list below:

1. pipes and pipe appurtenances;
2. adhesives and sealants;
3. gaskets and O-rings;
4. bolts, nuts, and washers;
5. clamps and hangers;
6. flanges and couplings;
7. lubricants and cleaners;
8. hand tools such as wrenches, pliers, and cutters;
9. power tools such as drills, saws, and grinders;
10. safety equipment such as gloves, goggles, and hard hats;
11. chemicals for water treatment such as chlorine, alum, and lime.

2.9 Water Supply System in Extreme Climate Conditions

It is also widely acknowledged that adverse meteorological events such as flash floods, droughts, heat waves, cold, and windstorms are becoming more common in the pan-India region, and that adaptation to water cycle variations is the primary focus of short to medium-term strategies in response to climate change and variability scenarios. They affect the capacity and operations of existing water infrastructures and services, and thereby threaten the protection such services offer to public health.

When the weather is abnormal or the climate is under pressure, water services systems risk losing much of their health benefits because of direct infrastructure damage (from floods, windstorms) or a lack of water (e.g., drought, when a cold environment turns water to ice).

These extreme conditions effect as follows:

- changes in water cycle;
- changes in water quality and quantity.

Strategy has to be developed keeping in view the following points which must be adapted in case-to-case basis:

- adopting several available structural measures;
- apply integrated risk management principles in development planning; the existence of well-defined institutional responsibilities; a democratic process of consultation and information; and an awareness campaign;
- proper communication, e.g., restrictions on water use need to be carefully communicated to consumers;
- put in place a plan to minimise impact of extreme events:
  - Strengthen communication with meteorological forecasting offices.
  - Implement pro-active measures to identify changes in quantity and quality of the resources water.
  - Identify alternative resources and ensure their timely use.
  - Plan in advance measures that should be taken if a critical site becomes unavailable due to an extreme event.
  - Develop emergency plans including the role of each organisational component,

individual or team that will respond.

- Develop operational programmes to regain drinking-water supply systems after extreme events.
- Develop in a pro-active manner site-specific plans that identify not only safe actions and escape routes for staff, but also minimise the impact of floodwater on operational equipment.

CHAPTER 3 : SOURCES OF WATER SUPPLY

3.1 Introduction

The water which precipitates onto the Earth's surface in the forms of rain, snow, hail, and sleet can be considered as the primary source of water. Four aspects should be considered in appraising water resources, e.g., quantity, quality, reliability, and sustainability of water. This chapter mainly discusses the protection of the water sources in terms of both quality and quantity.

3.1.1 Surface Water

Surface water accumulates mainly as a result of direct runoff from precipitation (rain or snow). Precipitation that does not enter the ground through infiltration or is not returned into the atmosphere by evaporation flows over the ground surface and this is classified as direct runoff. Direct runoff refers to water that drains from saturated or impermeable surfaces into the streams, channels, and then into natural or artificial storage sites (or into the ocean in coastal areas).

The amount of available surface water depends largely upon rainfall and the availability of surface water varies considerably between wet and dry years.

Surface water sources may be further divided into rivers, lakes, ponds, and reservoirs. Dams are constructed to create artificial storage. Canals or open channels can be constructed to convey surface water to the storage reservoir and/or water treatment plant. The water is also conveyed through pipes either by gravity or pumping mains.

In general, the quality of surface water sources is characterised by colour, pH, turbidity, hardness, dissolved oxygen, suspended solids, and microbial contamination. There are certain instances wherein the quality of water gets affected adversely at the source due to sewage discharge or industrial wastewater discharge. These fluctuations have to be monitored, and the operation and maintenance (O&M) of the entire water supply system to be readjusted/calibrated accordingly.

3.1.2 Groundwater

Part of the precipitation that falls, infiltrates into the ground. Water that percolates below the root zone finally reaches a level at which all the openings or voids in the earth's materials are filled with water. This zone is called the zone of saturation. The water in the zone of saturation is called the groundwater, and the upper level of the zone of saturation is called the water table. Groundwater that flows naturally from the ground is called a spring.

The extraction of groundwater is mainly by:

- Dug well with or without steining walls;
- Dug-cum-bore wells;
- Cavity bore;
- Radial collector wells;
- Infiltration galleries;
- Tube wells and borewells.

3.2 Effective O&M of Source

The following aspects need to be addressed for effective O&M of a source of water supply:

- Source water quantity must be maintained and monitored.
- Proper treatment should be given to adhere to Standard IS 10500:2012 of treated water quality.
- The repair and maintenance of infrastructure (e.g., intake well) built to draw water from the sources should be performed routinely and periodically.
- A methodical long-range programme of source inspection and monitoring should be adopted to identify issues that will guide regular preventive maintenance to ensure reliability and continuity.
- GIS-based survey maps must be obtained, prepared, and updated for all possible sources of water like rivers, reservoirs, lakes, canals, wells, springs, etc.
- A proper record must be maintained of the water quality and quantity at the source on a regular basis and made available to the water treatment operations staff so they can make correct treatment adjustments. Additionally, efforts should be established to collect archive and make historical data easily retrievable.
- The sustainability of water sources should be monitored each year, and effective measures should be adopted to maintain the same.

3.3 Sanitary Survey of Water Sources

The sanitary survey/inspection is an on-site survey to identify actual and potential causes/sources of surface as well as groundwater contamination. Sanitary surveys have to be conducted 10 km upstream and downstream of the intake point.

The details of the sanitary survey and the methodology to carry it out have been explained in Section 7.9 of Chapter 7: “Water Quality Testing and Laboratory Facilities”, Part A in this manual. The same can be referred to, and a sanitary survey can be carried out on a periodic basis so as to identify any quality issues at the source which may require the O&M of the entire water supply system to be readjusted/calibrated accordingly. **Annexure 3.1** illustrates sanitary inspection forms for the source of dug well, piped water supply with surface reservoir, and borehole with hand pump and deep hole with mechanised pumping, etc.

3.4 Surface Water

3.4.1 Use of Surface Reservoirs

Methods of managing lakes, ponds, and reservoirs used for domestic water supplies vary widely depending on local conditions. In addition to serving domestic water needs, a reservoir may be used for flood control, hydropower generation, regulating releases, and recreational purposes or agricultural, municipal and industrial usage.

A dam is a hydraulic structure built across a river to create a reservoir on its upstream for impounding water. Dams confine and utilise the flow of water for various human purposes.

The O&M of the dam is generally the responsibility of the state irrigation department so as to ensure that dam is performing safely and according to the design and purpose for which it is constructed. Therefore, regular operation, maintenance, and inspection of dams are important for detecting and preventing dams' failures. The preventive maintenance is to be performed routinely to include the servicing of the dam and its appurtenances with the intention of avoiding over-vegetation, animal impact, equipment deterioration, mechanical malfunctioning, and flooding or catastrophic dam failure. Extraordinary maintenance plans should be developed and adopted to include repairs required to correct these damages, if they do occur.

3.4.2 Factors Affecting Water Quality

Factors affecting water quality within the reservoirs and lakes are:

(a) used water, agricultural runoff, grazing of livestock, runoff from urban areas, and domestic and industrial discharges may all lead to deterioration in physical, chemical, or biological/bacteriological water quality. These may lead to the development of algae and further lead to eutrophication
(b) thermal stratification and turnover affect the quality of water stored
(c) extremes in climate variability cause the water temperature to rise, which may harm aquatic flora and fauna
(d) oil leaks and spills and petroleum exploration
(e) radioactive wastes/hazardous waste
(f) landfill leachate and waste disposal in the vicinity
(g) emerging contaminants
(h) natural factors

    - climate: sunlight, temperature, wind speed and direction, intensity and duration of precipitation;
    - watershed and drainage areas: geology, topography, type, and extent of vegetation and use by native animals;
    - wild fires;
    - reservoir areas: geology, landform including depth, area, bottom topography, and plant growth at the time the reservoir is filled.

Eutrophication, thermal stratification, and anaerobic conditions are discussed in the following sections.

3.4.2.1 Eutrophication

Moderate or large quantities of nutrients, such as phosphates, nitrates, and organic nitrogen compounds, reaching from various used water sources, act as nutrients in a reservoir to stimulate the growth of aquatic plants/algae, which causes algal bloom. The problems related to algal bloom are:

- taste, odour, and colour;
- increased pH;
- shortened filter runs of treatment plants;
- dissolved oxygen variation;
- organic loading;
- cyanotoxins.

Algae growth in the reservoirs/ponds/lakes (any impoundment) increases the productivity and decreases the usability of reservoirs as a water source. Flowing water-like streams do not result in algal proliferation due to continual movement, but static water bodies result in algal mats. The Urban Local Bodies (ULBs) should establish routine communication protocols with upstream ULBs/irrigation departments/pollution control departments to provide a channel to routinely emphasise the importance of ensuring that any inflow in the impoundment is free of or contains little or no phosphate, irrespective of the type of water use. Algicidal measures as described in Section 10.2.2.2 Chapter 10: Specific Water Treatment Processes of Part A of this manual may be adopted to control algae in reservoirs.

3.4.2.2 Thermal Stratification

Thermal stratification develops in lakes and reservoirs when the surface water begins to warm. The warm surface water expands and becomes lighter than the water beneath it. The water temperature difference causes variations in water densities, which create resistance to mixing. This ultimately results in anoxic (absence of oxygen) conditions in deeper zones that often result in dissolving harmful contaminants in sediment and moving them into the water column where they can exacerbate treatment issues and potentially enter the food chain, causing adverse health effects.

3.4.2.3 Anaerobic Conditions

Anaerobic conditions make water unpalatable due to colour and odour, and such conditions lead to an increase in the concentration of dissolved gases that are undesirable in drinking water. Another major problem occurs when iron, manganese, or other heavy metal contaminants exist in bottom sediments in the reduced or chemically changed form. Hence changed from insoluble to soluble state and passed into solution. The presence of either iron or manganese in appreciable quantities within the domestic supply makes the water look reddish, brown, or dirty and may stain clothes during washing and stain porcelain fixtures. Anaerobic condition can be alleviated through the process of aeration.

3.4.3 Intakes for Surface Water

An intake is a device or structure installed in a surface water source to withdraw water from the source and discharged into an intake conduit, where it will flow into the water supply system. The description and functions of intakes are already given in Section 4.9.1 of Chapter 4: Planning and Development of Water Sources, Part A which the details can be referred to.

O&M of intake structures is important to maintain the quality and quantity of the water supply systems, which are described in this section.

3.4.3.1 Problems in Operation

Some of the problems that may arise during the operation of intakes are given below.

a) fluctuations in water level;
b) difficulty of water withdrawal at various depths;
c) hydraulic surges, ice, floods, floating debris, boats, and barges;
d) operational difficulties for racks and screens designed to prevent the entry of objects that might damage pumps and treatment facilities;
e) minimising damage to aquatic life;
f) allocation of space for

i) equipment cleaning/preventive maintenance;
ii) handling before and after repair of machinery;
iii) storing, movement, and feeding of chemicals.

3.4.3.2 Operation and Maintenance

Some of the general points of consideration for O&M are as follows:

a) Operating criteria, equipment manufacturer's operating instructions, and standard operating procedures should be bound into a manual and used for reference by operators. If written references are not available for a particular facility, they should be prepared with the assistance of knowledgeable operators, engineers, and manufacturers.
b) Screens should be regularly inspected, maintained, and cleaned and a record of the activity entered into a properly designed maintenance management system for archival and quick retrieval.
c) Mechanical or hydraulic jet cleaning devices should be used to clean the screens.
d) Intake structures and related facilities should be periodically inspected, operated, and tested at regular intervals.
e) Proper servicing and lubrication of machinery/equipments at intake facilities are important.
f) Operation of gates and valves.

Some of the causes of faulty operation are as follows:

- settlement or shifting of supporting structures, which could cause binding of gates, valves, and below joints;
- worn, corroded, loose, or broken parts;
- lack of use;
- lack of lubrication;
- vibration;
- improper operating procedures;
- design errors or deficiencies;
- power source or circuit failure; and
- vandalism.

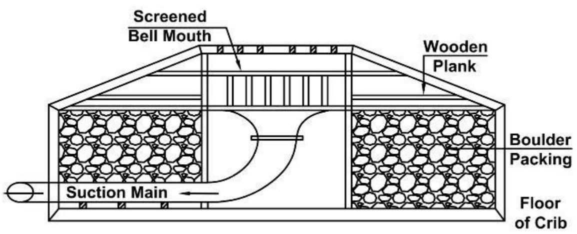
3.4.3.3 Intake for Abstraction of Surface Water

Intakes for withdrawal of surface water may be of various types as summarised below in Table 3.1:

a) Intake Well on water body;
b) Fixed Jetty intake on water body;
c) Floating Pontoon on water;
d) Submerged intake crib;
e) Protected Side Intake;
f) River Bottom Intake;
g) Sump Intake.

Table 3.1: O&M Activities and Maintenance Requirements at Intake for Surface Water

Type of Intake	O&M Activities
a) Intake Well  **Figure 3.1: Intake Well**	O&M includes (i) removal of deposits from the bottom of the well; (ii) checking of screens for removal of floating objects; (iii) checking the functioning of watertight inlet valves; (iv) status of the bottom plug of the well; (v) lubrication of headstocks and extended spindles fitted to valves; (vi) civil structure in general; (vii) mechanical and electrical components viz., pump, motor, M.C.C., HOT/EOT hoists, electrical wiring; and (viii) delivery header pipes, joints, valves, flowmeters, etc., for water tightness and sound performance. Intake well is shown in Figure 3.1.
b) Fixed Jetty  **Figure 3.2: Fixed Jetty**	O&M requirement of this kind of intake is almost similar to that of intake well. However, periodical painting of M.S. liner of RCC cast in situ bored piles and cleaning of the inlet screen fitted over suction bell mouth needs special attention (Figure 3.2).
c) Floating Pontoon  **Figure 3.3: Floating Pontoon**	A boat-shaped mild steel structure can also be used as an intake for water withdrawal. The deck of the boat is used as the floor of the pump house to accommodate all M&E accessories and piping required for withdrawal of water and delivery up to the WTP site. The pontoon is adequately anchored over the bed of the water body using chains and RCC blocks, so that movement of the pontoon is restricted over a horizontal plane (Figure 3.3). Since the basic structure is made of mild steel, periodical painting of the outer surface of the pontoon using

	anticorrosive paints needs to be done. For this, dry docking of the pontoon may be necessary, depending on the aggressiveness of the river water on which the pontoon floats. The chains used for anchoring need frequent inspection along with the connection with anchor blocks embedded below the bed of the water body.
d) Submerged intake crib  **Figure 3.4: Submergence intake crib**	This is a simple arrangement for the withdrawal of surface water from surface sources where fluctuation of water level is small, and requirement of water is less compared to various other types described here which are suitable for withdrawal of large/quantity of water. The water withdrawal pipe is placed below the LWL of the raw water source over a rigid floor slab of the crib. A bell mouth of adequate size with a screen is fitted over the inlet of the suction pipe at the entry point. The screen, with bell mouth, is protected by an adequately designed wooden crib or wire crates of boulder having its support over a rigid floor of the crib. Adequate protection in the shape of grating and a fine screen is provided over the bell mouth. This type of intake requires very little maintenance except for general cleanliness of the surroundings and painting / replacement of wooden crib (Figure 3.4).
e) Protected Side Intake	**Activities** • Operation of a protected- side intake system to be carried out by a caretaker (Figure 3.5). • Daily adjusting a valve or a sluice gate and checking the inlet to channel or pump for obstructing debris. • Preventive maintenance to include the screen painting and other metal parts.

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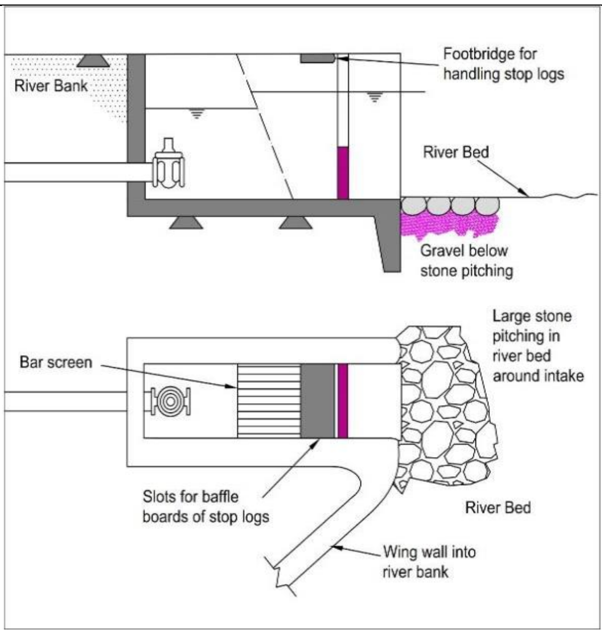
<tr><td rowspan="2">

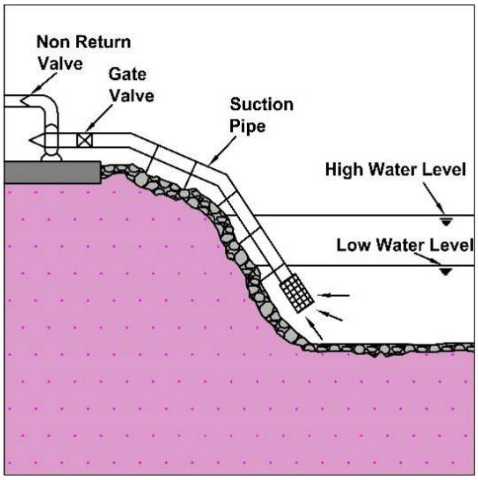
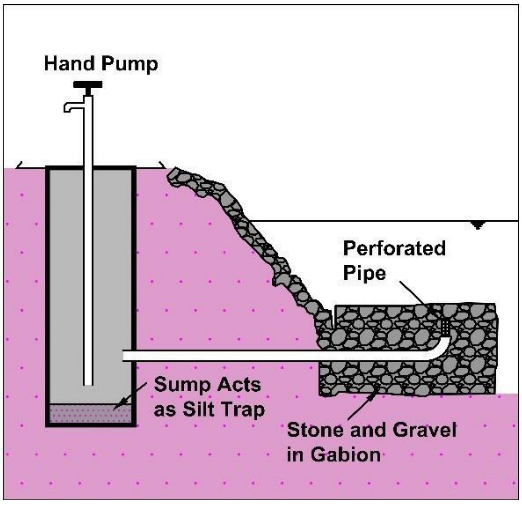
Figure 3.5: Protected Side Intake</td><td>
During the rainy season, the inlet needs checking.
Cracks in the concrete structure are to be repaired annually.
Cleaning after flooding.</td></tr>
<tr><td>Requirements
Daily inspection of the inlet and adjusting of valve or sluice gate.
Occasional cleaning of the inlet canal and screens.
Annually painting the metal parts and repairing the cracks in concrete.</td></tr>
<tr><td rowspan="2">f) River Bottom intake


Figure 3.6: River Bottom Intake</td><td>Activities
River bottom intake inlet to be checked regularly (Figure 3.6).
Painting the screens, sluice gates, or valves.
Sand traps and screens to be cleaned regularly.
Every year, concrete structures should be checked for cracks and repaired as needed.</td></tr>
<tr><td>Requirements
Daily inspect the inlet and adjust the valve or sluice gate.
Occasionally, clean/repair the screen.
Annually, paint metal parts / repair cracks in concrete.</td></tr>
<tr><td rowspan="2">g) Sump Intake</td><td>Activities
In sump intake, daily check-up of the sumps for sufficient water inflow / removing debris obstructing the flow (Figure 3.7).
Cleaning and desilting of intake.</td></tr>
<tr><td>Requirements
Daily inspection of the inlet.</td></tr>
</table>

 **Figure 3.7: Sump Intake**	• Occasional cleaning / repairing of the inlet for any damage due to erosion. • Annually desilting the pump.

3.4.4 Intake for Spring Water

A spring is a place where ground water emerges naturally on land surface. Springs descend down the hill with a velocity and corresponding yield dependent on the influence of seasonal variation. Spring sources are important sources of water since they generally provide year-round water for the water supply system. However, the year around availability is dependent on annual spring catchment recharge for which spring-shed management is required to be undertaken.

Springs are susceptible to contamination by surface water especially during rainstorm. During a monsoon, when the velocity is high, it carries a huge silt load along with tree branches and weeds in its downward movement. Therefore, the separation of these unwanted objects from the water is an absolute necessity before it is made fit for consumption. Also, rolling boulders along the course of spring sometimes create severe damage to water supply infrastructure, which also needs to be taken care of to ensure a sustainable supply of water. Therefore, a U-shaped surface drainage diversion ditch or an earth-berm should be constructed at least 15 m uphill from spring to divert any surface run-off away from the spring. The area must be fenced at least 30 m in all direction around the spring-box to prevent contaminants.

Generally, submerged intakes are preferred for spring water intakes. These are constructed as cribs or bell mouths. The cribs are made of heavy timber framework which is partly or wholly filled with riprap to protect the intake-conduit against damages. The top of the crib is normally covered with cost-iron or mesh grating.

3.4.5 Intake for Sea Water

An open seawater intake collects water directly from the ocean via an offshore or onshore inlet structure, with a pipeline connecting the desalination plant to the structure. Typically, this system comprises the following components:

- forebay (inlet structure);
- coarse bar screen;
- source water conveyance channel;
- concrete screen chamber; and

- mechanical fine screens.

The inlet structure is situated at a suitable sea depth and in an accessible location. The open intake appears to be the more popular option because it ensures quality water and has unlimited hydraulic capacity. Development of the maintenance setup, including training and recruitment of pump and electrical maintenance staff, etc., is an important element in ensuring smooth operation.

3.4.6 Riverbank Filtration and Lake bank Filtration

These are induced ground water recharge systems and the details can be referred from Part A, Chapter 4: Planning and Development of Water Sources.

3.4.7 Ponds and Lakes

Ponds and lakes are water retention facilities. Lake restoration is important because it can store water (for flood control) and provide water for many purposes such as water supply, irrigation, fisheries, tourism, etc. It also serves as a sink for carbon storage and provides habitats for plants and animal species. Restoring lakes and ponds consists in enhancing their structure and functioning where they have been drained in times.

The water bodies (ponds and lakes) are treated as a community resource. Such water bodies, particularly in urban areas, have a vital role as a source of drinking water and means of groundwater recharge. Management of such water bodies is of great importance. Oligotrophic lakes are young lakes that have little or no aquatic vegetation and are quite clear hence are a good source of water.

Strategies for long-term management and restoration of water bodies are to be implemented in a phased manner as per the guidelines “Indicative Guidelines for Restoration of Waterbodies”, June 2019, published by CPCB. The “Advisory on Conservation and Restoration of Waterbodies in Urban Areas, August 2013, published by CPHEEO, may also be referred to. Potential phases include the restoration phase, protection phase, improvement phase, and sustenance phase.

Lake and pond restoration techniques are given in Table 3.2.

Table 3.2: Lake and Pond Restoration Methods

S. No.	Restoration Methods	Anticipated Achievements
1.	Aeration of lake water and phosphorous inactivation and biomanipulation with remove of cyprinids	Reduction in nutrients, cyanobacterial blooms, and phytoplankton.
2.	Stoppage of wastewater flow to the lake/soil dredging / harvesting of algae	Reduction in pollutant concentration (NO3/PO4/BOD and TSS).
3.	Supplying nitrate-rich water from small tributaries to hypolimnion of the lake	Enabling hydrogen sulphide to disappear and then measuring redox potential in hypolimnion.

S. No.	Restoration Methods	Anticipated Achievements
4.	Sediment dredging (quantity and quality of dredged material)	Reduction is phosphorous organic matter, TSS and reduction and replacement in plankton dominance in lake by less eutrophic species.
5.	Using specific Legal Framework Act to protect Lake Wetland	Using Tank Conservation and Development Act 2014 with the role function of protecting, conserving, and restoring lake/s to facilitate recharge of depleting groundwater.
6.	Improving habitat quality	By reducing point and non-point sewage impacts.

Restoration of Dal Lake:

The State Government of J&K has initiated a partnership campaign between citizens and authorities for the rejuvenation of Dal Lake. De-weeding and dredging have been planned to be conducted in collaboration with citizens. De-weeding of the lake commenced and will be followed by dredging to restore a sizeable area of 60,000 m^2 of the lake. Source: J&K (LCMA)

3.4.8 Pond and Lake Maintenance Equipment:

Following is a list of a wide range of tools typically used to maintain ponds and lakes.

A. Dredgers: These machines are used to remove accumulated sediment from the bottom, sides, or banks of a lake or pond. Dredgers remove sediment and transport it to another area for different uses, which is a typical option. Plain, cutter, and auger-suction or jet-lift dredgers are some of the several types of portable dredgers.
Dredgers are the best options for cleaning up build-up silt and making water body healthier.

B. Aerators: Oxygen levels in ponds and lakes are raised and stabilised using aeration systems. An aerator's main function is to eliminate stratification caused by thermocline. Aerators work to add oxygen to the lake or pond, which is advantageous for aquatic life like fish and other animals. Aerating also enhances the look of the area, the health of the environment, lowers mulch, and gets rid of bad smells from stagnant water.

C. Weed Harvesters: These can limit the growth of weeds and other aquatic plants in ponds and lakes. Around 2–3 m below the surface of the water, a harvester removes aquatic weeds. Additionally, it also cleans algal and debris from the surface water source.

D. Aquatic Skimmers: Aquatic skimmers remove trash and debris from the surface of lakes or ponds. Surface machines are capable of collecting surface floatables like fluids, algae, bottles, garbage, cans, and wood.

E. **Lake Rakes:** These are ideal for harvesting weeds. Depending on the size of the pond or lake, a long-reach rake may be required. It uses thrusting action to retrieve debris.

F. **De-Icers:** These push rainwater to the surface of a lake or pond to prevent ice build-up. The de-icing equipment removes excessive plant growth and stagnant water.

Managing a pond or lake is easy when right equipment and knowledge to operate exists and is applied at the correct time. The use of the correct water management device can clean the area and create a healthier ecosystem. The dredgers and aerators used described above depend on the power of submersible pumps and need a power source.

Robotic inspection, cleaning, and repair of underwater assets:

The classical method to maintain underwater assets is sending divers for execution of inspection, cleaning, and repair works. Now robotic technologies are available for inspection and cleaning of such water assets, minimising while providing quality service. Robot assisted underwater welding and other repair works provide cost-effective work with high quality.

Inspection of inaccessible and underwater assets can be done using remotely- operated robotic inspection systems. Periodic inspection of underwater assets for silt-level estimation should be carried out followed by desilting for corrective measures.

Robotic Inspection

Robotic Dam Desilting

To ensure the integrity and longevity of critical hydropower assets, it is advised to carry out periodic conditional assessment inspections using robotic technologies to overcome inaccessibility and ensuring safety of humans. Silt measurement service should also be carried out periodically followed by desilting using robotic technologies.

3.5 Groundwater

Groundwater is a part of the precipitation which infiltrates into the soil. The water that drains down (percolates) fills all the gaps or voids in the soil; thus, a water zone is created. This zone is known as the saturation zone, and the water is known as groundwater. The rainwater that infiltrates into the unsaturated zone is referred to as subsurface water. This subsurface water is used to feed infiltration wells and galleries. Groundwater sources are being used extensively by the ULBs as sources for their water supply system and hence are required to be properly managed and maintained.

Important requirements of managing groundwater are:

- regulation of groundwater;
- prevention of pollution of groundwater;

- conservation of groundwater;
- effective preventive maintenance; and
- artificial recharge of groundwater.

The groundwater, when used as a source, has a system of components that are working in alignment with each other. These may include wells, pumps, groundwater collection systems, and storage tanks. Present-day groundwater system also includes the water that is stored by rainwater collection systems. O&M of these components are discussed in the following sections.

3.5.1 Preventive Maintenance

According to available data, the specific capacity of wells should be measured at regular intervals, either monthly or bi-monthly, and it should be compared with the original specific capacity. As soon as a 10% to 15% decrease in specific capacity is observed, steps should be taken to determine the cause, and accordingly, corrective measures should be taken. Rehabilitation procedures should be initiated before the specific capacity is declined by 25%. A checklist given below can be used to evaluate the performance of a well:

i) Static water level in the production well.
ii) Pumping rate after a specified period of continuous pumping.
iii) Specific capacity after a specified period of continuous pumping.
iv) Sand content in a water sample after a specified period of continuous pumping.
v) Efficiency of the well.
vi) Normal pumping rate and hours of operation per day.
vii) General trend in water level in wells in the area.
viii) Drawdown created in the production well because of pumping from nearby wells.

A significant change in any of the conditions listed above indicates that a well or pumping rate needs attention.

The preventive maintenance programme begins with well construction records showing geological conditions, water quality, and pumping performance. The data of optimum and efficient limit of operation should be available, which is created at the time of testing and commissioning of the well. This data is normally in the form of a discharge draw-down curve (called a yield draw-down curve). According to this curve, there is a straight line up to a certain stage of drawdown, beyond which the drawdown increases disproportionately to yield. The endpoint of the straight line is the point of optimum efficiency for the operation of the well, as shown in Figure 3.8. This is generally found to be 70% of yield at drawdown, which can be created.

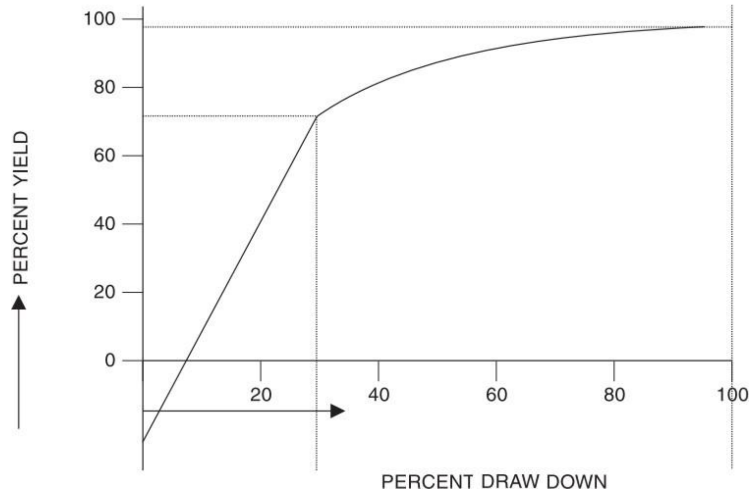


Figure 3.8: Yield draw-down curve

3.5.2 Determining Static Water Level (SWL)

SWL refers to the level of water under normal, undisturbed, non-pumping conditions. SWL is measured in several ways, including an electric sounder or electric depth gauge, wetted tape, or an airline.

(a) **Electric sounder:** It's made up of a weight suspended on standard insulated wire with depth indications and an ammeter to show if the circuit is closed. When the wire's end hits the water's surface, current flows through the circuit. A modest 9-volt or 12-volt battery provides current.

(b) **Wetted tape:** This technology can accurately measure water levels up to a depth of 30 m. A levelling weight is fastened to the end of a 30 m steel tape. Before each measurement, the 3 m of tape end is dried and chalked. The tape is levelled into the well until a chunk of the chalked section is submerged. After that, the tape is lifted up to read the mark where the line is moist. The true depth is determined by subtracting the wetted mark held and marked at the top of the casing from the water level.

(c) **Airline:** Airline gauge method is most commonly used for measurement of SWL, pumping water level, and drawdown. The air pipe can be lowered into a tubewell through a slot or hole provided in the flange in case of flanged assembly and in the annular space in case of socketed assembly. In this method, the air is pumped into the line until the maximum possible pressure is reached. Normally, the airline is full of water up to the level of water in the well (static or pumping water level). When air is forced into the line, it creates pressure which forces water out of the lower end until it is completely expelled and the line is full of air. If more air is pumped in, air, instead of water, is expelled, and it is not possible to increase the pressure further. The head of water, C or E (as shown in Figure 3.9), above the end of the line, maintains this pressure, and the gauge shows the pressure or head above the end of the line. If the gauge is graduated in metres of water, it directly registers the amount of submergence of the end of the line. This reading subtracted from the length A of the line gives the water level B or D (static or pumping water level).

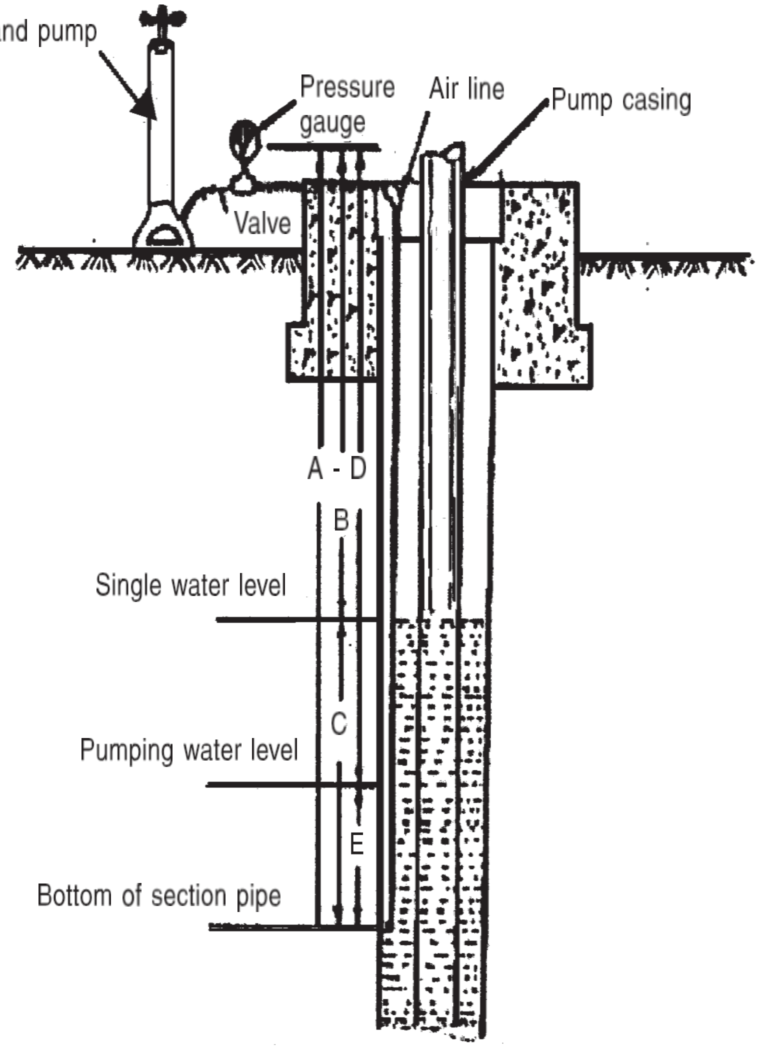


Figure 3.9: Airline installed in a tubewell for measuring water level

(d) Tubewell sounding: For identification of lithological details, electrical logging can be used for uncased bores, while Gamma logging can be used for both cased and uncased bores. A borehole camera can identify the condition of the borehole, casing, and strainer pipes. These devices are commonly available in the market.

3.5.3 Intake for Abstraction of Groundwater

The O&M of intake for abstraction of groundwater and other components is given in Table 3.3.

Table 3.3: Operation and Maintenance of Intake for the Abstraction of Groundwater

Intake	Monthly/Quarterly	Yearly
Dug well (wells in rocky formations and alluvial soils)	• Removing debris from well • Lubricating pulley as required • Cleaning the concrete apron • Replacing bucket	• Dewatering well and cleaning the bottom. • Repairing of the well wall. • Desilting/deepening the well in the monsoon period.
Hand pump (HP)	• Checking of HP and spout pipe	• Checking water discharge.

Intake	Monthly/Quarterly	Yearly
	• Checking of nuts and bolts. • Test-water quality • Cleaning inside of the pump • Checking of anchor-bolt • Cleaning rusty patches	• Repairing handle as needed. • Repairing/replacing valves. • Removing pump and cleaning of pipe.
Tube/Borewell	• Operate pump starter and isolation valve. • Checking whether adequate water is being produced. • Checking of voltmeter and meter readings.	• Carry out inspection by removing pump and rising main from the well. • Inspecting electrical cables and checking insulation between cables. • Cleaning pump house. • Checking leaks in rising main. • Replacing corroded pipes. • Testing water quality using a field test kit. • Checking pipe threads. • Record servicing and maintenance in the logbook. • Deepening the bore to approximate level.
Infiltration gallery	• Inlets should be inspected regularly for debris that may clog the system.	• Infiltration wells are to be protected from sand mining done around them. • During floods such wells get tilted for which packing of sandbags should be put around the wells.
Radial collector wells (Ranney Wells)	• Check the yield by well yield test • Servicing of pump sets • Flushing pipeline system for removing silt, if any	• Cleaning well by pumping / air compressor / manually • Cleaning of the gravel pack • Taking measures for corrosion prevention

3.5.4 Groundwater Collection System

It should be inspected annually for debris accumulation and erosion and repaired as needed.

3.5.5 Storage Components

Regular inspection of the storage system is important:

- Tanks should be inspected periodically during operation to monitor the growth of microorganisms and sludge since these can degrade water quality.

- Sediment accumulation in tanks should be monitored monthly during the first year of operation to determine the rate of accumulation.
- Tanks may need to be flushed periodically and disinfected to correct the problem.

3.5.6 Inadequate Development of Wells

Sometimes owing to several reasons, at the time of construction, proper development of the tubewell is not done, which results in a constant inflow of sand particles causing choking of the filtering media and strainers, such tubewells need redevelopment. The redevelopment of the tubewell will have the following effects:

i) Redevelopment of the well involves the removal of finer material from around the well screen, thereby enlarging the passages in the packing formation to facilitate smooth entry of water.
ii) Redevelopment removes some degree of clogging of the water-bearing formation.
iii) It increases the porosity and permeability of the water-bearing formation in the vicinity of the well.
iv) It stabilises the formations around the well screen so that the well will yield sand-free water.
v) Redevelopment increases the effective radius of the well and, consequently, its yield.

3.5.6.1 Methods of Redevelopment

Following are the methods of tubewell redevelopment: redevelopment:

i) Overpumping with pump.
ii) Surging with surge block and bailing.
iii) Surging and pumping with air compressor.
iv) Back-washing.
v) High-velocity jetting.
vi) Dynamiting and acid treatment.

For rehabilitation purposes, any suitable method of redevelopment can be used as mentioned above. The largely used method is surging and pumping with compressed air. Pumping is done with an ordinary airlift pump. The submergence ratio (along with two air pipes in water divided by its total length) is important to achieve successful redevelopment of the well. The ideal submergence ratio should be about 60% for obtaining the best results. The efficiency of development reduces rapidly if the desired submergence ratio is not maintained.

The equipment required for surging and pumping operation consists of an air compressor and a tank of the required size, a drop pipe and an air pipe with a suitable arrangement for raising and lowering each independently, a flexible high-pressure air hose for the supply of compressed air to the air pipe, pressure gauge, relief valve, a quick opening wall in the outlet of the tank, tee joint, and pipe jointing material.

Normally, air compressors of 500 m^3/hr at 7 kg/cm^2 to 800 m^3/hr at 17 kg/cm^2 are used for the development/redevelopment work of the tubewell. Whenever under capacity air compressor is used for the development of the well, proper development is not possible, and such wells become sick after a short period of use. These tubewells can only be rehabilitated by redevelopment of the well.

3.5.6.2 Selection of Air Compressor

The two most important factors in the selection of an air compressor for well development/redevelopment are the requirement of pressure and capacity. The required air pressure is determined based on the length of the air pipe below the SWL. Before air can be discharged from the lower end of the air pipe, the compressed air must push all the water out of the pipe. To do this, the air pressure must be greater than the water pressure before starting to pump water. The required pressure of the compressor will be slightly more than the submergence of the airline in the water.

A useful thumb rule to estimate the compressor capacity is to provide about 0.28 m^3/L of free air for each L/min. of water at the anticipated pumping rate.

3.5.6.3 Redevelopment Procedure

For the redevelopment of the tubewell, the following steps are to be followed:

- Lower the drop pipe and air pipe in the well up to the desired submergence. The bottom of the drop pipe should be kept about 60 cm above the bottom of the screen, and the air pipe is kept about 30 cm higher than the bottom end of the drop pipe.
- Turn on the air from the compressor and the well pumped by the conventional air lift principle until the discharge water is free from sand.
- Air entry into the well is then cut off by closing the valve between the tank and the compressor, and in the meantime, the airline is lowered so that it is about 30 cm below the bottom of the drop pipe. The air pipe is thus at the same position as in the back-washing method.
- The air valve is quickly opened to allow the compressed air from the tank into the well, and this tends to surge water outwards through the well-screen openings.
- The air pipe is raised again and the cycle is repeated until the water discharged from the well is relatively free of sand. The above operation of back-washing and pumping completes one operation of surging.
- The entire assembly is then raised to a height of about 1 m and the operations are repeated until the well section along the entire length of the screen has been developed.
- Finally, the air pipe is lowered again to the bottom of the well, and the equipment is operated as a pump to flush out any sand that might have accumulated inside the screen.

Normally, with this method of redevelopment, all the wells drilled in alluvial formation with inadequate development can be successfully redeveloped. The use of disbursing agents like polyphosphates have also been found useful in rehabilitating the wells with redevelopment method, drilled in alluvial formation with inadequate development.

3.5.7 Causes of Failure of Wells

Wells failure may be due to inadequate design, faulty construction and operation, lack of timely maintenance and repair, and failures due to mechanical and chemical agents and adverse aquifer conditions. The following are the categories of main causes for failure of wells:

a) Incorrect design, for instance, use of improper material and size of a well and housing pipe, screen and gravel pack, wrong pinpointing of well site resulting in interference from nearby wells.

b) Poor construction, e.g., use of improper screen material, non-watertight joints, the bore may not be vertical, the joints may be leaky, wrong placement of well screen, non-uniform slots of the screen, improper construction of cement slurry seal to prevent inflow from the polluted aquifer. Corrosion of well pipes and screens due to chemical action of water resulting in rupture.

c) Faulty operation, e.g., overpumping, poor maintenance.
d) Adverse aquifer conditions result in lowering of water table and deterioration of water quality.
e) Mechanical failure, e.g., falling of foreign objects, including pumping assembly and its components.
f) Incrustations due to chemical action by the water of the aquifer.
g) Inadequate development of wells.
h) Inadequate submergence of air pipe causing increased vibration, low flow rates, and diminished discharge head (pressure) for the pump.

The table in **Annexure 3.2** indicates causes of failure of wells and **Annexure 3.3** explains well problems and their suggested solutions.

3.5.8 Rehabilitation of Tubewells and Bore Wells

Decision on whether to rehabilitate an old well or construct a new one should be based on a cost-benefit analysis. Following remedial measures can be taken to correct the situation.

3.5.8.1 Corrective Operation

The tubewell should run in such a way that the pumping water level should always remain above the level of the well screen. Overpumping will expose the well screen, which may result in an imbalance of chemical constituents of aquifer water, including dissolved gases, incrustation, and corrosion. Overpumping results in excessive drawdown, which may cause differential hydrostatic pressures and excess water velocity through the screen, causing the flow of aquifer material in the well, leading to rupture of well screen. Negligence in timely repair and maintenance may result in poor performance of the tubewell. Therefore, before any permanent damage is done to the tubewell, it should be ensured that the tubewell is operated at its designed capacity and timely corrective actions are taken.

3.5.8.2 Controlled Aquifer Operations

In adverse aquifer conditions where the water table has depleted, but the quality has not deteriorated, pumping with the considerably reduced discharge shall be restored to.

3.5.8.3 Mechanical Maintenance

The falling of the pumping set assembly and its components into the borehole can be minimised by the following:

- Providing steel wire holdings throughout and around the assembly length, including the pumping set.
- Providing and clamping a steel strip around the pumping assembly.

The following are the steps to be taken for fishing out the fallen objects in the boreholes:

a) Impression Block

An impression block is used to obtain an impression of the top of the object before attempting any fishing operation. Impression blocks are of many forms and designs. Figure 3.10 illustrates an impression block made from a block of soft wood turned on a lathe. The diameter of the block is 2.0 cm less than that of a drilled hole. The upper portion is shaped in the form of a pin and driven to fit tightly into the box collar of a drill pipe. To ensure further safety, the wooden block is tied with wire or pinned securely to the collar. Alternatively, the block could be fixed to a bailer. A number of nails are driven into the lower end of the block.

With about 1.0 cm of it projecting out, a sheet metal cylinder of about 5.0 to 7.0 cm is temporarily nailed around the block to hold molten wax, which is poured into it. Warm paraffin wax, soap, or other plastic material is poured into the cylinder is left to cool and solidify. The metal cylinder is then removed. The nail heads hold the plastic material to the block. To locate the position of a lost object, the impression block is carefully lowered into the hole until the object is reached. After a proper stamp is ensured, the tool is raised to the ground surface, where the impression made in the plastic material is examined for identifying the position of the lost object and designing or selecting the right fishing tool.

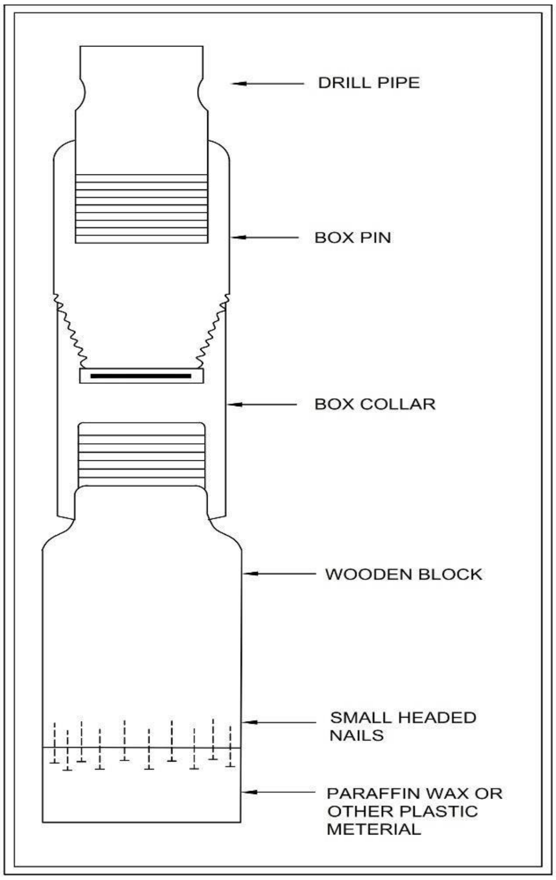


Figure 3.10: Impression Block

b) Fishing Tools to Recover Fallen Objects

The term “fish”, as used in tubewell technology, describes a well drilling tool, pump component, or other foreign body accidentally fallen or struck in bored wells and wells. The type of fishing tools required for a specific job will depend on the object to be lifted and the position in which it is lying in the well. Designing a fishing tool to suit a particular job may often be necessary. However, a series of fishing tools suitable for different jobs are available in the market, which could be adapted or modified to suit a particular requirement.

3.5.8.4 Maintenance

The most common methods to rehabilitate water well such as tubewells and bore wells are:

(i) **Chemicals to dissolve the incrusting materials from the well:** Physically cleaning the well using a brush attached to a drilling rig, high- pressure jetting, hydro-fracturing, and well surging.

(ii) **Treatment of chemical installation:** Incrustation removal using acid treatment procedures is quite effective and the employment of mechanical procedures in conjunction with acid treatment improves the outcome. To eliminate biological residues, chemical bacteria are used in conjunction with the physical agitation of wellbore water.

(iii) **Treatment of physical plugging:** The correct well-development method is the most significant preventive step to avoid physical plugging. The aquifer material is stabilised by adequate well development. Using a high-velocity jet is the most efficient means of agitating well water as a measure of well progress.

(iv) **Treatment of corrosion:** The best way to fix the problem of corrosion is to select appropriate corrosion-resistant casing and screening materials.

3.5.9 Incrustation

Incrustations are physical obstructions, mostly in the form of minerals, which deposit/develop on well screens and rock fractures or openings delivering water to the well screen or borehole.

3.5.9.1 Diagnosing Encrustation Problem

Chemical encrustation is indicated by a gradual reduction in the yield of the well. However, it can also happen with a gradual lowering of the water table due to overpumping or inadequate groundwater recharge. This fact can be verified by studying the behaviour of the groundwater level over the service period of the tubewell. Incrustation in the form of slime produced by iron bacteria decreases well yield due to clogging of the well screen and casing. Incrustation also clogs the fractures and fissures of the rocky zone of well, which is prevalent in borewells. Water quality analyses are used to identify the type of incrustation.

3.5.9.2 Types of Incrustation

The various types of incrustation in order of the frequency of occurrence are:

- Precipitation of carbonates, sulphates, and silicates of calcium and magnesium
- Precipitation of hydroxides, oxides, and other compounds of iron and manganese
- Slime is produced by iron bacteria and other slime-producing organisms
- Deposition of soil materials (mechanical incrustation)

a) Calcium and Magnesium

Calcium carbonate is one of the most extensively found minerals. On pumping, a low-pressure zone is created around the well, and some dissolved carbon dioxide is released from the solution. Some calcium bicarbonate is then reconverted into calcium carbonate, which is deposited as cement-like material on the screen and in the sand and gravel around it. This incrustation builds up a shell around the screen, which may be several centimetres thick. In addition to the sand grains around the well, which are cemented together, other substances like aluminium silicates, iron compounds, and organic material may also be entrapped in the carbonate scales. This type of deposit accounts for about 90% of the cases of incrustation.

b) Iron and Manganese Salts

Bicarbonates of iron and manganese are more soluble in water than their hydroxides. Oxidation can then occur due to the dissolved oxygen in the water and these are transformed into hydrated oxides. Hydrated ferrous oxide is a black sludge, while ferric oxide is reddish-brown like common crust. Ferrous bicarbonates are moderately soluble in water, the solubility increases if the water is acidic. Ferric salts are, however, insoluble in alkaline or weakly acidic water. Thus, a reduction of acidity can also cause precipitation of iron salts. Ferrous bicarbonates also get oxidised, when they come in contact with oxygen to form insoluble ferric hydroxide.

In general, waters containing more than 400 ppm bicarbonates, 100 ppm sulphates, or 400 ppm silicates can be considered incrusting. Water containing 2 ppm iron or 1 ppm manganese can be considered incrusting. Water can also pick up iron from the well pipe itself if iron pipes and screens are used in well construction.

c) Bacteria

Iron bacteria, such as *crenothrix polyspora*, grow attached to the screens or voids of the aquifer and feed on carbon compounds like bicarbonates and carbon dioxide in addition to the iron in the solution. They change the dissolved iron into the insoluble ferric state during their life cycle. This is deposited in the void of the aquifer surrounding the screen or in a jelly-like sheath that surrounds the bacteria. This slime can clog the screen slots and the pores of the aquifer.

Sometimes sulphate reducing bacteria are also found in groundwater which reduces the sulphates in the water to hydrogen sulphide. Hydrogen sulphide attacks the iron pipes to form insoluble iron sulphide, which is deposited as a scale.

d) Silt and Clay Deposits (Mechanical Incrustation)

Silt and clay materials can sometimes move onto the screen and clog it. These may also clog the fractures and fissures of the rocky zone of a well, which are prevalent in bore wells. Such clogging may be because of improper development or inadequate design and construction.

3.5.9.3 Prevention of Incrustation

At the time of construction of wells and even afterward, some measures can be taken for the prevention of incrustation. In the case of wells where the water is charged with undesirable chemicals, incrustation cannot be prevented entirely, but it can be delayed and kept in check by keeping the drawdown as small as possible. In this way, a considerable release of carbon dioxide does not take place and precipitation of carbonates in well screens is kept in check. In order to reduce the head loss to a minimum, the well should be developed properly, so that aquifer losses are reduced to a minimum. A screen having a large open area and fully penetrating the aquifer should be installed. This results in lower entrance velocities as well, due to which precipitation of iron salts and carbonates is retarded. The pumping rate should be reduced and the pumping period increased. Lastly, the screen should be cleaned periodically, say once a year, even if the discharge has not fallen off. This last point is very important because if partial choking takes place, it is very difficult to eradicate the same completely.

3.5.10 Rehabilitation of Encrusted Tube Wells and Borewells

It is necessary that the type of encrustation is determined before deciding upon the corrective action to be taken.

The most important factor in the treatment by chemicals is an effective contact between the chemical and the deposit on the well screen as well as in the aquifer adjacent to it. The chemical solution tends to penetrate only those parts of the aquifer where it gets the least resistance, i.e., which are comparatively free from clogging. Hence, it is necessary to agitate the solution vigorously and force it into areas that offer resistance. A treatment may have to be repeated a couple of times, and the second or subsequent treatment will open up the more heavily clogged-up areas.

Incrusted wells can be cleaned by acids, chlorine, dispersing agents, etc. Hydrochloric and sulphuric acid are effective in removing carbonates and partially effective in removing iron and manganese oxides. Glassy phosphates are able to disperse iron and manganese oxides, silts, and clays. Chlorine is effective in removing bacterial growth and slime.

Different methods of rehabilitating incrusted wells are given below:

3.5.10.1 Hydrochloric Acid Treatment

a) **Inhibitor**

Carbonate-type incrustation (mineral scale) is removed by hydrochloric acid treatment. Concentrated hydrochloric acid of commercial grade (28% strength) is usually used in well treatment. It should contain a suitable inhibitor that helps in the quick dissolution of calcium and magnesium carbonates. It also slows down the acid attack on the mild-steel well pipe. Hence, the possibility of any damage to the pipe during treatment is minimised. A home-made inhibitor can be used if inhibited acid cannot be obtained. A solution of about 0.7 kg of gelatine in warm water added to 100 litres of acid is usually adequate. Figure 3.11 shows the set up for acid treatment of tubewells.

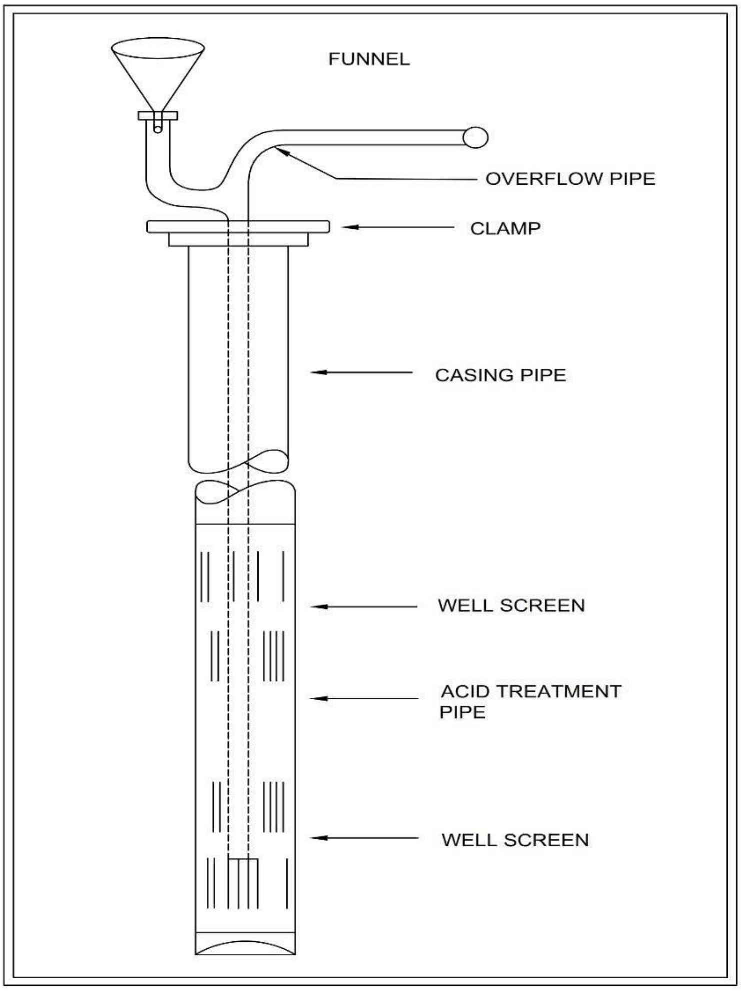


Figure 3.11: Set up for Acid Treatment of Tube Wells

b) Adaptability

Hydrochloric acid treatment is best suited when incrustation is due to calcium and magnesium carbonates. The treatment may not be successful in removing iron and manganese crusts. It is not suitable for agricultural strainers which consists of brass wire mesh wrapped over a perforated galvanised iron pipe. All persons handling the acid should use rubber gloves and protective masks.

c) Safety measures

Hydrochloric acid is harmful to the skin and can result in serious injury to the eyes if not handled carefully. Similarly, the formation of gases when the acid is poured into the well can cause suffocation which could be fatal. Therefore, necessary care should be taken while treating the well. All persons handling the acid should use rubber gloves and protective masks. A box of baking soda is kept handy to neutralise the effect of acid if it falls on the body.

3.5.10.2 Sulphamic Acid Treatment

1) Hydrochloric acid and sulphamic acid are used when calcium carbonate is the principal incrusting material. Sulphatic acid is commonly used for treatment in the case of wells having mild steel screens or well pipes with deposits of calcium and magnesium salts.

Sulphamic acid ($H3NSO3$) is commercially available in granular and pelletised forms, and it is available under different trade names having a corrosion inhibitor and a wetting agent. A colour indicator is also introduced in the pellet, which would change the colour of the solution from violet to orange-yellow once the incrustation is completely dissolved. Sulphamic acid is soluble in water and the weak solution does not give any hazardous fumes nor irritate the skin.

2) The quantity of sulphamic acid required depends on the quantity of water in the well. The usually recommended quantity of sulphamic acid (by weight) to be added in a tubewell is about 7% to 10% of the weight of water in the well. Thus, in a 20 cm–diameter tubewell with a water column of 100 m, the volume of water being 3.14 m^3, the total quantity of sulphamic acid required for treatment is about 250 kg. It is often desirable to add a corrosion inhibitor and a wetting agent (low detergent soap) to improve the performance of the acid. The quantities of both these additives are about 10% each of the weight of sulphamic acid. The corrosion inhibitor prevents the corrosive action of the acid on the metal of the well pipe. The wetting agent improves the dispersing and cleaning action of the acid. Fluronic F-68 or Pluronic L-62 are commonly used as wetting agents.

3) **Safety precautions:** Sulphamic acid in granular and pelletised forms, though less aggressive than hydrochloric acid, should be handled with caution. Waterproof gloves and goggles should be worn by those handling it. Hydrogen sulphide and carbon dioxide gases are produced in considerable volumes during the reaction, and the former is produced when iron sulphate is present. Both these gases are heavier than air. Hence, no person should be allowed to stand in a depression or a pit near the well during treatment.

4) **Necessary conditions for acid treatment:** The following are the major requirements for acid treatment of water wells:

   a) The material of the well screen must be such that it is not damaged by the acid.
   b) The well screen must be constructed of a single metal in order to avoid electrolytic corrosion, and it is, therefore, advisable to use non-metallic screen material.
   c) A fair knowledge of the kind of incrusting material is essential to determine the proper procedure in well treatment. Water quality analysis is also useful to obtain information on the kind of incrusting material.
   d) Adequate ventilation of well treatment site is necessary.
   e) Wells located in the neighbourhood of the well based on the same aquifer must be shut down during the process of treatment.

In all acid treatments, the acid should be handled with care. Good ventilation should be provided when operating in a confined area, like a pump house. Adequate provision should be made for the safe disposal of the used water which is pumped out during its treatment. The used water must be kept away from domestic wells, ponds, or other water bodies used for human or cattle consumption. Pumping the waste during acid treatment is a process of brisk surging, followed by slow pumping until the water becomes clear and free from odour and foam.

3.5.10.3 Aquifer Conditions Non-Responsive to Acid Treatment

Acid treatment of water wells, though suitable under most conditions, may not result in any appreciable improvement under the following aquifer conditions:

i) Shallow, limited aquifers, subjected to recurring periods of over-draft.
ii) Deeply buried narrow aquifers approaching over-development.

iii) Aquifers of low permeability where operating heads are large.

Controlled pumping tests to determine well efficiencies and the hydraulic characteristics of aquifers are essential in determining the effectiveness of acid treatment or other development methods to increase the yield of water wells.

3.5.10.4 Glassy Phosphate (Optical Glass) Treatment

Glassy phosphates or polyphosphates are used for well treatment when iron oxide, manganese oxide, silt, and clay are the materials causing incrustation. Sodium hexametaphosphate $(NaPO_3)_6$ is one of the most commonly used polyphosphates. They do not dissolve the incrusting material and fuming, or boiling does not take place. Phosphates have cleaning and dispersing properties which break the incrusting material when coupled with vigorous agitation. Thus, the incrustation gets dispersed and is easily pumped out. Calcium hypochlorite is also added to it in small quantities. It helps in chlorinating the well and killing the iron bacteria or similar organisms which may be present in well water.

a) **Treatment Procedure**
Glassy phosphate solution is prepared in a tank or drum. The amount of glassy phosphate to be added depends on the quantity of water in the well. Generally, 15 to 30 kg of glassy phosphate is used for every 1000 litres of water in the well. It should be dissolved in water by suspending it in a tank in a cloth net or gunny bag and should not be simply dumped. A mixture of about 1.2 kg of calcium hypochlorite per 1000 litres of water is desirable. It helps kill iron bacteria and other organisms. The prepared solution is then poured into the well. The chemical is quite safe to use and does not require any special safety precautions.

b) **Removal of Hydrogen Sulfide (H2S) Biofouling**
Sulfate-reducing bacteria in groundwater reduce the sulphates in the water to hydrogen sulfide, which produces a foul smell known as biofouling. This biofouling can be removed by the method mentioned above and this can also be removed by super chlorination of water.

3.5.10.5 Chlorine Treatment

In the case of wells incrusted with bacterial growth and slime deposits, chlorine treatment has been found most effective, thus loosening it.

Calcium hypochlorite $(Ca(ClO)_2)$ is often used for chlorine treatment. It is available in powder form, containing about 70% free chlorine. The quantity required is generally 20 kg to 25 kg for deep wells. Sodium hypochlorite (NaOCl) can also be used. Sometimes chlorine gas in water solution is also used, but special equipment is required for its application.

Treatment Procedure
The desired amount of the chemical is put in the well directly or in a water solution to give the proper concentration of chlorine. When chlorine solution is used, it can be introduced into the well slowly through a plastic pipe of small diameter, over a period of about 12 hours in case of large wells. About 14 to 18 kg of chlorine will be required for this purpose. Small wells require less chlorine and the period of application can be decreased accordingly.

Chlorine is corrosive in the presence of water. It should, therefore, be handled carefully so that it does not harm the pump, well casing, and screen. As soon as the chlorine solution is introduced, a sufficient quantity of water (50 to 100 times the volume of water standing in the well) is added to the well from an outside source, with a view to forcing the chlorine solution into the water-bearing formation. The well is then surged, using any of the standard techniques of surging. In case the pump has not been removed, the same can be used for surging, though not very effectively. Successful chlorine treatment of a well may require three or four successive operations.

3.5.10.6 Combined Hydrochloric Acid and Chlorine Treatment

Hydrochloric acid treatment followed by chlorine treatment is highly effective. The acid readily dissolves the carbonates, while the chlorine helps to remove the slime deposited by iron bacteria. The two treatments are alternated, the acid treatment being performed first, and the cycle may be repeated two or more times.

3.5.10.7 Dry Ice Treatment

Dry ice is carbon dioxide gas that is solidified by the application of large pressure. When placed in a well, it is quickly converted into gas and is not allowed to escape, and is then forced through a screen. In this process, the material choking the screen is loosened. There may also be some reconversion of salts into soluble bicarbonates due to the action of dry ice. Dry ice can also be used after acid treatment for agitating and creating back pressures for surging. It may cause severe burns if it comes in contact with the body. Hence, heavy-duty gloves or tongs should be used while handling it.

3.5.10.8 Hydro-fracturing

This process is generally not commonly used in this country for development purposes. Hydro-fracturing is a process used to open-up clogged fractures and fissures in the rock surrounding the bore well by injecting water at very high pressure. The hydro-fracturing method can be used for rejuvenation of a low-yielding or nearly dry bore well at the cost of 10% to 70% of the cost of a bore well.

(a) Conditions necessary for hydro- fracturing

1. Low yield/dry bore wells shall be considered for hydro- fracturing.
2. Lithology of each bore well should be known.
3. Well-logging is to be conducted to confirm the lithology and fracture zones of the bore well.
4. Quality of the water should be known.
5. Bore well should be of sufficient depth.
6. Bore well should be in good physical condition (like a uniform diameter and verticality).

(b) Basic components of hydro-fracturing unit

The basic components of the hydro-fracturing unit include packer assembly, hydraulic pump for packing, supercharge pump for injecting water under high pressure, water tank, generator, and submersible pumps of different horse powers.

(c) Operation

Hydro-fracturing can be carried out by:

- Single packer;
- Double packer.

In the single packer technique, the packer will be placed above the fracture/work zone in the bore well, and the bottom of the bore well acts as the closed end. In the double packer system, the packers are placed at predetermined depths within the bore well.

The verticality of the bore well is checked up to the depth of the packer setting, and the packer is lowered and fixed by applying hydraulic pressure up to 300– 350 bars and followed by injection of water into the bore well under great pressure, depending upon the depth, dimension, and area of the fracture. The pressure ranges from a few tens to 170 bars. Once the maximum pressure builds up, the fractures, fissures, and joints will break and interconnects among them, and the pressure drops down suddenly, indicating the development of fresh fractures or interconnection of existing fractures. Thus, this process can be repeated for lower fracture zones also. Subsequently, well-logging and pump tests will be conducted to assess the degree of hydro-fracturing and improvement in yield. The set up of hydro-fracturing unit is shown in Figure 3.12.

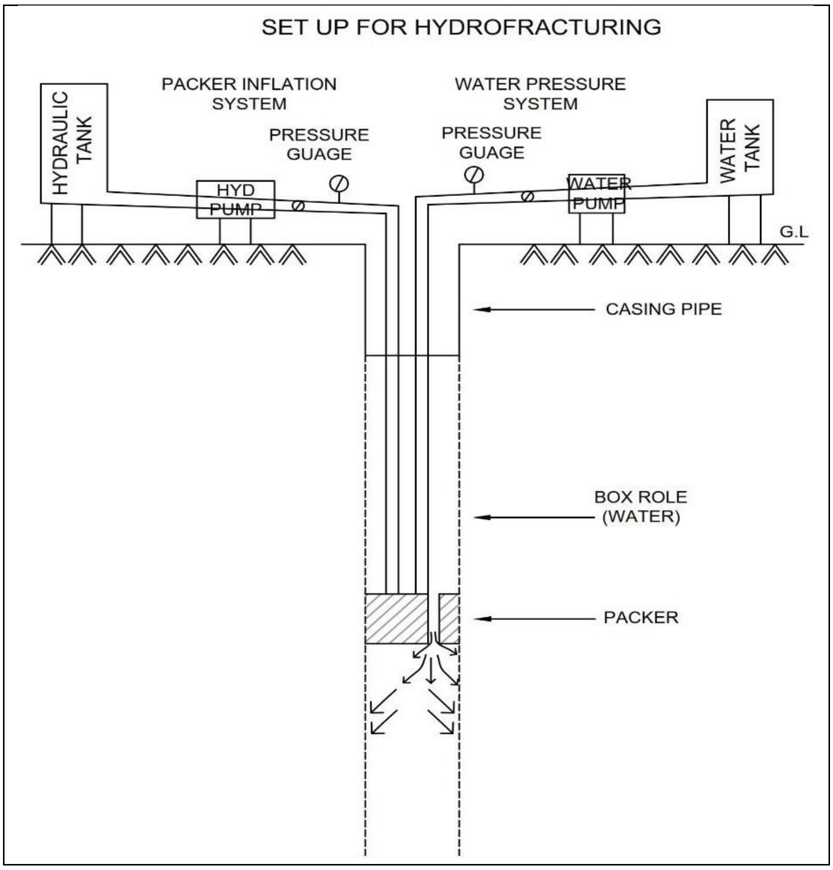


Figure 3.12: Set up of Hydro-Fracturing Unit

3.5.10.9 Explosives

Explosives are sometimes employed to develop and enlarge incrusted crevices and fissures of bore wells. Charges are used according to the hardness of the rock and the depth at which the charge is to be detonated.

3.5.11 Corrosion

Corrosion is an electrochemical attack on the metallic pipes which results in the loss of pipe materials at the place of occurrence and is usually transported and deposited at the adjacent site. Corrosion, including tuberculation and encrustation, is one of the major problems which results in leakage and sometimes bursting and reduction of discharge capacity. Corrosion can be prevented by the following methods:

i. **Application of Corrosion Resistant Paints and Coatings**
Corrosion can be controlled to a large extent by applying anti-corrosive paints on the steel pipes during the time of construction of the tube well. Non-corrosive casing pipes and strainers (such as PVC pipes and strainers) can also be used during the time of construction of the tube well to avoid corrosion. Some commonly used paints/coatings to control corrosion of aluminium, asphalt, red lead, and coal tar. Nowadays, a number of epoxy paints for this purpose are also available in the market.

ii. **Cathodic Protection of Mild Pipes**
The following are two methods for applying cathodic protection against corrosion of mild steel pipes:

- **Sacrificial Anode**
For wells, sacrificial anode cathodic protection is used, which is detailed below:

In the case of the sacrificial anode system of cathodic protection, a metal of higher negative potential than that of the material of the pipe to be protected is used as the anode. The metal pipe acts as the cathode and the intervening water as electrolyte (Figure 3.13), thus establishing the flow of electrons from the anode to this cathode. During electrolysis, the anode gets dissolved slowly, and the metal ions in the solution are deposited at the cathode. Thus, the main pipe (well pipe) is protected from corrosion by sacrificing the metal of the anode. Sacrificial anodes are easy to install, and no power costs are involved. They are effective in prolonging the service life of mild steel tube wells in corrosive water. However, the anodes have to be replaced periodically at the end of their useful life.

The anodes may be made of magnesium, zinc, aluminium, tin, or alloys. They are commercially available in diameters ranging from 1.5 to 8 cm and lengths of 1 to 3 m. Research findings have established the adaptability of aluminium-zinc-tin-alloy in the cathodic protection of tube wells (a commonly used alloy has Al 90%, Zn 7%, and Sn 3%). Alloys cast in steel core pipes of 1 cm diameter are also available. The anode rods are threaded at their ends for joining with each other through sockets or couplings. Figure 3.13 shows a cathodic protecting arrangement of tube well.

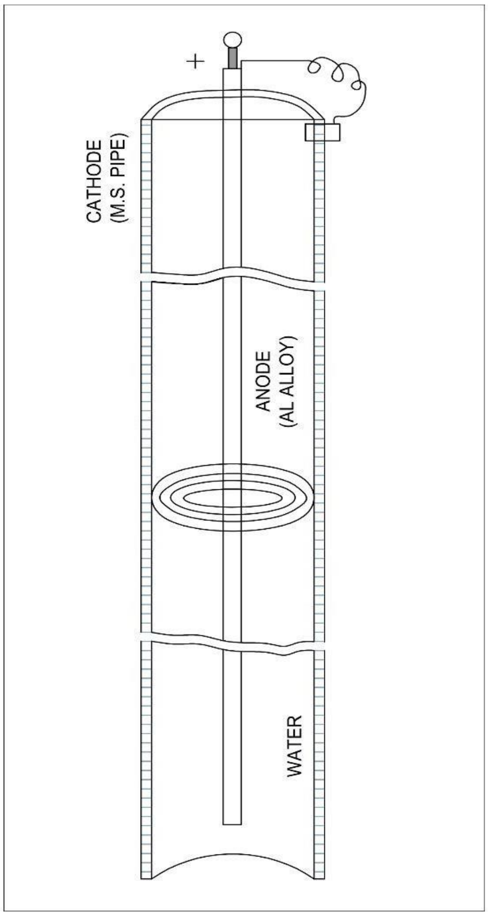


Figure 3.13: Cathodic Protecting Arrangement of Tube Well

- **Impressed Current:**
  In the impressed current method, electric current is passed from the current source through anodes buried in the soil some distance from a mild steel pipeline. This method is extensively used in protecting mild steel pipelines in water supply projects, but its applicability in wells has not yet been established.

3.5.12 Conservation of Groundwater

Following are the steps for the conservation of groundwater:

i) Rainwater harvesting and artificial aquifer recharge
ii) Rejuvenation of waterbodies
iii) Controlled groundwater withdrawal under adverse aquifer conditions

3.5.13 Artificial Recharge of Groundwater

Artificial recharge of groundwater can be achieved by the following:

a) Streamflow harvesting comprising of

- Anicuts
- Gully plugging
- Loose stone check dams (LSCD)
- Dams

b) Surface flow harvesting

- Tanks
- Ponds

c) Direct recharge

- Recharge of wells
- Recharge through injected wells
- Recharge through rooftop rainwater harvesting structures

3.5.14 Rainwater Harvesting (RWH) Systems

The RWH system, also called rainwater collection system or rainwater catchment system, collects and stores water for human consumption or domestic purposes or ground water recharge. In cities and towns, much of the rain that falls on buildings, roofs, roads, and other hard landscaping does not percolate inside and is instead diverted into storm sewers for disposal. The simplest RWH systems are non-pressurised systems, such as rain barrels where pipes run from rain gutters into a tank.

Roofs made from smooth, clean, and non-toxic materials should be used for harvesting purposes. Also, a first flush device shall have to be inserted in the conveyance system before allowing the entry of water into the system. When there is no first flush system, the first downpour water shall have to be diverted manually as this water is of inferior quality owning to the presence of dust, vegetation, animal excreta, insects, etc. High winds or intense storms can damage gutters and downspout points and therefore, additional inspection is recommended following the large storm. Leaves, twigs, and organic debris should be removed from screens during the spring and fall season. Collected rainwater shall have to be stored and handled safely. It should ideally be disinfected properly before its consumption.

Proper O&M of the RWH system helps to protect water quality in several ways. Regular inspection and cleaning of the catchment, gutters, filters, and tanks reduce the chances of contamination. Mixing harvested rainwater with water from other sources in the storage tank is discouraged.

3.6 Record Keeping

The records to be maintained shall include the following aspects:

a) A log of O&M performed on surface and groundwater intake facilities.
b) When and under what conditions do failure or malfunctions occur.
c) Periodic (monthly, quarterly, and yearly) O&M of intakes for abstraction of surface/groundwater.
d) Maintaining record of water quality test results from intake wells, hand pumps, and tube wells.
e) Maintaining quarterly and yearly records of servicing and maintenance of intakes/tube wells/bore wells.

3.7 Safety

When working around intake structures, proper safety procedures involving the use of electrical and mechanical equipment and water safety should be observed. Proper safety procedures should be documented and included in the manual containing the operating procedures. For more details, refer to Chapter 13: "Safety Practices" of Part B.

CHAPTER 4 : TRANSMISSION OF WATER

4.1 Introduction

The overall objective of a transmission system is to deliver raw water from the source to the treatment plants and transmit treated water from treatment plants to the storage reservoirs for onward supply into distribution network. The transmission system comprises of components, viz., pipelines, valves, bulk meters, pumping system, and surge protection devices.

The operation and maintenance (O&M) objective is to make optimum utilisation of the transmission system to maintain pressure with minimum leakages and costs.

To attain this objective, the ULB/agency has to evolve standard operation procedures (SOPs) to ensure that the system can operate satisfactorily, function efficiently and continuously, and last as long as possible at the lowest cost.

The transmission system is the key for delivering a 24×7 Pressurised Water Supply with Drink from Tap initiative and thus needs extensive monitoring of pressure, flow, and quality. This gives rise to utilities, having trained staff, and robust Standard Operating Procedures (SOPs) developed to operate and maintain the pipelines, reservoirs, and DMA meters and ultimately provide safe water at the tap, with good consumer services.

Routine and emergency operating procedures should be well documented and clear to all operators with authority to act in normal as well as emergency situations. Further specific operational procedures are required to be specified for inspecting, monitoring, testing, repairing, disinfecting the system and locating the buried pipes and valves. System records and maps should be updated and have sufficient details of the installed system facilities.

The routine operations are the operation of valves at reservoirs from where transmission channel/main starts and the operation of pumps (in the case of pumping mains) from where the transmission main starts. Operation of chlorinators, if installed, are also included in the routine operations.

4.2 Mapping, Investigation and Condition Assessment

To operate and maintain a transmission system, the operator must keep the existing system's maps up-to-date and carry out investigations/assessments of its system to take appropriate actions for efficiently operating and maintaining the system.

4.2.1 Mapping of System

Survey maps must be procured or prepared for the entire existing and proposed canal/pipe network, which could be the probable source of raw water for drinking water supply projects. Existing cross-country transmission mains which are laid above-ground can also be mapped by drone survey, LiDAR (Light Detection and Ranging) survey, etc. These maps shall show the contours, spot levels, and essential land features for the whole area where the water supply schemes are to be implemented or augmented.

The alignment of all main canals, branches, distributaries, and all pipelines with appurtenances shall be marked on the maps, and the maps should be updated from time to time.

4.2.2 Field Survey

Existing maps are used, or a conventional survey is carried out to prepare and update the maps showing all the levels and alignments.

4.2.3 GIS Maps

Geographic Information System (GIS) helps in combining maps with detailed information on physical infrastructures with geographic areas. GIS also has compatibility with AutoCAD systems. The remote sensing techniques can be used to prepare a base map of the utilities in combination with GIS. The GIS creates a database within a mapped area such as streets, valves, valve chambers pipe networks, and pumping stations. The attributes can be attached, including the number of valve chamber pipe length, diameter, invert, and quadrant (co-ordinates), engineering information, maintenance information, and inspection information. The utility staff can update the maps and retrieve information geographically. These maps can be used to inform the maintenance crew to locate the place of work. The utility can use a work order system for new/repair works so that after completion of the work, like a line is added or a valve is fixed, or a new connection is given; the work order can be used by the map unit for updating the map and other attributes. These thematic maps can be used to indicate layers of maps for water lines, sewers, power cables, telecom cables, etc. GIS mapping is extensively discussed in the Advisory on "GIS Mapping of Water Supply & Sewerage infrastructure," published by MoHUA. In April 2020.

4.2.4 In-line Leak Detection Techniques

With With the advent of new technologies, in-line leak detection techniques are used for large diameter pipelines. Probes are placed in the pipe which picks up leak noises/pressure differences as they pass through it.

These methods/techniques are highly sophisticated and need skilled supervision. They may be applicable only under specific conditions, like availability of full bore, branchless lengths, absence of air valves/scour valves which may draw the sensor to its stub, etc. Therefore, the reader is advised to consider the use of such gadgets after a thorough study. Some of these techniques are explained below.

4.2.4.1 Parachute/Tethering device

Parachute / tethering device is a tool which can be used in pipelines larger than 150 mm diameter without the need to put the pipeline out of the service. The tool is connected with the pipes, hence, a leak, air pockets and visual anomalies can be monitored.

A tap of 50mm or more may be used to insert the tool into an active pipeline. The flow velocity of the water inflates a small parachute or drogue after the tool is inserted. The parachute pulls the tool through the pipe, with the probe lighting the way with its onboard LED lighting system, highlighting any visual defects in the pipeline as shown in Figure 4.1.

If the tool detects any acoustic events, such as a leak, the operator can stop the tool at the precise location of the leak, and an above-ground operator can locate the sensor as shown in Figure 4.2, marking the exact leak location within plus or minus 0.5 metres. This enables users to know in real time where the leaks are, and where repairs are needed.

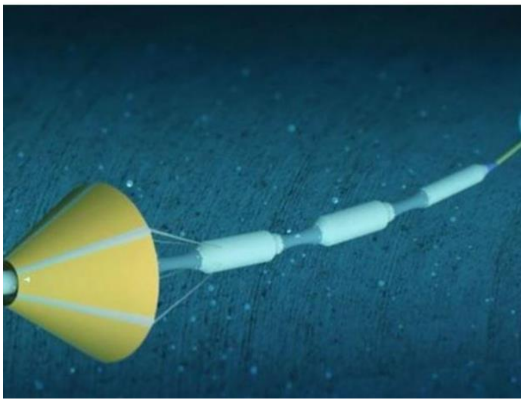


Figure 4.1: Tethering Device for Inline Leak Detection System

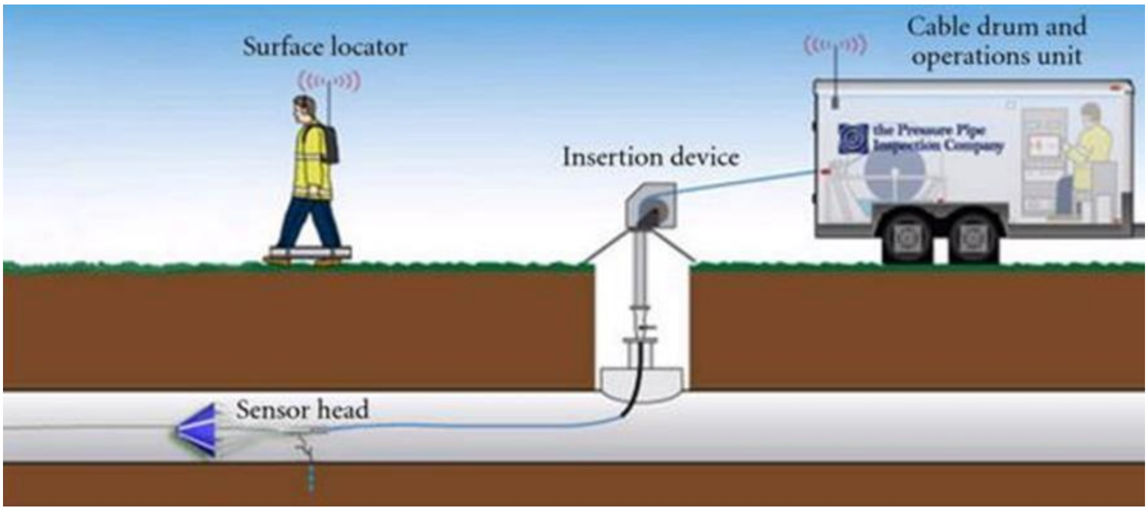


Figure 4.2: Surface Locator

4.2.4.2 Robot for Leak Detection

A robot with a soft rubber skirt/hand (Figure. 4.3) attached at the rear end, which fills the diameter of the pipe, is inserted into the system through hydrants, Tee, etc. This robot inspects pipes as it moves/propels with the water through the pipe, and its "hands" touch the pipe to detect the suction forces created by leaks. The gadget is subsequently recovered with a net through another hydrant, and its data is uploaded, revealing the location and size of the leak. No digging is required, and there is no need for any interruption of the water service.

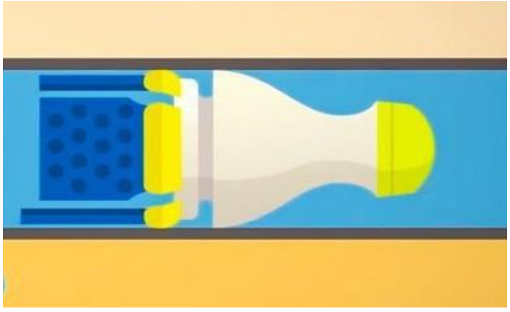


Figure 4.3: Robot for Leak Detection

4.2.4.3 Free-swim Ball Technique

A free-swim ball is an inspection tool used to detect leaks and gas pockets and map pipelines. The tool can be used in pressurised water pipelines without disrupting regular service. It can be an important component of a proactive pipeline management programme, assisting utilities in understanding the status and location of buried assets. With this information, utilities can focus on the assets that need repair or replacement, which reduces capital expenditures while increasing operational confidence.

Using accelerometer and gyroscope sensors and global positioning system (GPS) points, the free-swim ball can map the pipeline's X and Y co-ordinates. The tool can help confirm pipeline alignment or identify major conflicts with utility records compared with available pipeline information.

The tool is finally captured by means of a screen that is inserted at the end of the inspection length, as shown in Figure 4.4.

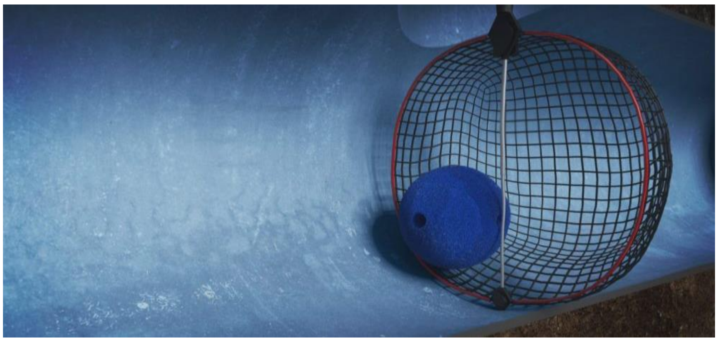


Figure 4.4: Free-Swim Ball Technique being captured at the end of Inspection Length

4.2.5 Off-Line Leak Detection Techniques:

Following off-line leak detection techniques are also practiced for transmission system:

4.2.5.1 Acoustic Leak Detection

Acoustic Leak Detection is a method of detecting leaks by listening to the sound/noise created by the leaking water stream from the narrow opening at the leak point as shown in Figure 4.5. As the basis of leak detection is noise, it works best in networks with: (1) metallic pipes which carry the noise to longer distance; and (2) pressurised system, where higher pressure creates greater noise. Acoustic leak detection is usually carried out during wee hours when the consumption is low, allowing higher pressure in the system and low background noise from vehicular movement. The method requires stepwise approach for better results starting with pre-localisation of leak prone or high loss areas. This is achieved with zoning, step testing, noise logging, etc. The Acoustic Leak Detection can be done by the following methods:

- **Electronic Listening Stick:** It is a system comprises of microphone, noise amplifier and in-built noise filters. The stick needs to be connected/touched to a pipe or a fitting like valve, hydrant and the leak noise travelling in the pipe is listened and requires trained ear to differentiate between leak noise and other noise. It is difficult to pinpoint the leak.
- **Ground Microphone (Elephant Foot):** It has a system of large sensor which touches the

ground, amplifiers and noise filters, display unit which allows to set, filter, visualise the noise levels. The sensor is kept on the ground where leak is suspected, and the noise is listened over a period to pinpoint leak below. It can be used by trained technicians.

- **Noise Loggers:** These are noise recording pods which are programmed to record noise for a set period and transfer the log data. The noise from leaks travelling through the pipe material and valve (usually up to 100 m radius) is intercepted and recorded. Access to pipe or valve is needed to fix the logger. It does not pinpoint the leak and can be used only by trained technicians and engineers.
- **Leak Noise Correlator:** The correlator is a unit composed of two probes, two emitters, and a calculator-receiver. The probes are placed at the ends of the pipe, directly on the pipe (or in contact with the water for hydrophones). They record the noise (intensity, frequency) and transmit a signal to the emitters. For precise results, accurate length of pipe inspected, the type of pipe and its diameter needs to be inserted in the programme. This device has the advantage of being little affected by external noises and can pinpoint leaks. It gives best results in straight length of pipe with two access points and high- pressure lines and can be used only by trained technicians and engineers.

Figure 4.5: Acoustic Leak Detection

4.2.5.2 Detection of leak through gas

With this technique, a non-toxic, water insoluble and gas (such as helium or hydrogen) which is lighter than air, is injected into an isolated segment of a water pipe. The gas escapes at a leak opening and then, being lighter than air, permeates to the surface through the soil and pavement. The leak is located by scanning the ground surface directly above the pipe with an extremely sensitive gas detector (Figure 4.6).

Figure 4.6: Detection of Leak through Gas

A comparison between Helium Leak Detection Technique and Acoustic Leak Detection Technique is described in Table 4.1 below:

Table 4.1: Comparison between Helium and Acoustic Leak Detection Technique

Helium	Acoustic
No water required during detection. Once Helium is injected during supply time, detection can be carried out in next 2–3 days.	Requires running water in the network during time of detection.
Works accurately on low pressure in the network system.	Require high pressure in the network.
Detection can be carried out during any hours of the day. Saves time and hence cost (project duration).	During silence hours (nighttime) as background noise creates nuisance to the operator and reduces efficiency and speed of detection.
Effectively works across all pipe materials.	Pipe material plays critical role. Sound travels better in metallic pipes than as in RCC/PVC pipes.
Robust and works on wide range of pipe sizes and topsoil quality.	Sensitive to frequency range of the system and topsoil quality (more audible on sandy soil, asphalt top than on clayed soil and grass).

4.2.5.3 Satellite Imaging/Mapping

Satellite Imaging of water supply network is a new technique of detecting leaks in water transmission system. This technique uses multispectral aerial imaging taken from satellite mounted sensors to spot leakage in underground transmission pipelines. The raw imaginary is processed by algorithms looking for a particular spectral “signature” typical to drinking water. The system generates locations of water leaks which can be presented in a mobile web application displaying the leak locations and size overlapped on to the existing GIS maps. The Satellite leak detection maps are displayed in an easy-to-use application accessed on a smart phone.

4.3 Transmission through Open Channels

Open channels and canals are exposed watercourses for transmission of water from one specific point to another. Whereas “Open Channel” is a general name for such a watercourse, a “Canal” normally forms a part of a canal network taken off from a river, a dam, or a reservoir. The criteria for the design, O&M of open channels are identical to those of a canal.

The canals are meant primarily for irrigation purposes, and the canal water is, however, liberally made available for drinking water supply schemes. While designing new canal projects, the requirement for drinking purposes is pre-determined, and necessary provisions are made in the design of the canal projects.

Under special circumstances, a specific canal may be constructed exclusively for a drinking water supply project. However, a large number of small water channels are taken off from the main canal system and are meant exclusively for the drinking water supply schemes.

The canals may run continuously or on a scheduled basis, depending on the availability of water and demand. Depending on a canal's closure period, adequate raw water storage must be created at the site of the waterworks to ensure an uninterrupted water supply. Such storage is in the form of an open square or rectangular tank whose side slopes and bed are properly lined. The surfaces of such storage tanks are identical to those of the canals, with the difference that the canal surfaces are exposed to flowing water, whereas the water in the storage tanks is comparatively static.

It is recommended to carry out the lining of the unlined canals to reduce leakage and maintenance. The solar panels installed on the canals produce clean energy, reduce evaporation losses, and provide a better return on investment, as explained below with the case study of Punjab.

Uniqueness of the Canal Top Solar PV Projects: An experience of Punjab, India

A Pilot-cum-Demonstration Project for development of grid connected solar PV power plants on canal tops of capacity 20 MW was allotted to the State of Punjab in 2014. The State Government has implemented this programme in four Projects having a total capacity of 20 MW under the NRSE Policy-2012 on Build Operate & Own (BOO) basis on the irrigation canals, through the private developers under the guidelines of MNRE, GoI. These projects are first of its kind on the canals having width 28–40 m and above, as compared to other states where the project on canals have been set up, have canal top width of 10 m to 20 m only. By installing canal top solar PV projects, about 110 acre of agriculture land and evaporation of water from the canals have been saved. These projects have been designed in such a manner that the canal banks have not been touched for the safety of the canal, service road, and inhabitants in the vicinity of the canals. The canals are the lifeline of agriculture and are closed only for 10–15 days in a year for canal maintenance. Periodic de- silting/cleaning of the canal bed with floating pontoons will be done for maintaining the safety of the canals and smooth flow of water.


Solar Panels Installed on the Canals

4.3.1 Operation

The key objective of proper O&M of the canal system is to ensure: (1) efficient, uninterrupted, assured, authorised water supply from head to tail of a canal distribution system; and (2) reduce seepage losses at economical maintenance cost. Hence, a timely and methodically well-planned execution programme for the operation, maintenance, and repair of the canal system is very important.

The available quantity of canal water is generally far less than the daily raw water requirements, except during the active monsoon months. In order to overcome this problem, the entire canal network is divided into different groups, which are run strictly according to the sanctioned/notified rotational programme. Each feeding channel has a full supply turn followed by a closure turn, and no supply can be allowed to be done out of turn.

4.3.2 Maintenance of Unlined Canals

Some of the most desirable requirements are:

- a clean bed;
- straight clean slopes;
- uniform berm widths;
- uniform regular top width.

4.3.2.1 Bed and Berms

The beds and berms should be correctly aligned. These should be scraped, where necessary and especially in tail reaches. The canal should be straightened. The kinks and irregularities should be removed, and curves should be eased off where scouring or silting takes place. Clearing operations should be started from downstream to upstream.

a) Bed

All grass should be scraped, and weeds removed from the silted bed wherever they are found to exist since their presence induces silt deposits.

All accumulation or deposits or mounds of silt should be removed. Beds should be levelled, and their gradient regularised.

The canals that carry silt-free water from the reservoirs generally get infested with aquatic weed growth, which reduces their capacity and impairs proper functioning. Such canals should be kept clear of aquatic weeds.

b) Berms

Berms should be kept straight by trimming projections after aligning them correctly.

4.3.2.2 Silt Clearance

Silt ejectors/desilting basins, wherever provided, should be operated regularly to prevent the accumulation of silt. Longitudinal sections of the silted bed of canals should be taken during closure immediately after monsoons, and the gradient at which silt should be removed should be ascertained.

4.3.2.3 Bridges and Siphons

When a canal runs, brushwood that collects at bridges, siphons, and falls should be removed from the banks, dried, and burnt. When trees fall into a canal, they should be removed at once. Silt and rubbish should be cleared from under the bridges.

4.3.2.4 Scouring

In case of excessive scouring at any point, adequate measures should be taken to control the scouring.

4.3.2.5 Flow and Gauges

To have effective control in regulation, it is desirable to observe discharge at conspicuous places. Gauges should be installed at the head and tail of all the channels and at important points in between, and their readings should be observed and recorded daily.

4.3.2.6 Banks

i) The banks should be brought up and maintained to full section. The fallen or loose lumps of the earth should be removed. Filling and repairing should be properly done. Both edges of the bank, especially the inner ones, should be neatly aligned parallel to the canal. The banks' inner and outer slopes and toes should be free from irregularities. The top of both the banks should be kept smooth and free from holes.

ii) Side slopes are usually kept 1:1 in cutting and 1.5:1 in the filling. If the soil is comparatively sandy, gentler slopes, say 1.5:1 in cutting and 2:1, may be provided.

iii) Following precautions may be taken to ensure the stability of the embankments and to maintain their slopes.

- adequate compaction to avoid settling on saturation;
- prevention of cracks due to settling of fills;
- prevention of seepage;
- protection from burrowing animals.

Roots from multiple trees inside and outside of the canal embankment can create a continuous path. In the case of long canals with chronic weed nuisance, it is advisable to take up Integrated Vegetation Management Plans. This plan can:

a. determine the most effective weed and pest control methods;
b. reduce cost of O&M;
c. reduce herbicides in canal water;
d. reduce the likelihood of canal failure;
e. prevent the spread of invasive species.

4.3.2.7 Roads and Ramps

Roads and ramps should be kept smooth and shall have a regular longitudinal grade. At outlets and bridge crossings, the road should be specially constructed. A dowel should be made to the desired size. The ramps for bridges over the canal should be maintained in proper conditions to ensure that the canal bank is not encroached upon. The roadways should not be allowed to remain blocked by fallen trees or any encroachment or in dangerous condition by potholes. Repair to canal roadway should be taken after the first heavy rainfall and should not be postponed till the end of monsoon. While undertaking any repair work on service road, suitable diversion should be provided to allow uninterrupted traffic.

4.3.2.8 Cross Drainage Works

A canal may intercept various drainage systems along its route, and most crossings are of the following types.

a) Crossing the canal over the drainage
   - Aqueducts
   - Syphon Aqueducts

b) Crossing the Drainage over the Canal
   - Supper Passage
   - Syphon

The water passages through these drainage works are usually restricted. These are liable to get damaged due to the obstructions created by floating objects like logs, trees, trunks, dead animals, and soft material like twigs and leaves. Adequate measures must be taken to avoid damage to these water passages. In order to reduce water loss and operational cost of treatment on account of chemical consumption, it is advisable to convert the unlined canal to lined canal or better to conduit water transmission system.

4.3.3 Maintenance of Lined Canals

The lined canal should be maintained so that it continues to function effectively and efficiently and serves the purpose for which it has been constructed. In addition to maintaining its imperviousness, the lining shall be maintained so that it also continues to have the same discharge capacity for which it has been designed and which it had when it started operating soon after the construction was over. Details of maintenance of lined canals are given below and for more information IS4839 (part 2) 1992 (revised 2001) – Maintenance of canals - code of practice: Lined canal may be referred.

4.3.3.1 Discharge Requirement

The reduction of discharge in lined canal may be due to:

i) Accumulation of silt;
ii) Cracking of lining;
iii) Failure of drainage;
iv) Growth of weeds, algae, etc.;
v) Seepage and evaporation.

4.3.3.2 Inspection of Lining

The lining, auxiliaries, and special design features should be carefully inspected during the canal closure period. The following points should be noted:

i) whether any cavities or pockets have been formed behind the lining;
ii) development of any cracks or displacement, or damage to the lining;
iii) whether the filter material in the joints of the lining is sound, intact, and leak- proof and if any weed growth in the joints has taken place;
iv) whether any pressure release arrangements and humps or regulators function effectively;

v) whether pipes and openings provided in the crest of the falls are choked.
vi) silt deposits and weed growth;
vii) full supply water level, gauges, benchmarks, etc.;
viii) whether the canal is properly protected against encroachment, theft of water, parapets against cattle or vehicles falling, etc.;
ix) whether any water is flowing into the canal from higher level tanks, possibly bringing in pollutants, sewage, etc.

4.3.3.3 Lining – Defects and their Repairs

i. Defects

Defects ranging from small settlement cracks to excessive heaving displacement and sinking of the lining may be due to the following reasons:

- cuts in soft fine ground soils especially when lining was laid on the soil without any special preparation of the subgrade;
- the high-water table is situated considerably above the canal bed, especially in fine-grained soils, where weep holes or other simple drainage devices are not very effective;
- freshly laid embankments;
- high continuous spoil banks, left too near the canal excavation without sufficiently wide berms and adequate arrangement for draining the rainwater away from the canal and similar situations permitting surface drainage to enter behind the lining;
- cavities behind the lining are caused due to sucking out the action on subgrade material by oscillating waves or fluctuating supplies of water of the canal through cracks, open joints, and holes in the lining.

ii. Remedies

- Pockets or any activities detected behind the lining should be carefully packed with sand or other suitable material. However, during such operations, care should be taken to ensure that the lining is not damaged or displaced.
- Damaged or displaced portions of the lining should be removed and replaced by a fresh lining of a quality comparable to the original lining. The subgrade should be thoroughly compacted and prepared before laying the fresh lining. The cracks (other than hair cracks) should be filled to ensure watertightness of the lining. More effective sealing of the cracks may be obtained by cutting a V-groove along the face of the cracks before filling with a sealing compound. Dumping powered clay upstream of the cracks may seal minor cracks on the lining.
- The damaged or displaced portions of the joint filter should be carefully removed. The joint should be cleaned of dirt, weed, etc., before filling in the fresh filter material.
- The choked pressure release pipes should be cleaned by intermittent application of air and water by rodding. Defective flap valves or other parts should be repaired or replaced, and the humps or regulators should be well maintained and repaired.
- All drainage and pressure release pipes and openings should be cleaned of any dirt, debris, etc., and water accumulating upstream of the fall, if any, should be drained.
- In pervious linings, such as boulder lining, any portion in which excessive settlement has taken place should be repaired by dismantling, making up the subgrade, and relaying the lining.

4.3.3.4 Reaches with High Subsoil Water Level

The subsoil water level should be observed carefully and regularly during and after the rainy season, besides routine observations from time to time. In case of rise, the adequacy of pressure release systems or other remedial measures like humps, regulators, etc., provided for the safety of the lining should be reviewed and further measures adopted.

4.3.3.5 Seepage through Embankments

Seepage through embankments, if any, should be observed at reasonable intervals of time. Observations of seepage flow should be made, and abnormal increases in the seepage rate should be controlled with suitable protective measures.

4.3.3.6 Silt Clearance

If any silt deposition is detected during inspection, steps should be taken to investigate the causes thereof and to take remedial measures for the same. Only in exceptional circumstances, it may be necessary to excavate the silt and remove it. Where silt clearance is unavoidable, it should be done carefully by manual labour to prevent damage to the lining.

4.3.3.7 Weed Removal

Aquatic weed growth should be removed if observed below the supply level. Land weed growing over the freeboard should also be controlled.

4.3.3.8 Canal Banks and Ramps

The canal banks should be inspected for the seepage conditions at the outer slope and for some distance beyond the toe, especially in high fill reaches. The roads and ramps should be properly maintained.

Robotic Inspection and Cleaning of Canal Networks

In the classical method, inspection, cleaning, and repair of canals is done during the closure period of the canal which has high social cost. Several robotic technologies are available for inspection of canals in running condition without requirement of closure period.

The inspection and silt level estimation of canals can be done using various floating, submersible, and crawler-type ROVs. Robotic survey systems are available for bathymetry of large canals and other water bodies.

For the purpose of cleaning unlined canals in running condition, several dredging technologies are available. For lined canals, liner-safe robotic dredgers, both floating and submersible-crawler type, should be used for desilting/dredging the canal in running condition.

Robotic Canal Inspection

Robotic Canal Cleaning

Siphon aqueducts are also a matter of concern since rectification of siltation issues in confined space is difficult. Water pipeline desilting robots can clean siphon aqueducts efficiently without any need for sending divers inside.

Overall, use of modern robotic techniques can significantly increase the availability of water through canals while minimising the risk of hazard.

4.4 Transmission through Pipes

The O&M procedures and requirements depend on the type of pipe material used for transmission lines. Ideally, the leakage through a pipe transmission line should be zero. However, due to reasons like air entrapment, "breathing" of rubber joints, flanges, and packing, aging, corrosion, settlement of bed resulting in stress in joints, etc., some leaks cannot be ruled out.

Depending upon the purpose, resistance to backfill and shock loads various materials of pipes and their joints are used for water transmission system which can be categorised in three groups namely, Rigid-Cast Iron (CI), Asbestos Cement (AC), and Concrete; Semi-Rigid Ductile Iron (DI), and Steel; and Flexible-Polyethylene (PE), Glass Reinforced Plastics (GRP) . Each type of pipe material has its advantages and disadvantages for its O&M and accordingly, the most suitable material as per site condition can be chosen.

4.4.1 Problems in Transmission Mains

The transmission mains encounter various operational problems such as leakage and blockage through pipes and appurtenances, water hammer, air entrainment, age of the system, lack of proper records and other miscellaneous issues which affect to achieve optimum utilisation of the installed capacity and to function efficiently and continuously of the transmission system with minimum transmission losses. The problems encountered in transmission mains are outlined as below:

4.4.1.1 Leakage through pipes and appurtenances

Water gets wasted through leaking pipes, joints, valves, and fittings of the transmission system either due to bad quality of materials used, poor workmanship, corrosion, age of the installations, or through vandalism. This leads to reduced supply and loss of water pressure. A review of flow meter data will indicate possible leakages. The leakages can be either visible or invisible. In the case of invisible leaks, sections of the pipeline can be isolated, and a search is carried out for the location of the leaks.

The most common leaks through appurtenances include leaks through the glands of sluice valves. Leaks also occur through expansion joints where the bolts have become loose, and gland packing is not in position. Leaks through air valves occur due to an improperly seated ball either due to the damage of the gasket or due to abrasion of the ball, through the gland of the isolating sluice valve or through the small orifice.

4.4.1.2 Air Entrainment

It is the entrainment of un-dissolved air bubbles and air pockets that are carried away within the flowing water. In the transmission mains, the air is introduced through vortices at intakes, pumps, vents, and other causes. Air pockets are cavities of air formed by action of bubbles coalescence or by air entrapment during pipeline filling. The air entrainment, in the transmission mains cause reduction of effective cross-sectional area which results loss of carrying capacity of pipelines, increase in head loss, disruption of flow leads to damage, reduction in screen/filter and pumps efficiency. Other causes will be enhanced erosion of ferrous pipes, increased biological activities leading to odours/corrosion, increased foaming for flow with chemical dosing, potential for false readings on measuring devices, malfunctioning of valves, and sometimes even bursting of pipes. Air valves are frequently used to eliminate the air that is on the top of the water surface in the pipelines.

4.4.1.3 Transients Conditions

The pressure rise due to the water hammer may have sufficient magnitude to rupture the transmission pipe or damage the valves fixed on the pipeline. Water hammer in water supply systems occurs due to rapid closure of valves and sudden shut-off or unexpected failure of power supply to the pumps.

Transient conditions are caused by normal and accidental or emergency pump and valve operations in events like a pumping station power failure or an accidental pipe rupture by external forces. Hydraulic transient phenomena may have consequences like water hammer and water surge caused by rapid increase of pressure, vacuum condition, cavitation and may contribute occurrence of leaks resulting water losses and risk of contamination. Three solutions may be proposed in case the transient conditions reveal unacceptable increase in pressures. These are modifications of transient events such as slower valve closure or a flywheel; modification of the system including change of pipe material or other pipe routing, etc., and application of anti-surge device like surge tank or surge tower. The surge protective device ‘Surge tank’ provides a shock absorbing effect that protects the system and its components from both positive and negative system surges. Without surge protections or failure of surge protection devices, the transmission system can have serious down surge (low negative surge pressure) problems which have potential surge damages.

4.4.1.4 Age of the system

With age, there is a considerable reduction in the carrying capacity of the pipelines, particularly with unlined CI, MS, DI, and GI pipes, resulting in corroded pipes leading to leaks and hence resulting in reduced quantity and pressures.

4.4.1.5 Blockage

The blockage in the transmission mains occurs due to the deposition of debris and minerals which causes interruptions of the water flow and sometimes damage to the pipes. In order to prevent such situation, the blockage should be detected as early as possible. Various methods for detection of blockage in pipelines such as acoustic reflectometry, vibration analysis, frequency response method, radioisotope technology etc. are used.

4.4.1.6 Absence of Records

In many water supply schemes maps showing the actual alignment of transmission mains are not readily available. As-built drawings/map showing different components of the transmission system with details and locations are required for its proper O&M. The location of pipes and the valve on the ground becomes difficult to locate in the absence of system maps. Some minimum information about the location of pipes and valves and size of pipes and valves, the direction of opening of valves, etc., are required to operate and maintain the system efficiently.

4.4.2 Operation Schedule

The effective, efficient, and economical operation of transmission mains along with all other components of the water supply system is essential to attain the objective of supply safe and clean water equitably to the consumers in the various operating DMAs of project area, so that ‘Drink from Tap’ is possible. Depending upon the topography, the transmission mains are either gravity mains or pumping mains. The operation of the pumping mains is more complex and complicated as compared to that of gravity mains. Regular inspection schedule of transmission mains alignments for illegal and unauthorised tapings and detailed schedule for routine operation of water transmission system to be carried out daily, weekly, monthly, and annually should be worked out and copy of the same should be made available to the concerned officers and the operators and accordingly they need to be trained. The schedule of operation may have to be altered to suit raw water and treated water quantity, hours of availability of power, breakdown, etc. Routine operations shall be specified to indicate the activities to be taken up for adjusting the valves and operation of pumps to match the prevailing conditions (flows, pressures, levels, and operation of pumps).

4.4.2.1 Normal conditions

Valve and pump operations will have to be controlled as per the schedule. The schedule shall contain operations for operating the transmission system. It should contain procedures to obtain, process, and analyse the variables related to water flows, pressures, and levels, as well as the consequences of manipulating control devices, such as the operation of valves and/or pumps, so that the hydraulic status of the system can match the required capacity of the system for transmission of water. When operators change their shifts, valve closure and opening information must be exchanged.

The operation schedule with respect to transmission system for appurtenances, viz., gates, valves, such as air valves, control valves, scour valves, shall have to be categorised as under regular operation and non-functional operation, for the effective working. The work involves mapping of all those assets and categorising them against reactive maintenance. A typical and routine operations schedule that is followed is given in Table 4.2.

Table 4.2: Typical and routine operations schedule

Period	Action
Daily	❖ Detections of sudden flow and pressure change. ❖ Leakage detection in pipes, valves, etc. ❖ Check for physical tampering throughout the length. ❖ Check security and safety devices. ❖ Record pertinent information in operating log. ❖ Inspect booster pump stations. ❖ Check instrumentation for proper signal input/output. ❖ Investigate customer complaints. ❖ Record threats or suspicious activity.
Monthly	❖ Check control Valves are working properly. ❖ Check fence conditions and caution signs.
Quarterly	❖ Flushing of scour valves ❖ Non-functional valves to be operated
Annually	❖ Calibrations of bulk meters ❖ Anticorrosion painting on exposed pipes and appurtenances ❖ Review Standing Operating Procedure (SOPs) ❖ Inspect concrete and masonry surfaces for deterioration, including scaling, pitting, spalling, pop-outs, crumbling, cracking ❖ Operate all valves

4.4.2.2 Operations in abnormal conditions

Operations other than routine, viz., during abnormal conditions such as rare and odd operating scenarios like sudden valve closures/openings, shutdown/tripping of pumps, reduction of water level (reservoir), breakdowns, leakages, bursting of pipes, damage during construction works or other utilities causing sudden flow and pressure change leading to emergencies which are to be specified in these circumstances. In order to take remedial measures caused by abnormal operating conditions, the devices installed like pump bypass reflux valve/non-return valve, air valves, zero velocity valves, discharge tanks/air vessels, etc., are operated to control water hammer and other side effects to the system.

4.4.2.3 Evaluation of Hydraulic Conditions and System Pressures

For evaluating the hydraulic condition and system pressures, it is necessary to provide pressure gauge points on the air valves along the transmission line at about 5 km intervals and monitor their readings regularly round the years at different pumping/flow combinations, this is then compared to the original HGL of the system. In that case, the regions of choking, high head loss or leakage can be identified, and investigations that are more intensive can be taken up at such locations.

Evaluation of the hydraulic conditions such as pressure and flow of the transmission main can be done after obtaining the data on water volumes in the reservoirs, flow meter readings from and into the reservoirs connected to a transmission system and compared with the expected performance. This evaluation shall lead to the identification of operational problems and/or system faults. Depending on the type of problems, actions have can be initiated to ensure that the system functions as per the requirement.

Locations along the transmission mains that show low pressures must be promptly investigated, if necessary, by measuring pressures with pressure gauges. Low pressures may be due to:

i) purposefully or accidentally, a line valve is left closed or partly closed, or blockage may occur due to any material causing loss of pressure leading to high velocity;
ii) leakage/breakage in transmission main causing low water levels feeding into the service reservoir;
iii) failure of pumps due to either power failure or mechanical failure feeding the transmission system.

4.4.2.4 System Surveillance

Surveillance of the transmission system is done to accomplish the following objectives:

- To detect and correct any sanitary hazards along transmission lines.
- To detect and correct any deterioration of the transmission system facilities.
- To detect encroachment of transmission system facilities by other utilities such as sewer and storm water lines, power cables, telecom cables, etc. and by any other unauthorised encroachment.
- To detect or correct if there is any unauthorised tapping of pipeline.
- To detect and correct damage to the transmission system facilities by vandalism.

These checks are carried out routinely. In addition, checks are done under special circumstances to assess the damage to the transmission system after flooding along the alignment following a heavy storm. These checks are also done for above-ground water facilities such as valves, valve chambers, or exposed pipelines. Any activity or situation that might endanger the water facility or water quality shall be investigated, and corrective action is to be taken. Surveillance shall also include looking for unauthorised construction activity on or near the utility's pipelines which may pose a physical threat to the mains. The utility staff shall closely supervise any digging, excavation, or blasting near the mains.

4.4.3 Maintenance Schedule

A maintenance schedule is required to be prepared to improve the water transmission system's maintenance level through improved co-ordination, planning of administrative, and fieldwork and with adequate techniques, equipment, and materials supported by the quick deployment of manpower for field maintenance. The schedule must be flexible to achieve team action with the available vehicles and tools. Co-ordination of activities is required for spares and fittings, quality control of materials used, and services rendered. The trainings to the maintenance staffs are very important and should include technical skills as well as behavioural skills to achieve better public relations with consumers. The maintenance schedule can be divided into three categories, viz., preventive, periodic, and breakdown maintenance, which are explained in detail as below:

4.4.3.1 Preventive/Periodic Maintenance

A preventive maintenance schedule must be prepared for:

i) Maintenance of the pipelines;
ii) Servicing of valves, expansion joints, etc.;
iii) Maintenance of valve chambers;
iv) Maintenance of record of tools, materials, labour; and
v) Cost required to carry out each task.

Some of the aspects for preventive maintenance of components are as follows:

a) Servicing of Valves

Seating of valves that are subject to operations several times is likely to become leaky or pass the flow downstream even after closing tight. For valves, expansion joints, flow meters, and pressure gauges, periodical servicing will be required. Corrosion of valves is the main problem in some areas and can cause the failure of bonnet and gland bolts. Leaks from spindle rods occur, and the bonnet separates from the body. Stainless steel bolts can be used for replacement, and the valve can be wrapped in polyethylene wrap to prevent corrosion.

b) Manufacturers' Catalogues

The manufacturer's catalogues may be referred, and comprehensive servicing procedures should be prepared for the periodical servicing. These procedures shall contain the manufacturer's name, address, telephone number, etc., and also the technical information furnished by the manufacturers of the equipment used in the transmission system, such as sluice valves, BF valves, and air valves, pressure gauges, flow meters, etc. The test certificates, inspection reports, and warranty certificates for this equipment shall also be kept along with the manual.

c) List of Spares

A list of spares/resources should be kept ready at all installations covering material components as needed, as follows.

Component	Resources required
Pipes	Material wise, diameter wise,
Valves	Types and diameters
Surge protection equipment	Spares, components
Chambers	Covers, material for repair, dewatering
Specials and Joints	Material, diameters, specific

d) List of Tools

The necessary tools and equipment to properly repair and correct the routine problems and facilitate repairs and replacements in a transmission system have to be identified and provided to the maintenance staff. Some of the tools for the maintenance work in a transmission system are key rods for the operation of all sluice valves, hooks for lifting manhole covers, pipe wrench of appropriate sizes (200, 300, or 450 mm), DE spanner set, ring spanner set, screwdrivers, pliers, hammers, chisels, caulking tools for lead and spun yarn, ladles, and pans for melting and pouring lead joints, excavation tools such as crowbars, spades, iron baskets, buckets, and dewatering pumps. In the case of a large diameter transmission system, excavators, cranes, diesel welding sets, welding electrodes, gas cutting accessories and gas cylinders shall also be required.

e) Maintenance of Chambers for Appurtenances

Valve chambers shall be checked to ensure that they are not damaged nor filled up with earth or buried in the pavement. Cover of valve chambers are stolen or broken up by vandalism or accidentally leading to damage to the valve itself or will lead to accidental fall into the open valve chamber; such situations must be corrected on priority. Road improvement works require the constant attention of water utility staff since the valves may be lost, or at times the valve chambers in the roads must be reconstructed to match the renewed road surface. Valve chambers on cross-country pipelines are likely to be tampered with to collect water and are likely to be affected by floods and agricultural and industrial activities. Leakages at such places will affect the water quality by cross-connections; hence, these leaks must be attended on priority.

f) Maintenance of Surge Protection Device

There are various types of surge protection devices installed in the transmission system, e.g., Bypass to pumps, Surge tanks, Two-way surge tanks, One-way surge tanks, Air vessels, Standpipe, Surge anticipation valves (Surge Suppressor/Surge Release Valve), Three-stage air valves, Pressure relief valve, Air cushion valve, zero velocity valve, etc., which need very specific maintenance. The maintenance schedule provided by the equipment manufacturer or developer/operator has to be implemented carefully. The devices are generally on cross-country pipelines, are likely to be tampered with to collect water, and are likely to be affected by floods and agricultural and industrial activities.

4.4.3.2 Periodic Maintenance

A programme must be prepared for each zone of the transmission system, which shall contain procedures for routine tasks, checks, and inspections at intervals, viz., daily, weekly, quarterly, semi-annually, or annually. This plan shall fix responsibility, the timing for action, ways and means of completing the action as to when and who should act, and the need to take these actions. Simple checklists for use by the managerial staff can be prepared to ensure that the O&M staff have completed the tasks assigned to them. Table 4.3 below provides an indicative checklist.

Table 4.3: Check List

S. No.	Checks required/undertaken	Suggested frequency of reporting	Status
1.	Check whether the operation of valves is smooth without any abrupt stoppage during the closure	Monthly	
2.	Check whether closure of a valve results in complete stoppage of flow or if any flow passes the valve (passing valve)	Monthly	
3.	Check for status of scouring and then proper closure of washout valves	Quarterly	
4.	Check for leaks through pipes	Daily	
5.	Check for leakage through valves at gland, bolts, or any other place	Daily	
6.	Check for leaks at the appurtenances, including expansion joints	Daily	
7.	Check for any signs of corrosion of pipelines	Annually	
8.	Check for the status of manhole covers over the chamber covers; are they corroded	Monthly	

S. No.	Checks required/undertaken	Suggested frequency of reporting	Status
9.	Inspect for any possibilities of pollution of the transmission systems	Daily	
10.	Check status of out-fall drain for scour valves and chances of contamination at scours	Quarterly	
11.	Assess the need for the painting of the exposed piping work	Annually, before monsoon	
12.	Check for availability of spares for valves, expansion joints and pipes, and jointing materials	Monthly	
13.	Carry out a review of pressures	Daily	
14.	Carry out a review of flows	Daily	
15.	Check the age of pipes/C value of pipes	Annually	
16	Check for corrosive water	Annually	
17.	Study inflows and outflows into the reservoirs linked to the transmission system and record of daily water	Daily	
18.	Identify the source of leakage	Daily	
19.	Status of bulk metering	Monthly	
20.	Review facilities for repair of meters	Annually	
21.	Availabilty of updated system map	Quarterly	

4.4.3.3 Breakdown Maintenance

A breakdown maintenance schedule has to be prepared as follows:

i) Locate the burst/leak.
ii) Inform the affected consumers.
iii) Identify an alternative supply line/source and isolate the defective component.
iv) Assess if the repair is possible without shutting the flow of water.
v) Prepare an action plan to avoid water contamination by nearby soil, etc., at the time of repair.
vi) Prepare a list of resources required, and methods to be followed for carrying out repair.
vii) Check the component after repair to function properly as intended and take steps to avoid the same failure again.
viii) If the component gets contaminated, provide disinfection.
ix) Depending on the level of action required there might also be needed to notify state agencies.

4.4.4 Critical Monitoring and Surveillance Issues

With the passage of time, the metallic pipes lose effective wall thickness due to internal and external corrosion whereas the cement-based pipes lose effective wall thickness, and the pipes get weakened due to leaching of cement by the aggressive water which cause leakage resulting loss of water. Hence, the pipelines must be carefully and monitored in real time. The condition assessment of the pipelines based on monitoring and surveillance is to be carried out, in order to take preventive and corrective measures. It is difficult to monitor the condition of the pipes, especially the pipes which are buried. The critical monitoring and surveillance issues of the transmission pipelines are outlined as below:

4.4.4.1 Main Breaks

Pipeline bursts/main breaks can occur at any time, and the utility shall have a plan for attending such events. This plan must be written down, disseminated to all concerned, and the agency must always be in readiness to implement the plan immediately after the pipe break is reported. After a pipe break is located, determine which valve is to be closed to isolate the section where the break has occurred. The affected consumers must be informed about the probable interruption in the water supply and the estimated time of resumption of water supply.

After the closure of the valve, the dewatering/mud pumps are used to drain the pipe break points. The trenches' sides must be properly protected before the workers enter the pit. The damaged pipe is removed, the accumulated silt is removed from inside the pipe, the damaged pipe is replaced, and the line is disinfected before being used.

4.4.4.2 Illegal Puncturing of Pipes

The transmission main in general, carries drinking water at a high head to fulfil the requirement of residual pressure and staging of the service reservoir. These pipes, if punctured for an illegal service or bulk connection, will allow drawing water at a high head and higher quantity which was not envisaged in the design; hence, the reservoirs being fed will suffer. Hence, it is required to stay vigilant and ensure that the transmission mains are not illegally punctured, and no connections are to be given.

Pipeline operators and utilities may adopt different approaches to address the issues. Some of these are as follows:

- In-line inspection devices may be adopted to find suspected but previously undetected tapings.
- Rigorous patrolling by multiple teams and night patrolling vehicles may be employed with support from law enforcement officials.
- Current attenuation test survey to detect these tapings.
- Stakeholder consultation and IEC activities shall be carried out to make people aware of the impact of illegal puncture on the downstream population.
- Installation of a sensitive leak detection system.

4.4.4.3 Tampering with Air Valves, Other Valves and Appurtenances

Tampering and physical damage to valves and other appurtenances should be always safeguarded. All appurtenances should have a cover in the form of chamber or a steel cage over them to prevent from any unauthorised accessibility.

The arrangement of safety-relief valves must be such that the possibility of tampering is minimised. If the pressure setting adjustment is done externally, the relief valves must have a way to seal the adjustment.

At points where the valve or appurtenances are located at a sagging point causing flooding due to leakage or accumulation of wastewater, they must be protected by constructing chambers high enough to avoid flooding and ingress of contamination into pipes caused due to intermittent water supply system.

4.4.4.4 Deterioration of Pipes

Pipes deteriorate on the inside because of water corrosion and erosion and on the outside because of corrosion from aggressive soil and water/moisture. Depending upon the material of the pipes, these are subject to some deterioration, loss of water carrying capacity, leaks, corrosion and pitting, tuberculation, deposition of sediment, and slime growth. Preventive maintenance of the transmission system assures the twin objectives of preserving the bacteriological quality of water carried in the transmission mains and providing conditions for adequate flow through the pipelines. Incidentally, this will prolong the effective life of the pipeline and restore the original carrying capacity. Some of the main functions in the management of preventive aspects in the maintenance of pipelines are assessment, detection, and prevention of wastage of water from pipelines through leaks, maintaining pipelines' capacity, cleaning pipelines, and relining. The topic of assessment of leaks is dealt with in detail in Section 11.8.2.1 of Chapter 11: Water Audit and Leakage Control, Part B, of this manual.

4.4.4.5 Flushing of Pipelines

Flushing is done to clean the transmission lines by removing impurities or sediment that may be present in the pipe; this is particularly essential in the case of transmission lines carrying raw water. Routine flushing of raw water pipelines is often necessary. It is advisable that a programme for flushing is prepared and followed so that water mains are flushed before the water quality deteriorates, and consumers start complaining. Since flushing is not the only solution to the water quality problems of a transmission system, proper operation of the treatment process and cleaning of service reservoirs supplying water to the transmission system shall also be planned along with the flushing of the distribution system. Flushing is usually done in low water demand when the weather is favourable. Prior planning and good publicity with the public will allow the flushing to proceed quickly and without confusion. While taking up flushing of pipes, care to allow air into the pipeline before flushing and purging out air systematically while refilling has to be done under the guidance of an experienced staff.

4.4.4.6 Restoration of Lining and Coating

The present trend is to use cast iron, mild steel, ductile iron, RCC, polyethylene, asbestos cement pressure pipe (ACP), and bar-wrapped steel cylinder (BWSC) pipes in the transmission system. Generally, the metallic pipes are provided with durable, smooth internal linings of concrete and cement mortar/epoxy lining so that their carrying capacity is not affected by use and age.

Still, there are several existing pipelines with a bare metal surface, such as CI or MS. With the passage of time, these pipelines deteriorate and require rehabilitation. In situ cement mortar lining of existing metal water mains is done and has been beneficial in the following areas:

i) Pipe carrying capacity has reduced due to tuberculation, and abrasion;

ii) Water quality is affected due to the release of corrosion products from the pipes into the water; and

iii) Leaks occur through joints and pipe walls.

4.4.4.7 Leakage Control

Leakage of water in transmission sytem occurs by way of leakage from pipes, joints and fittings, reservoirs and overflow of reservoirs and sumps. The objective of leakage control programme is to reduce to a minimum the time that elapses between the occurrence of a leak and its repair. The volume of water lost through each leak should be reduced by taking whatever action is technically and economically feasible to ensure that the leak is repaired as quickly as possible. To achieve this, the agency shall prescribe procedures for identifying, reporting, repairing, and accounting for all visible leaks. Identification of leaks can be done using various techniques such as leak noise loggers, hydrophones, accelerometers, leak noise correlation, manual listening sticks, and other methods like gas injection smart ball technique, parachute, robotic camera, etc. It will be beneficial for the agency if the procedures involve the conscious and active participation of the population served by the agency apart from its own staff. For detailed information, refer to Section 11.8.2.1 Part B, Chapter 11: Water Audit and Leakage Control and other methods discussed in Section 4.2.5 of this chapter.

4.4.4.8 Procedures for Reporting and Repair of Visible Leaks

The utility has to establish procedures whereby the population residing along the transmission mains can notify the visible leaks to the agency. The utility staff should provide security for the safety of their assets and carry out effective vigilance which can report visible leaks. The utility has to establish procedures for prompt repair of leaks and for attending efficiently and accurately to the leaks. Critical spots where leaks often occur must be identified, and appropriate corrective measures must be implemented. The format to report and repair of visible leaks are given in **Annexure 4.1**.

4.4.4.9 Procedures for Detecting Invisible Leaks

In case of transmission mains, the leaks become visible due to the high pressures. However, if it is necessary to identify the invisible leaks, procedures must be established to detect and locate non-visible leaks. The selection and procurement of equipment for the detection and location of leaks must take into account the cost- effectiveness and financial capability of the agency. Management has to process the data and evaluate the work on detection and location of leaks and for dissemination of the results and initiate actions to control the overall problem of water loss.

4.4.4.10 Encrustation and Corrosion

Corrosion is an electrochemical attack on the metallic pipes which results in loss of pipe materials at the place of occurrence and usually transported and deposited at the adjacent site. However, encrustation is an electrochemical reduction-oxidation (redox) reaction or precipitation process, which results in the reverting of specific dissolved compounds to a settleable solid deposited on the pipe’s internal surface. Corrosion including tuberculation and encrustation are one of the major problems, which results in leakage and sometimes bursting and reduction in discharge capacity of the transmission mains.

Corrosion of pipeline has also been reported when the pipeline is laid in soil having low soil resistivity.

Customer complaints are usually the first signs of a water system corrosion problem. The most common symptoms, along with possible causes, are listed in Table 4.4 below.

Table 4.4: Common Complaints with symptoms of corrosion problem and possible causes

Customer complaint	Possible cause
Red water or reddish-brown staining of fixtures and laundry	Corrosion of iron pipes or the presence of iron in raw water
Blackwater	Sulphide corrosion of iron lines
Foul taste and/or odours	By-products from microbial activity
Loss of pressure	Excessive scaling, tubercle build-up from pitting corrosion, leak in the system from pitting, or other types of corrosion
Short service life of household plumbing fixtures	Rapid deterioration of pipes from pitting or other types of corrosion

Complaints do not necessarily have to be due to corrosion. For example, red water can also be caused by iron in the raw water that is not removed during the process. Therefore, in some cases, further investigation may be needed.

It is generally desirable to collect water samples at the following locations within the system:

i) Water entering the distribution system (i.e., high-service pumping);
ii) Water at various locations in the distribution system prior to household service lines;
iii) Water in several household service lines throughout the system; and
iv) Water at the customer's taps.

A. Prevention of Encrustation

Encrustations are deposits that form in pipes due to a rise in temperature, presence of suspended material, and low water flow rate, which favours sedimentation and increase in the amount of hardness in the water.

The following solution may be adopted for this problem:

i) **Cooling water**: cool water will help in keeping from precipitation the salts while in transit. This may be achieved by providing a buried pipeline of the maximum possible length.
ii) **Modification of water quality:** Adequate treatment shall be given to water to soften it.

B. Prevention of Corrosion

Corrosion is induced by a chemical reaction between the pipe material and the water when they are in direct contact. As a result, there are three fundamental methods for preventing corrosion:

1. Modify the water quality so that it is less corrosive to the pipe material.
2. Provide lining to the pipe.
3. Use pipe materials and design the system so that it is not corroded by the water.
4. Use inhibitors and cathodic protection.

I. Cathodic Protection

Pipe in contact with water, soil, moist air, etc., are susceptible to corrosion. Cathodic protection is a method that successfully mitigates corrosion. IS 8062 (Part 2): 2006 deals with the general principles and requirements of cathodic protection system for prevention against corrosion of external underground buried surface of metallic high pressure hydrocarbon product pipeline/structure and guide for establishing minimum requirements for control of external corrosion on pipeline/structure system.

II. Linings, Coatings, and Paints

These linings are normally applied mechanically, either during the manufacturing process or before the pipe is laid in the field. Some linings can be applied in situ after the pipe has been put into service, although this is a far more expensive process. Coal tar enamels, epoxy paint, cement mortar, and polyethylene are the most prevalent pipe linings. Table 4.5 below discusses these linings and their use with advantages and disadvantages.

Table 4.5: Pipe Wall linings

Material	Use	Advantages	Disadvantages
Hot applied coal tar enamel	Lining for steel pipes (used in 50 to 80% of steel pipes in the distribution system)	• Long service life (>50 years) • Good erosion resistance to silt or sand • Resistant to biological attachment	• Need to reapply to welded areas • Extreme heat may cause cracking • Extreme cold may cause brittleness • May cause an increase in trace organics in water
Food Grade Epoxy	Lining for steel and ductile iron pipes (can be applied in the field or in a foundry)	Smooth surface results in reduced pumping costs	• Relatively expensive • Less resistant to abrasion than coal tar enamel • Service life <15 years
Cement Mortar	Standard lining for ductile iron pipes, sometimes used in steel or cast-iron pipes	• Relatively inexpensive • Easy to apply (can be applied in place or in the pipe manufacturing process) • Calcium hydroxide release may protect uncoated metal at pipe joints	• Rigidity of lining may lead to cracking or sloughing • Thickness of coating reduces the cross-sectional area of the pipe and reduces carrying capacity
Polyethylene	Lining used in ductile iron and steel pipe (applied at foundry)	• Long service life (50 years) • Good erosion resistance to abrasives (silt and sand) • Good resistance to bacterial corrosion • Smooth surface results in reduced pumping costs	• Relatively Expensive

Material	Use	Advantages	Disadvantages
Polyurethane	• Lining used in ductile iron and steel pipe (usually applied at manufacturer's works) • Suitable for Field application also • Fast curing, Self-priming, Two-component 100% solids (powder), quick setting. (AWWA C222)	• Long Service, better ageing resistance than epoxy • Highly inert and non-toxic with negligible leach rate allows use in drinking water systems • Good wear, erosion resistance to abrasives (silt and sand) • Good resistance to bacterial corrosion • Smoothest surface results in reduced pumping costs.	• Expensive • Stringent application procedure

III. Actions to address corrosion

Various steps will have to be taken to identify, locate, monitor, and implement control measures; the flow chart in Figure 4.7 explains the process in detail.

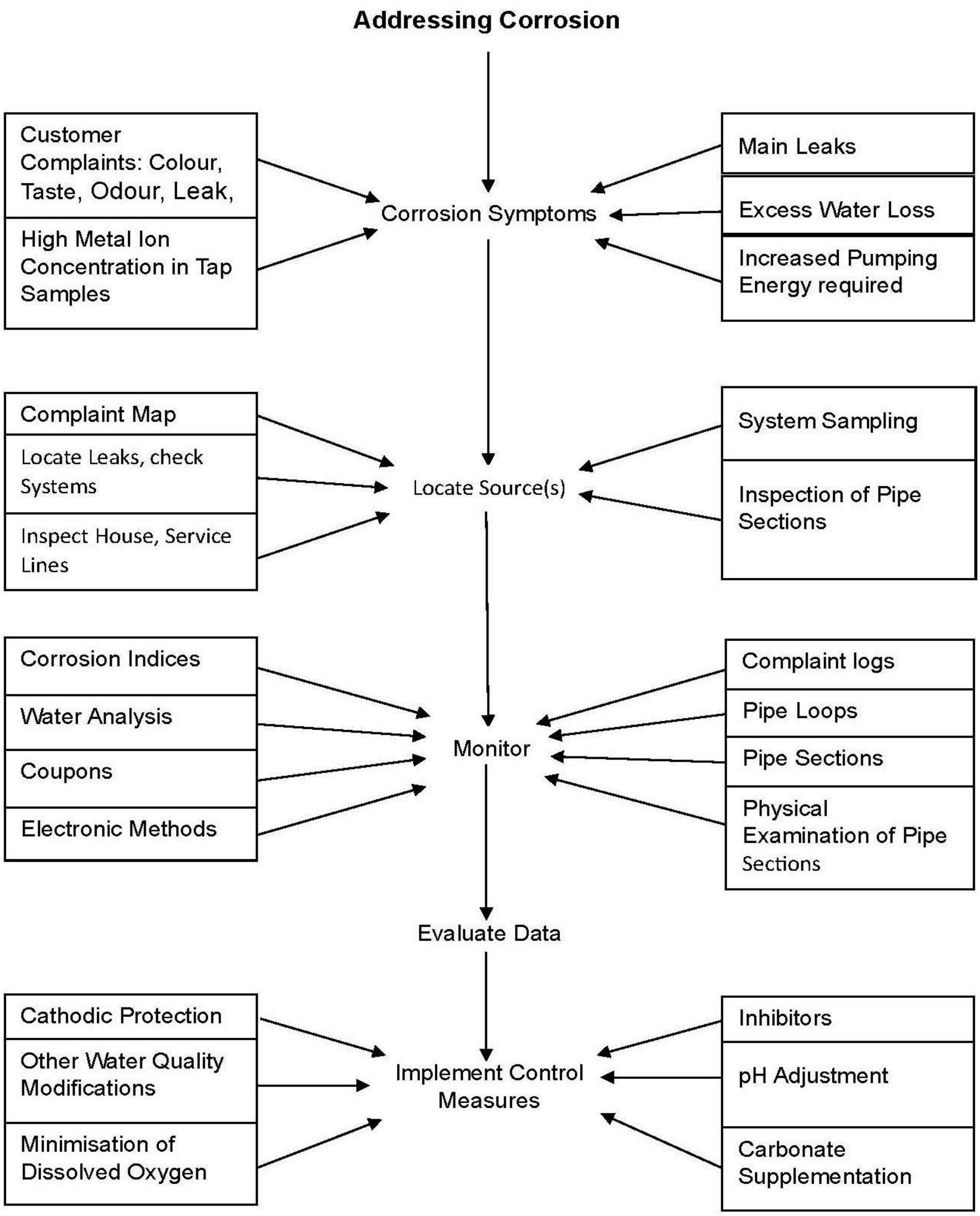


Figure 4.7: Schematic Flow Chart for Steps to Control Corrosion

4.4.4.11 Machinery to Clean the Pipes

Pipes/Pipeline cleaning methods depend on many factors like pipe materials, source and type of debris and incrustation, diameter, length, etc. The methods are categorised into three categories namely (i) Mechanical method (ii) Hydraulic method and (iii) Chemical method. The mechanical cleaning includes rodding, balling, chain scrapping or reaming, drag scrapping, etc. and are used to remove very hard deposits and incrustations; whereas the Hydraulic cleaning includes techniques like high pressure water flushing, jetting, pigging techniques including foam pigs, ice pigs, polyurethane, coated pigs, etc., and are used to remove loose debris and contaminants. The chemical cleaning technique involves use of chemical solutions like organic oxide scavenger which is mixed with a predetermined quantity of muriatic acid and circulated through an isolated sections of the transmission mains and kept for certain time before getting it washed properly by high pressure water. This technique does not involve time taking process of digging of the pipeline and help to restore old pipelines to optimise the flow at fraction of the cost of replacing the pipeline. Various emerging new technologies and equipment are available, like the equipment shown in Figure 4.8, which uses robotics and high-pressure cleaning methodology to remove corrosion, tuberculation, calcium, and scaling.

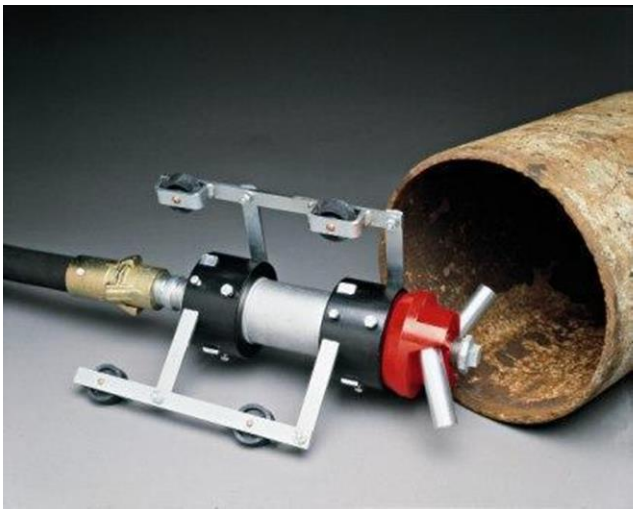


Figure 4.8: Machinery to Clean Pipe

4.4.5 Repair of Pipeline

It is one of the most important responsibilities of water supply service department to properly maintain the transmission and distribution mains in order to prevent waste and provide a constant pressurised flow of potable water to the consumers. It is equally important to prevent damage to the public property which could arise for not properly repairing a defective pipe. Proper planning and implementation of remedial measures will avoid leakages and breakdowns.

4.4.5.1 Repair Action Plan

Following general procedure may be followed:

a) Internal mobilisation
b) Detection of pipe failure: Inspection of site
c) Notification of interruption in water supply and related issues.
d) Location and demarcation
e) Repair planning
f) Repair work: Selection of most appropriate method for repair.
g) Testing of ‘dry’ repair
h) Restoration
i) Completion
j) Hygiene
k) Notice of restoration and completion

4.4.5.2 Implementation of Action Plan

A. Monitoring of Internal Mobilisation

Some of the important activities relating to the mobilisation of the internal activities are summarised below.

a) Senior Level Management
Necessary information to the Senior Level Management may be submitted and sought their interim approval. Details approval can follow in due course of time.

b) O&M staff of the running water supply system
The entire staff must be made fully aware of the likely activities required to be undertaken so as to ensure minimum possible interruption in the system.

c) Alternative arrangement
Alternative arrangement for water supply may be planned and duties of staff to be fixed accordingly.

d) Existing installations
The operation of the water supply system with regard to intake, head works, pumping machinery, treatment plant, pipe network, etc., must be co-related with the proposed repair work.

e) Mobilisation of men
Necessary staff may be arranged for the following duties;

(i) location of section;
(ii) isolation of section;
(iii) scouring of section;
(iv) arranging transport, material, machinery, equipment, tools, pipes, fittings, etc.;
(v) other miscellaneous duties.

f) Manpower, material, machinery, transport, lighting, safety measures, communication, pipes with fittings and specials etc. for the repairing operation.

These details are variable and depend upon various factors as per the local situation. Some of the factors to be considered are;

(i) the importance, utility, and function of the affected pipeline with the piping network. This may be the only feeder main of the system. It may be one of the two or many parallel feeder mains. It may be initial portion of the distribution system serving as the only main to supply water to the rest of the area to be served. It may be a distribution pipe serving only a part of the system;
(ii) size and material of the affected pipe: These are especially crucial factors which determine the magnitude of the repair to be undertaken;
(iii) depth of the pipeline. Deeper pipes require more labour work for repairing;
(iv) subsoil water table. If the pipe is laid much below the local water table, additional work will be required to dewater the trenches excavated for repair;
(v) other unforeseen factors.

Depending on these factors the requirement of workforce, material, machinery, tools, equipment, pipes, specials, fittings, etc., is to be worked out. Given below Table 4.6, Table 4.7, and Table 4.8 is an indicative list to meet the requirement of a big distribution main which is a life for the water supply system. This may be considered as a guideline only. Exact requirement may be worked out dependingupon the local conditions.

Table 4.6: Manpower

Designation	Number
Manager	1
Supervisor	1
Fitters	3
Welders	3
Crane operator	1
Excavator operator	1
Truck operator	1
Jeep operator	1
Emergency Van operator	1
Electrician	1
Mechanic	1
Helper	1
Semi- skilled	8
Pump operator	1

MATERIAL

Electrodes, Gaskets, Rubber insertion, Bolts and nuts, Gland rope, Manila rope, Pig lead, Cotton waste, Wooden sleepers, PVC hose pipe, Canvas hose, Engine oil, Wire slings, Grease, M.S. Plates, Diesel, Kerosene, Firewood, Cement, Sand, Spun yarn, Hard Crete, M seal, Sandbags and various HPDE/ PVC/DI/GI fitting and specials.

Table 4.7: Machinery

Machinery	Number
Crane	1
Excavator	1
Pump set (Electric)	2
Portable Diesel pump set	2
Welding generator	1
25KVA generator	1
Lighting generator	1
Welding set	2
Mud pump	2
Cutting set	2
Pressure Grouting machine	1
Flexible grinder	1
Hand drilling	1
Butt welding / Electro fusion for PE	1

Table 4.8: Transport

Vehicle	Number
Truck	1
Jeep	1

Vehicle	Number
Emergency breakdown van	1

TOOLS

Scour rod with lever, motor driven pipe cutter with extra cutters, H.T. wire cutter, sheet cutter, screw jacks, hammers, spades, buckets, baskets, crow bars, hammers, shovels, caulking tools (spun caulking, cement caulking, lead caulking), power wrenches 36 in. to 15 in., adjustable spanner 18 in. to 12 in., chain tong 36 in. long, ring spanner set, DE spanner set, screw drivers, cutting plier, knife, nose plier, knife, chisels, lead pan with sport and bucket, Temporary platforms, files, bench vice and pipe vice.

PIPE SPECIALS

All pipe specials to be anticipated and procured.

COMMUNICATION

Wireless set, mobile wireless set, cell phone.

LIGHTING

Flood lighting, tube light fittings, wire, three core cable, insulation tape, main switch, fuse wire, kit kats, welding cable, emergency lights, torch lights, gas lights.

SAFETY EQUIPMENT

First aid box, helmets, headlight, gum boot shoes, hand gloves (rubber, leather), gas masks, oxygen cylinder, and other PPE as required.

AMMENITIES

Tents, water cans, jugs and glasses, tarpaulins, electric heaters, raincoats, food (tea and snacks, meals)

B. Detection of Pipe Failure

a) Inspect site and ascertain the nature of the failure.
b) Assess any possible damage or dispute that may arise and take steps to face such situations.
c) Investigate the access to the site so as to plan the arrangement of plant and equipment.
d) Assess urgency of repair, availability of men and equipment, effect on consumers and fix time and day of repair.
e) Locate isolating valves for proper control of requisite activities required for repair work.
f) Depending upon the seriousness of the leakage or burst, the likely effect on the local supplies, decision may be taken on:
    i. maintenance of supplies as long as possible;
    ii. prevention of possible contamination of the pipeline; and
    iii. quick location of the actual position of the pipeline.
g) Establish control and communication network after deciding the time of repair work to be undertaken.

h) Ascertain the sensitivity of the affected area and take steps to avoid undesirable situations.
i) Issue notification and warnings of the likely interruptions.
j) Mobilise.

C. Notification

Notification and acknowledgements should be made wherever necessary. The location, type and extent, also time period of water supply shutdown should be notified for convenience of the consumers and operational staff.

Notices should be issued to the affected consumers and the departments looking after other affected facilities like telephones, cables, electric lines, etc. Such notifications may be done by mobile loudspeakers, hand bills, telephones, local media channels, social media and apps, etc.

The contents of the notification will be as under:

- time of closure and affected area;
- a brief and simple reason for interruption;
- an estimated time of restoration of supplies;
- contact point for any problems;
- advice on conservation, flushing, boiling, etc.

D. Location and Extent of Failure

The location and type of leakage whether joint leakage or pipe crack should be detected. Assessment regarding whether pipe needs to be replaced should be taken for prompt arrangement of leakage repairing. Labour and material should be kept ready accordingly at site for minimum time consumption in leakage repair.

a) Location of the failure
Make use of local knowledge, plan, and experience in locating the failure. Depending on the local conditions, if need be, leak detectors may be used.

b) Protective signs
Before undertaking any excavation work, all protective measures may be taken including signs, lighting, etc. Traffic rules must be complied with. All local utilities must be located and marked, and liaison kept with local representatives of these affected utilities.

c) Excavation
The conventional methods of excavation may be supplemented with more mechanised processes keeping in view the existence and location of the water main.

d) Shuttering and support
Pay due attention to safety below ground by providing support to trench sides and any exposed pipes and cables.

e) Extent of failure
The full extent of damage, both to pipe work and any support works, should be assessed.

f) Workspace
Ample workspace should be created to allow for:

i. Detailed inspection around the pipe;

ii. Provision of sump for continuous operation of a drainage pump;
iii. Movement of men with jointing material and equipment to be used safely and effectively.

g) **Provide safe dewatering system and discharge points**
The discharge of any dewatering apparatus should be checked to ensure free outflow and to avoid any danger or inconvenience caused by flooding.

h) **Control by Valves**
Ensure effective operation of repair work by proper control of valves which should be in perfect working condition.

E. Repair Planning

Considering the declining residual life of in-service pipelines and their future breakage rates, there is no doubt that repair programmes are necessary in order to prevent failure when a pipeline reaches the end of its useful life. Usually, repair actions are taken as a response to the detection of a leak, which results in the inefficient management of the allocated finance. Therefore, a repair planning should be undertaken to utilise available limited funds efficiently. The age of pipeline, frequency of leakage repair in the past years, pipeline condition, pressure, illegal tapping should be recorded and analysed for preparing a repair plan for the distribution network so as to reduce leakage thereby reducing NRW.

a. **Note details of existing pipe**
The full details of the failed pipe and/or fitting should be noted including material type, approximate age, class, and general condition. Reasons for failure should be established as accurately as possible and recorded. Check actual external dimensions of the pipe and determine any tendency to ovality for effective repair.

b. **Type of repair – wet or dry**
A "wet" repair is defined as a repair which can be achieved while maintaining a nominal pressure in the pipeline. Split collars or identical fittings can be installed in this way if the conditions are favourable.

A "dry" repair is defined as one in which the main is completely isolated and drained out. 'Cut out 'repairs necessitating the removal of a section of the pipe and/or joints will require "dry" main on which to work, and the pipeline should be drained out.

c. **Extent of repair work and availability of repair fittings and tool**
The replacement pipe and/or repair fittings should be selected, and their dimensions marked on the pipeline. For a "dry" repair a final check should be made that all the required fittings and materials are available and are compatible before any attempt to cut the same is made.

d. **Bedding material**
Assess and make available the bedding material if required.

e. **Report to Control**
When ready to start repair, inform "control".

F. Repair Work

Following factors to be considered while undertaking pipeline repair work:

(i) type and diameter of pipe to be repaired;
(ii) type of soil underneath, whether hard rock. Considering the type of soil, manual

or excavator should be selected;

(iii) type of leakage whether circumferential or joint failure;

(iv) time period required for repairing so that shutdown of water supply can be planned;

(v) whether the portion to be repaired can be isolated from the rest of the distribution system. This will help with an uninterrupted water supply in rest of the system.

a) Repair of small, local defects – “wet repair”

For small local defects such as pinholes a single split collar or wraparound clamp may be all that is required. The repair can be carried out as a “wet” or “dry” operation. In case of “wet” repair care should be taken to maintain a steady, gentle flow so as not to dislodge the sealing elements.

b) Cut out – “dry repair”

For more extensive damage, e.g., a longitudinal fracture, a section of pipe is cut out and replaced by the use of two appropriate couplers. If the full extent of the fracture is not clearly defined, cuts should be made at least 300 mm beyond each end of the visible crack or defect, and in case of any doubt, the full length of damaged pipe should be replaced. This necessitates cutting out the joint at both ends of the affected pipe, thus the repair normally requires two replacement pipe sections and three couplers.

c) Replacement repairs – following observations are important

i. Carry out correct measurements and give allowance for expansion.
ii. All cuts should be made clean and square.
iii. In A.C. pipes, cuttings should be avoided.
iv. All cut edges should be prepared (scraped, deburred, chamfered, etc.) to the manufacturer’s recommendations.
v. Both exposed ends of the existing pipe should be similarly treated.
vi. Couplers should have their sealing rings lubricated if recommended.
vii. Correct expansion gaps should be allowed.
viii. Good alignment is essential particularly if narrow couplers are used.
ix. All couplers and collars should be centralised.
x. Tighten all bolts evenly.
xi. Do not over tighten bolts or compression joints.
xii. Restore any damaged coatings on the parent pipe.
xiii. Ensure full protection to the bolts and any exposed bare metal before burial.

d) Record of repair

Log the works before, during and after the repair.

e) Record of pipe

Record the following items:

i. Any visible damage to the pipe;
ii. State of protective system or coating;
iii. Internal condition of the pipe;
iv. Depth of cover;
v. Description of the soil/backfill.

G. Testing of “Dry” Repairs

a) Give additional support to repaired pipe portion, if necessary

All wet slurry should be removed to the extent possible, and the bottom of the excavation should be filled and the exposed pipe work rebedded, with suitable material sufficiently compacted to give adequate support to the invert and lower quadrants of the pipe and any fittings.

b) Renew bedding and compact

Additional material may be placed to support the repaired pipeline when under test pressure, but it is advisable to leave all joints visible in case of leakage.

c) Arrange air bleeding and slowly refill isolated section

Refilling the isolated section of the main with water should be done slowly and from one direction only. Arrangements should be made for the expulsion of the air by means of any convenient air valves, hydrants, washouts or taps. The repaired pipe is subjected to a pressure equivalent to the normal working pressure. The repaired pipe should remain under such working pressure until it is adjudged to be satisfactory. Some minor re-tightening of the joints may be necessary due to slight expansive movement of the assembly on being subjected to increase in pressure.

d) Control – Report situation to “control”

H. Restoration

a) Restore valves and the system in accordance with the original operational plan

The repaired section of main is reintroduced to the system by restoring all valves to their original status.

b) Checking restoration

The restoration of the supplies to the normal situation supplied at important points should be checked.

c) Removal of temporary supplies

All standby pipes, temporary supplies and emergency tankers should be removed.

d) Notification

Notification and acknowledgements should be made wherever necessary.

I. Hygiene

During the execution of the repair work hygienic conditions must be made to prevail at various stages till the completion of work.

a) Site cleanliness

During the repair work the area should be kept as clean as possible. All debris and contaminants should be removed from the site and the contamination of the trench from plant, equipment or any other potentially hazardous materials must be avoided.

b) Storage of tools and equipment

All pipes, fittings, tools, equipment, and vehicles to be used on site should be regularly maintained and cleaned. Equipment used for disinfection and sampling should be kept for this purpose and regularly maintained.

c) Prevention of contamination during repair work

Clean and spray with disinfectant on all surfaces that come in contact with potable water including the broken main, repair fittings and replacement pipe. Ensure that the contaminants do not enter the main where it is cut for repair. After completing the repair, flush the main at the nearest hydrant to remove any dirt, etc.

d) Disinfection procedure

For small repairs which do not require the main to be cut, the fracture should be cleaned and this, along with the repair collar, should be sprayed with disinfectant. For more major repairs requiring cut out, every care must be taken to prevent contamination.

J. Completion

a) Finishing touches

Wherever joints have been left exposed for testing purposes these should be restored to their original position. The bolts, bare metal surfaces etc, should be properly protected prior to side filling.

b) Side filling work should be suitably accomplished

The dug material should be returned to the trench and placed in layers. The first side fill layer should be placed and compacted under the lower quadrants of the pipe and up to the springing level of the pipe. Successive layers of up to 100 mm thickness may then be placed and compacted to a maximum height above the crown of 250 mm. Light vibrating machinery may be used but not directly above the pipe or the fittings.

c) Clear site

On completion of the work all materials and protective barriers should be removed from the site and the working area left clean and tidy. All records should be completed and submitted.

K. Notice of Completion

Notice of completion or interim or permanent reinstatement must be given within a reasonable period. Location of works and other relevant details should also be given.

L. Specific repair to Pre-Stressed Concrete Pipes

The most difficult and time-consuming repair problems relate to PSC pipes, particularly the bigger diameter pipes. Some of the cases connected with the damage and leakage of such pipes along with their suggested methods are discussed below:

i. **Extensive damage to pipeline:** Sometimes the damage is so extensive that the entire length of a pipe needs replacement. The replacement is done by inserting a steel pipe which shall be fabricated in three pieces. One piece shall consist of a spigot machine end, another of steel shell and the third a spigot machine end. The middle portion shall be of steel barrel with integral manhole. This manhole may be meant for temporary use only to be covered and rewelded suitably after the repairing operation has been satisfactorily carried out. The thickness of steel plate used for this purpose shall be equal to the design thickness plus 2 mm extra to take care of corrosion. A minimum of 10 mm may, however, be used. The burst pipe may be broken by taking due precautions and replaced with this set of three pieces. The two machine ends shall be fixed as per the normal procedure for laying PSC pipes. The steel barrel shall be introduced in between and duly welded internally and externally.

ii. **Damage restricted to a small length only:** Sometimes the damage is along a length of 1 m to 1.5 m only and the remaining portion of the pipe remains in a sound condition.

To make the damaged portion functional, two plain M.S. barrels shall be inserted into the pipe, to suit the internal diameter with a gap of 25 mm on either side of the pipe, 50 mm less than the internal diameter of the pipe, to facilitate jointing with jute and cement mortar. The barrels shall have two 12 mm diameter M.S. rings to fix over the shell at the ends. At least 500 mm of overlap on either side of the pipe, lengthwise, is provided for jointing. After following the normal procedure (as already discussed at length), break the damaged portion of the pipe to the extent (length wise) of cracks developed in the pipe for more than half of the pipe (diameter wise).

iii. Cut the H.T. wires core reinforcement.
iv. Clean the pipe internally, remove the broken debris and dewater the pipe.
v. Insert one piece of the M.S. barrel, duly fabricated with a temporary manhole for entry into the pipe for internal caulking, welding, etc.
vi. Shift barrel to one side to facilitate the insertion of the second barrel.
vii. Join the two pieces and weld the joint internally and externally.
viii. Keep the barrel in position by covering the damaged portion duly keeping at least 500 mm of overlap for jointing with P.S.C. pipe.
ix. Insert the M.S. ring at the ends and place at 150 mm from the outer ends of the barrel sand tag weld the rings to the barrel to caulk the jute firmly.
x. Caulk both the ends of the barrel with spun yarn for three layers and with cement mortar 1:1 duly mixing quick setting cement solution.
xi. Clean the pipe internally and paint with epoxy paint.
xii. Leakage through socket joint due to displacement of rubber joint: The joint has to be exposed. A medium leakage can be attended without taking the shut down by pushing the rubber gasket to the original position with the help of wooden caulking tools and also inserting lead pieces in the joint. Afterwards, caulking with cement mortar 1:1 will further strengthen the joint. The entire joint has to be caulked with cement mortar.
xiii. Leakage through damaged socket joint: Such leakage can be attended only by taking shut down and draining the pipeline. The joint shall be exposed by excavating the trench around the joint. The crack and joint shall be filled with lead wool, quick setting cement mortar and the stepped split collar fixed over the joint and filled with cement slurry or cement mortar mixed with quick setting solution.
xiv. Leakage through circumferential crack: Such leaks can be attended by providing split collars after arresting the leakage through crack either on running line or by availing shut down. Materials required for attending the leakage are lead wool, M seal, cement mortar, special adhesives like araldite and plain split collar.
xv. Leakage through hole: The hole can be covered with a plate and bolted to a flat inserted through the hole. The hole shall be covered with a lead washer under the plate and annular gap to be filled with m-seal compound or other suitable sealing material. If the hole is very close to the joint, a plane cover or a stepped split collar can be fixed and caulked with cement mortar after caulking the joint with lead pieces or lead wool.

4.4.6 Repair Method for Different Types of Pipes

Common failures are listed below, and action & resources required for different types of pipes are given in Table 4.9:

1. Joint failure
2. Brittle failure
3. Corrosion

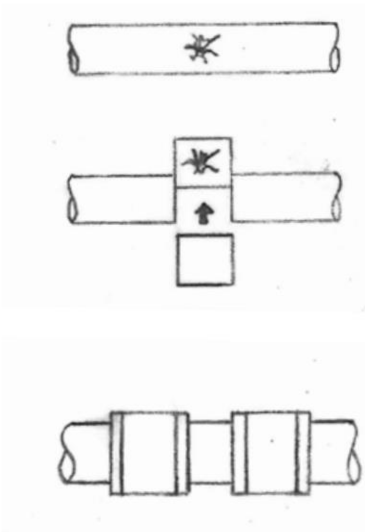
4. Pin holing
5. Ductile failure
6. Extensive pin holing
7. Localised pin holing
8. Isolated pin holing
9. Surface softening
10. Fast crack propagation

Table 4.9: Failures, Actions, and resources needed for different types of pipes

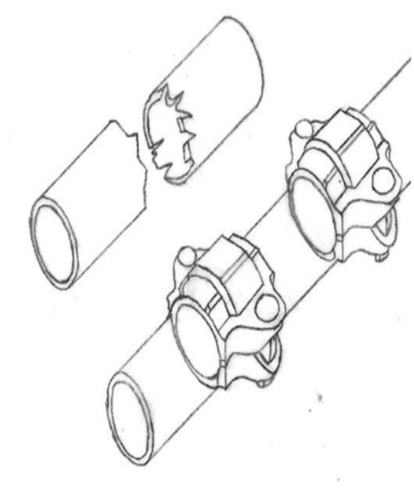
S. No.	Pipe Material	Failure	Action	Resources
1.	**Galvanised Iron**	1,2,3,4 and 5	Remove section / joint	• For Smaller pipes: one union, short piece and new section • For larger pipes: CI/DI adaptors, couplings, and new section
2.	**Cast Iron**	1	Enclose joint Two couplers	Special joint clamp, two couplers, and new section
		2 and 3	Remove section/joint Rehabilitation technique Enclose failure	Two couplers and new section Slip lining, etc. Repair collar or clamp
3.	**Ductile Iron**	1	Enclose joint Remove section/joint	Special joint clamp, two couplers, and new section
		6	Rehabilitation technique Remove section/joint	Slip lining, etc., two couplers and new section
		5	Remove section/joint Enclose burst	Two couplers and new section. Repair collar or clamp
		7	Enclose burst	Repair collar or clamp
4.	**Mild Steel**	6	Rehabilitation Technique Remove section/joint	Slip lining, etc., two couplers, and new section

S. No.	Pipe Material	Failure	Action	Resources
		1	Remove section/joint Enclose joint	Two couplers and new section, Special joint clamp
		8	Enclose burst	Patch and weld, Repair collar or clamp
5.	**Pre-Stressed Concrete**	9	Remove complete length/joint Enclose joint	Two couplers/ MS socket spigot pieces and new pipe section, Special joint clamp, MS Barrel pieces
		1		
		2	Remove damaged section Enclose burst	
		1	Cut out joint	
5.	**Asbestos Cement Pressure Pipe**	1 & 2	With light hammer, Remove section /joint	Replace the affected ACP Pipe & AC Coupling with new full length ACP pipe and CID joints
6.	**P.E. Pipe**	1 & 2	cut the damaged pipe section/joint and remove	(a) Replace damaged section of pipe and joint by a new pipe or pre-fabricated flanged replacement section. (b) For welded jonts, connect new pipe to either ends of the old pipe by inserting type of fittings (subject to their pressure limitations) and by electro-fusion fittings.
7	**U-PVC, PVC-O, CPVC Pipe**	1 & 2	cut the damaged pipe section/joint and remove	Replace damaged pipe & coupling with new pipe with a spigot at each end and two double-socket repair couplings also called slip-coupling or with a length of socket pipe and one double-socket repair coupling.
8.	**Bar Wrapped Steel concrete pipe**	3,4,7,8	(a) Scrap concrete from and around the leaky portion (b) Drill the hole in leaky portion	1. Fit a fabricated Repair Sleeve over the damaged section to repair and reinforce damaged concrete steel cylinder pipe of all sizes. 2. Hot Tapping – Insert and weld a valve or fitting after drilling.

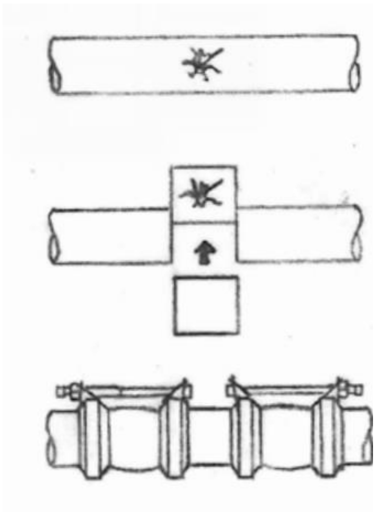
S. No.	Pipe Material	Failure	Action	Resources
				Close and seal the Valve or fiting. 3. Line stopping or line plugging – Identify the line stopping location on the pipe upstream. Insert a line stopping fitting or plug through a hot tap connection.
9	**GRP pipe**	1 & 2	prepare the pipe surface roughness to about 60 microns also inscribing lines on the surface in various directions for high bonding adhesion of epoxy coating	Prepare a suitable amount of underwater epoxy stick and suitable length of stainless-steel pipe clip. Mix the epoxy stick and tighten the pipe clip beside the pipe leak. Slide the stainless-steel pipe clip and tighten the adjustable fastener of stainless steel clip slightly onto the leak location.



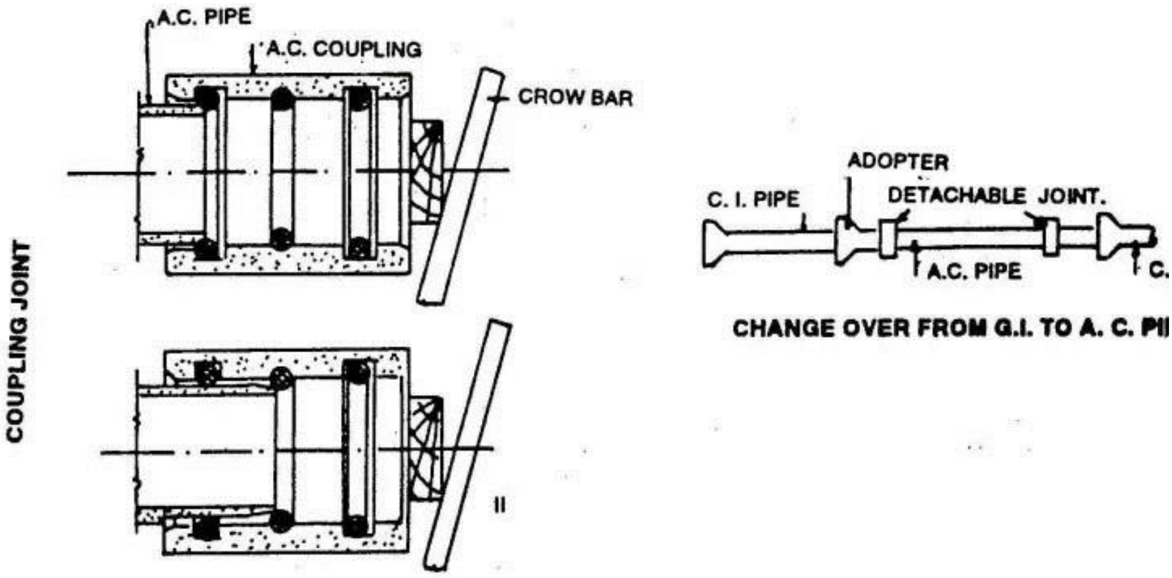
a) Repair of PVC pipe with couplers



b) Coupling arrangement for metallic pipes



c) Repair of metallic pipe with couplers



d) ACP Pipe repair

Figure 4.9: Typical repairs in PVC and metallic pipes

4.4.7 Monitoring System Manual Monitoring

Normally the managers of O&M of water utilities monitors levels in different service reservoirs fed by the transmission system and the flow meter readings of upstream and downstream reservoirs connected by a transmission system. The pressures of the pipeline at critical points are also monitored. Data on the operation of pumps, such as hours of pumping and failure of pumps, and on water quality by measuring residual chlorine is also monitored. The manager gathers the data, analyses the same, uses their discretion gained with experience and takes decisions to ensure that the system is operating with the required efficiency. These days acquisition of such data by Telemetry and SCADA, IoT is being adopted, which is discussed in the approved advisory on "Water Meters, Instrumentation & SCADA," published in June 2020, which is available on the website of MoHUA and in Chapter 10: Automation of Water Supply System in Part B of this manual. The Digital Twin Technology can be used to analyse data.

Online sensor monitoring

Online sensor monitoring system in water transmission networks is a technology that allows for continuous monitoring of water quality and network performance in real time. This system comprises a network of sensors and communication devices installed at various locations throughout the water transmission network, such as pump stations, valves, and reservoirs.

The sensors in this system can monitor a wide range of parameters, such as water pressure, flow rates, temperature, pH levels, and chlorine levels. The data collected from these sensors is then transmitted to a central data management system (SCADA and Digital Twin), where it is analysed to provide insights into the network's performance and detect any abnormalities or potential issues.

One of the main benefits of this system is that it enables water utility operators to identify and address network issues proactively. For instance, if the system detects a drop in water pressure, the operator can quickly identify the location of the issue and take corrective action to prevent further damage.

It can also help to improve water quality and reduce the risk of contamination. For example, if the system detects a change in pH levels or chlorine levels, the operator can take corrective action to adjust the chemical levels and maintain the water quality standards.

This system ensures the efficient and reliable operation of the networks and ensures the delivery of safe and high-quality water.

4.5 Records and Reports

The records of operation are to be maintained for efficient monitoring and decision- making. The following paragraphs explain the recording of the hydraulic parameters and operational activities. The most efficient way to keep and maintain records and report the same is to plan what data is essential and then prepare the various formats followed by the persons to fill the data, frequency and to whom the record is to be sent for review and report. Management Information System (MIS) and CMMS can be developed and implemented.

4.5.1 Record of Flow, Water Levels, and Pressures

A. Gravity Channels and Pipes

A record is kept at the transmitting and receiving reservoirs about the valve operations, water levels, and flows. Flow meters are installed at the start and end points of transmission channels/pipes for monitoring txdhe flows. Water levels in the reservoirs from which the channels/pipes transmit water and water levels in the receiving reservoirs are measured by visible gauges or automatic instruments.

B. Pumping Transmission Mains

Water levels in the sumps from which the water is being pumped are measured. Critical points are selected in the transmission system for pressure monitoring by installing pressure recorders and gauges. In the pumping systems, whenever water pressure in the pumping station drops below the designed system pressure, the operators are alerted to search for possible leaks in the pumping system. Similarly, at the receiving end, if the required water levels are not building up at the storage reservoir, it indicates that the required quantity is either not pumped or there may be leakages en-route. At times whenever the maximum levels in the receiving reservoirs have reached, the pumps will have to be stopped, or the outlet valves of the reservoir have to be opened.

4.5.2 Operational Records

A record system that should be realistic and applicable to the operating problems involved in the transmission system must be developed. Management must be clear as to why the data/information is collected, who will review the data, and who will respond to the results of the review. The most efficient way to keep records is to plan what data is essential, prepare the formats followed by guidelines, fill in the data and frequency, and send the record for review and report. Sample records to be maintained are given below for guidance.

i) updated transmission system map with alignment plan and longitudinal section of the pipeline showing the invert levels and hydraulic grade lines of the pipelines and location of appurtenances, flow meters, and pressure gauges;
ii) record of flow meter readings at upstream and downstream ends of the transmission system;
iii) record of water levels of the reservoirs at both upstream and downstream ends of the transmission system;

iv) pressure readings of the transmission system pipelines;
v) review of record of pressures and flows;
vi) identify the persistent low pressures in the transmission system;
vii) record on the age of pipes/quality of pipes;
viii) identify pipelines to be replaced;
ix) presence of corrosive water in the system;
x) identify the source of leaks;
xi) identify the persistent leak points;
xii) status of bulk meters – functional;
xiii) identify the residual chlorine levels at the receiving and transmitting ends of the transmission system;
xiv) identify the bacteriological quality of the water sampled from the reservoirs linked to the transmission system;
xv) identify reasons for residual chlorine being absent/where bacteriological samples are unwholesome;
xvi) record when the pipeline leaks were repaired, or pipes changed, and the cost of materials and labour cost thereof;
xvii) record on when the gland ropes of the valves were changed and the cost of materials and labour cost thereof;
xviii) record on when the spares of the valves were changed and the cost of materials and labour cost thereof;
xix) record on when the expansion joints were serviced and the cost of materials and labour spent for repairing the same;
xx) record when the manholes on the valve chambers were changed, and the cost of materials and labour cost thereof;
xxi) record on man-hours spent on routine operations in the transmission system in the previous year and the cost thereof;
xxii) record on the total cost of repairs and replacements in the previous year along with the breakup of material cost and labour cost with the amount spent on outside agencies for repairs and replacements.

4.5.3 Record of Deficiencies

With the accumulation of all essential data from the MIS and CMMS, reports can be generated/prepared to evaluate the O&M of the facility. Various types of reports can be generated/prepared with respect to the need of the operational people, department, or management. The report can identify the deficiencies in the system and its appurtenances and then plan future repairs to the transmission system, valves, and other equipment or for replacement of defective valves or other equipment.

CHAPTER 5 : WATER TREATMENT PLANT

5.1 Introduction

Water treatment is a very crucial step in delivering 24×7 Pressurised Water Supply System with “Drink from Tap”. The water source availability and the quality of source raw water governs the selection of treatment method to be adopted, so as to adhere to the drinking water quality as prescribed in IS 10500.

The objective of water treatment is to produce safe and potable drinking water. But poor operation and maintenance (O&M) practices have on many occasions largely contributed to decreased utility or even to an early failure of newly constructed water treatment and supply facilities. Thus, the health and social benefits for which the facilities were designed and implemented have not been realised. Capital investments have been wholly or partially lost and resources are expended on the premature replacement of equipment or the rehabilitation of facilities before they have been in operation for the full span of their useful lives. Hence, proper O&M is very essential for deriving the benefits continuously from the investments made.

This chapter deals with the details involved in the efficient O&M of individual process units of the water treatment system and water treatment as a whole, which is necessary for the trouble-free unit operation and processes on 24×7 basis to achieve “Drink from Tap”.

Water Treatment Plant (WTP) operation refers to the regular “running” of water treatment processes under normal or emergency conditions to make treated water available daily for 24 hours. WTP maintenance is defined as the art of keeping the structures, equipment and the plant as a whole in an optimum working order and proper functioning without any foreseen interruption.

Maintenance involves (a) scheduled or planned activities under normal operating conditions to maintain water treatment process units, including their associated equipment and assets essential to suitably treat the water for further disinfection and supplying safe water to consumers; and (b) unscheduled activities during unforeseen or emergency situations to bring the water supply system back to its normal operating conditions. There are two types of maintenance, viz., preventive maintenance and corrective maintenance.

Preventive maintenance constitutes routine works and precautions to be taken periodically to prevent the system from malfunctioning by mechanical adjustments, repairs, corrective actions, and planned maintenance.

Corrective maintenance involves carrying out works related to breakdown, which has actually occurred by replacements, correction of defects, etc.

Preventive maintenance is more economical than corrective maintenance and it provides uninterrupted service and avoids the need for corrective maintenance.

The O&M activities for the WTP require engagement of operational and maintenance personnel that basically includes the plant-in-charge, plant supervisor, process controller/operator, and maintenance staffs such as mechanics, electrician, water sample collector, etc., including in-house and contracted labours.

5.2 Basic Duties of O&M Staff

1) Assess raw water quality, as well as the quality of water from individual unit processes and treatment plant as a whole, to ensure that final water of the required quality is produced and

supplied to the taps of the consumers.

2) Understand the implications to consumers and other stakeholders if substandard water is produced and supplied.
3) Calculate and make adjustments to dosages and operating parameters in response to changes in raw water quality or other requirements.
4) Assess the performance of unit processes and the plant as a whole.
5) Identify potential causes of poor performance of unit processes.
6) Optimise the performance of unit processes and the plant as a whole.
7) Perform basic management tasks including water loss assessment & control, safety management and oversee treatment sludge dewatering, thickening & safe disposal.
8) Maintain records.

5.3 Flow Measurement in Open Channels

The measurement of flow in open channel is very important and crucial in operating various process in WTP to monitor and control the process. Flow measurement is also an important aspect of knowing the quantum of raw water entering the treatment plant either for auditing or calculating the losses in the process.

Ever since the development of the Parshall Flume (Parshall, 1926), continuous improvements have been made to simplify, reduce cost, increase accuracy, and reduce head losses in open channel flumes. Simple flumes do not require extensive upstream transition reducing the amount of materials needed and the cost for construction. They produce minimal head loss and are self-flushing and do not accumulate sediment often found in weirs or even in traditional weirs in low-gradient conditions. Simple flumes have been found to be an attractive and accurate option to consider when measuring flow.

The details of various flow measurement methods are discussed in Section 8.4 of Chapter 8: Water Treatment in Part A of the manual.

5.4 Treatment Process Units

The following processes generally form the treatment system:

1) Screens
2) Aeration
3) Pre-chlorination
4) Pre-sedimentation
5) Coagulation and flocculation
6) Clarification or sedimentation
7) Filtration
8) Disinfection
9) Other specific treatment processes, if required
10) Sludge Management

The above treatment process units have been explicitly described with fundamentals and design in Chapter 8: Conventional Water Treatment, Chapter 9: Disinfection and Chapter 10: Specific Water Treatment Processes of Part A manual and described in brief as follows.

5.4.1 Screens

Screens installed just before the pre-sedimentation process unit, screen out and remove large solids, logs, branches, twigs, rags, fish, floating objects, etc., in a very simple process called screening and incorporates mechanised trash removal system. This is necessary unit to control and ensure effective operation of sedimentation unit and lesser chemical uses during further down the line processes. This also ensures protection of pumps and pipes in WTPs.

In the case of hand raked screens, the screens should be raked at least hourly. Screenings should be allowed to drain for an hour, until the screen is raked again. Surfaces on which screenings have been deposited should be hosed down on daily basis in such a way that wash water flows back. There is often more than one grit channel or grit removal hopper. Grit channels should be taken out of operation at least once a day, drained and the grit deposited onto drainage platforms. The total flow should be read daily at the same time and recorded.

5.4.2 Aeration

The process of absorbing oxygen from air is known as aeration. All aerators are designed to create a greater amount of contact between air and water to enhance the transfer of gases and increase oxidation. Aeration is an in-line point-of-entry process that reduces the concentration of volatile organic compounds (VOCs). Aeration also removes dissolved gases such as hydrogen sulphide, radon, and some taste and odour problems such as methane.

It is also effective in precipitating dissolved iron and manganese. Aeration oxidises dissolved iron, although the resulting iron particles can foul the packing material in some aeration devices. Aeration raises the pH of water. Aeration is not effective for removal of heavy metals or pathogenic (disease-causing) organisms like bacteria and viruses.

Aeration devices range from a simple, open holding tank that allows dissolved gases to diffuse into the atmosphere to a more complex aeration system that has a column or tower filled with packing material. As water passes through the packing material, the gases are released. The details are discussed in Section 8.3 of Chapter 8: Conventional Water Treatment in Part A of the manual.

5.4.2.1 Problems with Aeration

Aeration typically raises the dissolved oxygen content of the raw water. In most cases, this is beneficial since a greater concentration of dissolved oxygen in the water can remove a flat taste. However, too much oxygen in the water can cause a variety of problems resulting from the water becoming supersaturated. Supersaturated water can cause corrosion (the gradual decomposition of metal surfaces) and sedimentation problems. In addition, air binding occurs when excess oxygen comes out of solution in the filter, resulting in air bubbles, which harm both the filtration and backwash process. Aeration can also cause other problems unrelated to the supersaturated water. Aeration can be a very energy-intensive treatment method, which can result in overuse of energy. In addition, aeration of water can promote algal growth in the water and can clog filters.

Waterfall/multiple trays and cascade aerators are prone to slime and algae growth on the surface which would require cleaning and periodic treatment with copper sulphate, with or without lime, to kill algae growth. Cascades maintained in a clean condition will ensure that maximum water surface and agitation are provided. Spray and diffusion aerators are required to be maintained by cleaning the pores of tubes, nozzles, and ancillaries, which may become partly clogged either from dust in the compressed air or from the collection of sediment on the outside surfaces. Aeration systems specifically those with fine bubble diffusers may require routine but usually infrequent maintenance.

5.4.2.2 Monitoring of Aeration Process

- Air volume look at amp draw from blowers: If the plant doesn't have flowmeter so long as pressure has been constant.
- Blower discharge pressure: Have a pressure gauge installed at the blower discharge but also try to monitor pressure as close as possible to the aeration system, either in drop pipes or using sensors inside of the submerged piping. The operator may be able to address rising pressure with a cleaning system.
- Bubble pattern: Monitor this visually but bubble pattern can be analysed with appropriate tool if obtained from the technology provider. Print a report and save it for comparison later on.
- Condensate purging: The operator should set a schedule to open purge valves, if using airlifts for condensate removal. Have a look here in case operator don't know which kind of purge system is installed by the manufacturer.
- Solids: Some plants collect grit on the floor. Periodically operator may want to use a sludge judge or ultrasonic sensor to detect floor sludge levels.
- Equipment: Submerged aeration equipment does age. Plastic gets brittle and rubber can stretch, shrink, or harden. Support stand nuts, straps or anchors can come loose. It's usually a good idea to catch these things before they happen. Install sensors or drain the tank periodically for inspection.

Aerators with multi-unit options are easy to maintain and clean without shutdown; while a single unit of aerator (particularly in small capacity treatment plants) requires a necessary shutdown with all necessary advance action to store treated water so as to avoid longtime disruption in water supply. When aeration units are shutdown, appropriate cleaning with detergents or acid brush wash should be attempted.

Clogging of diffuser plates could be minimised by,

i. Maintaining air filters in effective operation;
ii. Not over-lubricating air compressors and blowers;
iii. Maintaining air pressure on diffusers when compressors are shut down.

5.4.3 Pre-chlorination

Pre-chlorination is commonly used after screening and before flash mixing to (a) minimise operational problems associated with biological growth as well as taste and odour control during drinking water treatment; and (b) oxidise micropollutants into intermediate by-products. Pre-chlorination increases safety in disinfecting heavily contaminated water.

The details of pre-chlorination are described in Section 9.8.1 of Chapter 9: Disinfection, Part A manual.

5.4.3.1 Problems of Pre-chlorination

One of the problems associated with chlorination is the formation of chlorinated by- products such as trihalomethanes (THMs), which have been shown to have negative health effects and for this reason, the concentration of THMs is controlled at very low levels in drinking water. It is important, therefore, to control chlorination dosages and to pretreat the water before chlorine contact to remove organic material in the water to low levels. The details of chlorine disinfection processes are described in Section 9.5 of Chapter 9: Disinfection in Part A of the manual.

5.4.4 Pre-sedimentation

Purpose: Pre-sedimentation is a preliminary process to reduce heavy sediments prior to subsequent treatment process such as coagulation, flocculation, sedimentation, filtration, etc.

The details are described in Section 8.2 of Chapter 8: Conventional Water Treatment, Part A Manual.

5.4.4.1 Pre-sedimentation Tanks

I. Earthen Lagoons/Raw Water Settling Ponds

The details are described in Section 8.2 of Chapter 8: Conventional Water Treatment, Part A Manual.

II. Concrete Basin Clarifiers

The basic maintenance of these ponds and basins is periodical removal of accumulated silts by only mechanical method as mechanical sludge removal provides an easy and consistent method to remove solids.

The input water turbidity suddenly increases during rainfall and is not predictable, therefore it is necessary to service the tank in heavy rainfalls. If pre-sedimentation tank is not used in flood condition, the water turbidity will increase, so too much turbidity enters to filters. This problem causes to decrease interval backwash time.

The pre-sedimentation tank or basin would not require to be serviced due to low turbidity. If the water turbidity is 30 NTU, it can be prevented to consume additional energy and basin depreciation. It is suggested that pre- sedimentation tank should be put in-line only during flood time. For manual cleaning of pre-sedimentation tanks, minimum two units are required.

5.4.5 Coagulation and Flocculation

Agglomeration of colloidal and microparticles into settleable floc by ensuring multiple contacts of solids.

5.4.5.1 Coagulants Used and Coagulant Dosage

Although there is some relation between turbidity of the raw water and the proper coagulant dosage, the exact quantity can be determined only by trial conducted with Jar Tests. Even thus determined, the amount will vary with other factors such as time of mixing and water temperature. The use of the minimum quantity of coagulant determined to be effective in producing good flocculation in any given water, will usually require a fairly long stirring periods varying from 15 to 30 minutes in summer and 30 to 60 minutes in the colder months, as water temperatures approach the freezing point. Addition of coagulants in excess of the determined minimum quantity may increase bactericidal efficiency. It is, however, usually more economical to use the minimum quantity of coagulant and to depend on disinfectant for bacterial safety.

Very finely divided suspended matter is more difficult to coagulate than coarse particles, necessitating a larger quantity of coagulant for a given turbidity. The cation- exchange capacity of the particles of turbidity bears a significant relationship to the success of flocculation. Advance techniques for determining the dose of coagulant are by measuring "Zeta Potential" of the particles. The surface charge, or more importantly zeta potential (æ), is determined by measuring the particle velocity induced when a potential difference is applied across a capillary cell containing the sample (Zetasizer, Malvern Panalytical). Zeta potential affects the size and density of flocs formed. Increases in density cause more rapid flocculation. Low zeta potentials reduce the electrostatic interactions between particles allowing the particles to approach closely and hence produce more compact flocs. At zeta potentials more negative than -22 mV, the effluent turbidity rises sharply as the suspended particles become effectively stabilised in the water due to mutual repulsion. The characteristics of water especially pH have considerable influence on the satisfactory formation of flocs. Some natural waters need certain adjustments in acidity or alkalinity of water.

5.4.5.2 Optimum pH Zone

There is at least one pH zone for any given water in which good flocculation occurs in the shortest time with a given dose of coagulant, or in a given time with the required minimum dose of coagulant. Coagulation should be carried out within this optimum zone using alkalis and acids for correction of pH, wherever necessary. For many waters, usually those which are low in colours and well buffered and having pH in the optimum zone, no adjustment of pH is necessary. However, in waters of low mineral content, or in the presence of interfering organic matter, constant attention is needed for pH adjustment. Failure to operate within the optimum zone, may be a waste of coagulants and may be reflected in the lowered quality of the plant effluent. As a result of studies of the effect of pH on coagulation, it has been found that "the more dilute the water in total dissolved solid (TDS) and the less the Aluminium Sulphate (alum) added, the narrower becomes the pH zone".

In the case of coagulation with alum, the control over the alkalinity is very important. Not only should the water contain sufficient alkalinity to completely react with the aluminium sulphate but there should be a sufficient residual to ensure that the treated water is not corrosive. A consideration of the reaction involved shows that one molecule of "filter alum" (molecular weight of $Al_2(SO_4)_3.18\ H_2O$ = 666 requires three molecules of calcium bicarbonate $[Ca(HCO_3)_2] \times 3$ = 486 for complete reaction).

If the alkalinity is expressed in terms of calcium carbonate, the theoretical requirement of 666 parts of "filter alum" works out to 300 parts of alkalinity, i.e., approximately in the ratio of 2:1. This reduction of alkalinity should be taken into consideration and sufficient alkalinity should be added to the water, if necessary. For this purpose, hydrated lime ($Ca(OH)_2$) is usually added or "soda ash" (Na_2CO_3) may be used when the increase of hardness is to be avoided.

When ferrous sulphate is used as a coagulant, the pH should be maintained above 9.5 to ensure complete precipitation of the iron. This is done by the addition of hydrated lime. For this reason, the process is sometimes known as "iron and lime process".

5.4.5.3 Coagulant Aids

Coagulant aid is a coagulant, which when used along with main coagulant, improves or accelerates the process of coagulation and flocculation by producing quick- forming, dense, and rapid-settling flocs.

Finely divided clay, fuller's earth, bentonites, and activated carbon are the most commonly used materials as nuclei for floe formation. The particles may become negatively charged making them subject to attraction by the positively charged aluminium ion.

Activated silica, i.e., sodium silicate activated with aluminium sulphate, sulphuric acid, carbon dioxide or chlorine, when applied to water, produces a stable solution having a high negative charge which unites with the positively charged alum or another floc to make it denser and tougher. It is especially useful for clear waters that do not coagulate well with the usual processes. It has a wider range of uses in water softening.

Polyelectrolytes which are polymers containing ionisable units have been used successfully as both coagulant aids and coagulants but care should be taken to guard against their toxicity. They are soluble in water, conduct electricity, and are affected by the electrostatic forces between their charges. Cationic, anionic, and ampholytic polyelectrolytes have been used with the cationic being able to serve as both a coagulant and coagulant aid, while the other two as coagulant aids primarily polyelectrolytes create extraordinarily slippery surfaces when spilled on floor and are difficult to clean up.

Toxicity of any polyelectrolyte has to be checked before it can be used as coagulant or coagulant aid.

5.4.5.4 Choice of Coagulant

In selecting the best coagulant for any specific treatment problem, a choice has to be made from among various coagulants, each of which may offer specified advantages under different conditions. The common coagulants used in water works practice are salts of aluminium, viz., filter alum, poly-aluminium chloride (PAC), sodium aluminate and liquid alum and iron salts like ferrous sulphate (copperas), ferric sulphate, ferric chloride, and chlorinated copperas, which is an equimolecular mixture of ferrous sulphate and ferric chloride being obtained by chlorinating ferrous sulphate. Some coagulants derived from natural products, such as “Nirmali seeds” (Strychnos Potatorum), have also been used.

Selection of aluminium or iron coagulants is largely decided by the suitability of type and its easy availability. Both filter alum and ferric sulphate have certain specific advantages. Alum does not cause the unsightly reddish-brown staining of floors, walls, and equipment which may result when iron salts are used; nor is its solution as corrosive as the ferric form of iron salts. The dissolving or ferric sulphate also offers difficulties not encountered with alum. The trivalent aluminium ion is not reduced to a more soluble bivalent ion, as may be the case when ferric salts are used with waters high in organic matter. On the other hand, ferric floc is denser than alum floc and is more completely precipitated over a wider range. However, good flocculation with any coagulant is possible with detailed analysis of water quality and laboratory tests.

The choice of the coagulant to be used for any particular water should preferably be based upon a series of jar tests, so planned that it will permit accurate comparison of the materials being studied under identical experimental conditions. The coagulant dose in the field should be judiciously controlled in the light of the jar test values. It is seen that in India aluminium-based salts are used for treatment of surface waters. PAC is seen to be replacing aluminium as it is efficient over a wide range of pH. Ferric salts are preferred in pretreatment of RO feed water (desalination process) as the membranes are not tolerant to aluminium.

5.4.5.5 Coagulant Selection

Coagulation is a physical and chemical reaction occurring between the alkalinity of the water and the coagulant added to the water, which results in the formation of insoluble flocs.

The most important consideration is the selection of the proper type and amount of coagulant chemical to be added to the source water to be treated.

Overdosing as well as under-dosing of coagulants may lead to reduced solid removal efficiency. This condition may be corrected by carefully performing jar tests and verifying process performance after making any change in the coagulation process.

5.4.5.6 Sequence of Chemical Addition

Traditionally, the sequence of chemical addition for coagulation operations is to first add chemicals for pH correction, then add the metal coagulant, then add the flocculant aid. Not all these chemicals are necessarily added, but the sequence logic is often as described. However, there are instances when other sequences are more effective, including inverting the sequence of metal coagulant and polymer addition, and the sequence of metal coagulant addition and pH adjustment. The best sequence for a particular application can be determined by jar test experiments.

I. Jar Test

The jar test is the most widely used method to evaluate the coagulation process and to aid the plant operator in optimising the coagulation processes. The BIS Code IS 3025 (2001): *Methods of Sampling and Tests (Physical and Chemical) for Water and Wastewater, Part 50: Jar Test (Coagulation Test)* should be followed. Jar test is a laboratory procedure that simulates coagulation/flocculation with differing chemical doses. The purpose of the procedure is to estimate the minimum coagulant dose required to achieve certain water quality goals. Samples of water to be treated are placed in 6 jars. Various amounts of chemicals are added to each jar and stirred, and the settling of solids is observed. The lowest dose of chemicals that provides satisfactory settling is the dose used to treat the water.
To do extensive jar testing, it is best to use a gang stirrer. A gang stirrer is an instrument that can stir multiple beakers of water at a time, so multiple different chemicals or dosages can be tested on a sample at once. The instrument also ensures that the mixing is uniform throughout the samples.

Once the stirring system is setup, use the coagulant, flocculant, or both. Sometimes an acid or base is also needed due to certain water requiring a pH adjustment to be treated. Other equipment required for effective jar testing includes syringes, pH meters, magnets, a notebook, and a pen.

a) Stock solution preparation

Stock solutions of coagulant, coagulant aids, and other chemicals (for pH adjustment, etc.) shall be prepared at concentrations such that quantities suitable for use in jar test can be measured accurately and with ease. The Table 1, “Stock Solutions for Coagulation Test”, of the IS 3025-50 (2001) may be referred to for this.

b) Full list of jar testing equipment required

- Mixing device (gang stirrer)
- Glass beakers, bottles
- Syringes
- pH meter or pH paper
- Chemicals
- Timer
- Graduated cylinder
- Magnets (for mixing plates)
- Notebook

The below listed IS Code may be referred to which prescribes the sampling method and method for determining the optimum dosage of coagulant (single/mixed), coagulant aids, and the optimum pH of coagulation for removal of turbidity and colour caused by colloidal and non-settleable particles followed by sedimentation under quiescent (undisturbed/tranquil) condition:

a) BIS Code IS 3025-50 (2001, reaffirmed year: 2022): *Methods of Sampling and Tests (Physical and Chemical) for Water and Wastewater, Part 50: Jar Test (Coagulation Test)*; and

b) BIS Code IS 17614: Part 1: 2021: *Water Quality — Sampling, Part 1: Guidance on the Design of Sampling Programmes and Sampling Techniques*.

From the turbidity values of the pre-settled water, settling velocity distribution curves are drawn. These curves have been found to correlate well with the plant operating data and yield useful information in evaluating pretreatment, such as optimising velocity gradient value towards agitation and flocculation, pH, coagulant dosage, and coagulant solution strength. Such curves cannot be generalised and are specific to the raw water of a treatment plant for which the data have been collected through the jar tests. Table 5.1 shows a data sheet for collection of this data.

Table 5.1: Jar Test Data Sheet

Date and time	Flocculation period with RPM	Settling period	Jar no.	pH	Turbidity	Colour	Alkalinity CaCO3	Time for first floc formation	Remarks
			Control						
			1						
			2						
			3						
			4						
			5						
			6						

The results obtained from jar tests yield valuable information essential for process control and optimisation of treatment procedures. Presented below is an outline for interpreting jar test results:

1. Flocculation Performance: The jar test helps assess the efficiency of coagulants and flocculants in promoting the aggregation of suspended particles. The formation of large, well-settling flocs indicates effective flocculation. Factors to consider include floc size, density, and settling rate.
2. Turbidity Reduction: Turbidity measurements before and after the jar test provide insights into the effectiveness of the treatment process in removing suspended solids. A significant reduction in turbidity indicates improved clarification and removal of particles.
3. Settling Characteristics: The settling behaviour of suspended solids can be evaluated by observing the sedimentation rate and clarity of the supernatant. Faster settling and clearer supernatant suggest improved settling characteristics, which are essential for efficient sedimentation in clarifiers or sedimentation basins.
4. Optimal Dosage Determination: The jar test evaluates different chemical dosages to identify the optimal dosage for coagulants, flocculants, or other treatment chemicals. It helps determine the minimum dosage required to achieve the desired treatment objectives, such as turbidity reduction or particle removal.
5. pH and Alkalinity Considerations: pH and alkalinity can significantly impact the performance of coagulants and flocculants. Monitoring the pH and alkalinity during the jar test helps identify the optimal range for effective flocculation and settling. Adjustments may be necessary to optimise the treatment process.
6. Jar Test Variations: Various jar tests variations, such as jar stirring speed, settling time, and type of mixing mechanism, can impact the results. Maintaining consistent testing conditions and replicating the jar test procedure are important to ensure reliable and comparable results.

Interpreting jar test results requires considering the specific treatment objectives, target water quality standards, and the characteristics of the water being treated. Comparing the results with historical data or benchmarking against performance targets helps assess the effectiveness of the treatment process and determine any necessary adjustments or improvements.

5.4.5.7 Mixing – Rapid/Flash

Rapid or flash mixing in water treatment is a primary chemical dosing operation (pH adjusting compound, coagulant, coagulant aid). Rapid mixers are used to violently agitate the water with the chemicals for a short period of time before being released into the flocculation basin. The main requirement of the mix is that all the coagulant be rapidly mixed with the water to instantly form homogeneous mix effecting uniform distribution of coagulant in the water. The BIS Code IS 7090 (1985, reaffirmed 1996) should be referred to, which lays down design considerations, guidelines for materials, and methods of construction of the following types of rapid mixing devices:

a) **Mechanical**
   i. Vane-type mixer
   ii. Propeller-type mixer
   iii. Jet-type mixer

b) **Hydraulic**
   i. Hydraulic jump
   ii. Baffled channel

Mixing Methods

Any of the following methods are used to accomplish the mixing of the chemicals with the water to be treated:

- Hydraulic mixing
- Mechanical mixing
- Diffusers and grid system
- Pumped blenders.

Mixing of the chemical coagulant can be satisfactorily accomplished in a special coagulant tank with mixing devices. Mixing may also occur in the influent channel or a pipeline to the flocculation basin if the flow velocity is high enough to produce the necessary turbulence. The shape of the basin is part of the flash mix design.

The details are described in Section 8.5 (and its sub paras) of Chapter 8: Conventional Water Treatment in Part A of the manual.

5.4.5.8 Operational Problems

Operational problems associated with coagulation and flocculation processes typically relate to either equipment failure or process inefficiencies. Problems associated with equipment operations are specific to the installed equipment and are not discussed here. Problems associated with the coagulation process are typically indicated by high turbidity water in the sedimentation basin effluent and/or the filtered water. Some of the common causes for poor performance of coagulation and flocculation facilities are as follows:

- High effluent turbidity, with no floc carryover, can be the result of too little coagulant or incomplete dispersion of the coagulant. Jar tests with varying coagulant dilutions and rapid-mix intensities should be performed and the dosage should be adjusted accordingly.
- Unsatisfactory effluent turbidity can also result from raw water that has low initial turbidity. An insufficient number of particle collisions during flocculation will inhibit floc growth. Increase flocculation intensity, recycling of sludge, or addition of bentonite provide a nucleus for floc formation.
- High effluent turbidity with floc carryover is an indication of a poor settling of floc. High flocculation intensity will often shear floc and result in poor settling. Lowering the flocculation intensity or add a coagulant aid will toughen the floc and make it more readily settleable.
- Too much coagulant will often result in re-stabilisation of the colloids. If unsatisfactory performance is obtained, a series of jar tests with various coagulant dosages will help in determining appropriate dosage requirement. The feed rates should be adjusted accordingly.
- Calcium carbonate precipitate will often accumulate on lime feed pipes. Lime pipes should be flushed with an acid solution periodically, to dissolve the scale.
- Improper feed rate of coagulant through positive displacement metering pumps can be the result of siphoning through the pump. Pumps may be located in such a way that a positive head is present at all times on the pump discharge. An alternative correction method is to install a back-pressure valve on the pump discharge.

5.4.5.9 Preventive Maintenance

The following preventive maintenance procedures are necessary for the satisfactory operation of rapid mix and flocculation facilities.

- Performing jar tests on raw water samples daily when significant raw water quality changes are experienced. The coagulant dosages and mixer speeds should be adjusted accordingly.
- Cleaning of accumulated precipitate and sludge from rapid mix and flocculation basins.
- Every month calibration of chemical feeders.
- Checking the chemical analysis of each delivery of coagulant. Adjusting feed rates as indicated by the analysis and jar tests.
- Lubricating the flocculator and mixer gear boxes and bearings as specified by the manufacturer.
- Inspect rapid mix impellers and flocculator paddles annually. Removal ofany accumulations of floc or calcium carbonate scale. More frequent inspections are required if build up is severe.

5.4.5.10 Flocculation Basin

The objective of a flocculation basin is to produce a settled water of low turbidity which in turn will allow reasonably long filter runs. The BIS Code IS 7208 (1992, reaffirmed 2001), *Guidelines for Flocculator Devices*, should be referred to, which lays down guidelines for design and construction of flocculator devices used in water treatment works. This standard does not cover air agitation devices since such types have not been used in India. The general method adopted in India is by mechanical flocculation through the use of paddles.

5.4.5.11 Short Circuiting

An important factor that determines the functioning of a flocculator is the short circuiting. In a basin, against a predetermined 30-minute agitation, a large portion may get only 10 minutes while another sizeable amount may get 60 minutes. Under such circumstances, every inferior settled water is produced.

Short circuiting in flocculation basins is characterised by currents which move rapidly through and continue into the settling tanks. Properly operated entrance, curtain baffles, and exit weirs and launders can significantly improve settling.

The flocculators are circular, square, or rectangular in shape. The best flocculation is usually achieved in a baffled compartmentalised basin, where enough contact time with turbulence is possible. The compartments (most often three) are separated by baffles to prevent short circuiting of the water being treated. The turbulence can be reduced gradually by reducing the speed of the mixers in each succeeding tank or by reducing the surface area of the paddles. This is called tapered-energy mixing. The reason for reducing the speed of the stirrers is to prevent breaking apart the larger floc particles, which have already formed. If the floc is broken up nothing is accomplished and the filter gets overloaded.

5.4.5.12 Appropriate Coagulant Dosing Point

Rapid mix of coagulant at a spot of maximum turbulence, followed by tapered flocculation in three compartmentalised units allows a maximum of mixing (reduced short circuiting) followed by a period of agglomeration intended to build larger fast settling floc particles. The velocity gradient is gradually reduced from the first to the third unit. The concepts of velocity gradient and tapered flocculation have been discussed in Section 8.5.1.1 of Chapter 8: Conventional Water Treatment in Part A of the manual.

5.4.5.13 Interaction with Downstream Unit Operations (Sedimentation and Filtration)

The processes of coagulation and flocculation are required to precondition or prepare non-settleable particles, of less than one micron, present in the raw water for removal by sedimentation and filtration. Small particles (particularly colloids), without proper coagulation and flocculation are too light to settle out and will not be large enough to be trapped during filtration process.

Since the purpose of coagulation-flocculation is to produce particle removal, the effectiveness of the sedimentation and filtration processes, as well as overall performance, depends upon successful coagulation-flocculation.

5.4.5.14 Coagulation-Flocculation Process Actions

Typical jobs performed by an operator in the normal operation of the coagulation- flocculation process include the following:

- Monitor process performance.
- Evaluate water quality conditions (raw and treated water).
- Check and adjust process controls and equipment.
- Visually inspect facilities.

Figure 5.1 shows the overall plan view of the coagulation-flocculation process of a typical plant.

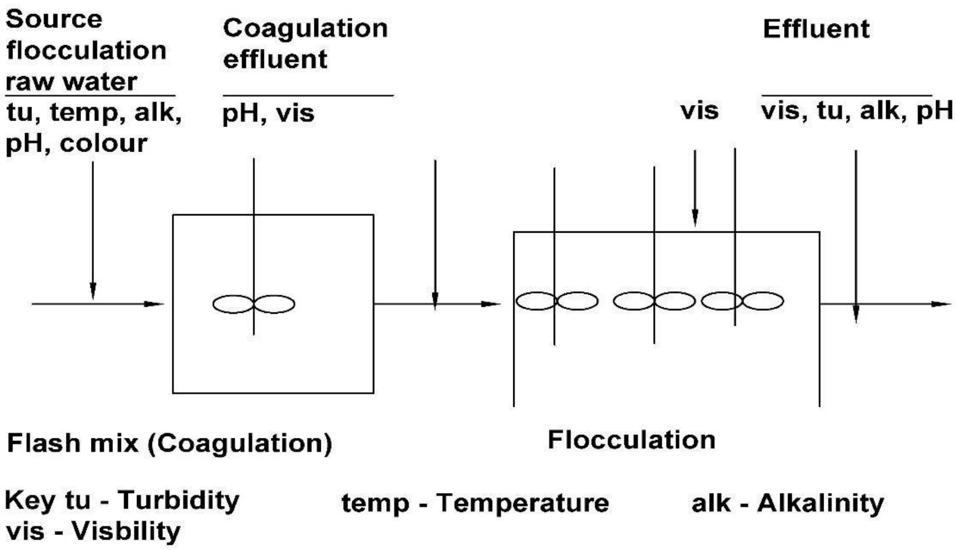


Figure 5.1: Coagulation-Flocculation Process Monitoring Guidelines

5.4.5.15 Floc Examination

Examine the water samples at several points enroute the flow line of the water. Look at the clarity of the water between the flocs and study the shape and size of the floc.

- Observe the floc as it enters the flocculation basins. The floc should be small and well dispersed throughout the flow.
- Tiny alum floc may be an indication that the chemical dose is too low. A "popcorn flake" is a desirable floc. If the water has a milky appearance or a bluish tint, the alum dose is probably too high.
- As the floc moves through the flocculation basins the size of the floc should be increasing. If the size of the floc increases and then later starts to break up, the mixing intensity of the downstream flocculator may be too high. Try reducing the speed of these flocculators or

increasing the coagulant dosage.

- Examine the settlement of the floc in the sedimentation basin. If a lot of floc is observed flowing over the laundering weirs the floc is too light for the detention time. By increasing the chemical dose or adding a coagulant aid such as a polymer, a heavier, larger floc may be produced. The appearance of the fine floc particles washing over the effluent weir could be an indication of too much alum and the dose should be reduced. For precise evaluation, you should make only one change at a time and evaluate the results.

Table 5.2 is a summary of coagulation-flocculation process problems, how to identify the causes of these problems, and also how to correct the problems.

Table 5.2: Coagulation-Flocculation Process Troubleshooting

Source Water Quality Changes	Operator Actions	Possible Process Changes
Turbidity Temperature	1. Perform necessary analysis to determine extent of change. 2. Evaluate overall process performance. 3. Perform jar tests. 4. Make appropriate process changes (see next column). 5. Increase frequency of process monitoring.	1. Adjust coagulant dosage. 2. Adjust flash mixer/flocculator mixing intensity. 3. Add coagulant aid or filter aid. 4. Adjust alkalinity or pH. 5. Change coagulant(s).
Coagulation Process Effluent Quality Changes	**Operator Actions**	**Possible Process Changes**
Turbidity Alkalinity pH	1. Evaluate source water quality. 2. Perform jar tests. 3. Verify process performance: (a) coagulant feed rate(s); and (b) flash mixer operation. 4. Make appropriate process changes.	1. Adjust coagulant dosage. 2. Adjust flash mixer intensity (if possible). 3. Adjust alkalinity or pH. 4. Change coagulant(s).
Flocculation Basin Floc Quality Changes	**Operator Actions**	**Possible Process Changes**

Floc formation	1. Observe floc condition in basin: (a) dispersion; (b) size; and (c) floc strength (breakup). 2. Evaluate overall process performance. 3. Perform jar tests: (a) evaluate floc size, settling rate, and strength; and (b) evaluate quality of supernatant; clarity (turbidity), pH, and colour. 4. Make appropriate process changes.	1. Adjust coagulant dosage. 2. Adjust flash mixer/flocculator mixing intensity. 3. Add coagulant aid. 4. Adjust alkalinity or pH. 5. Change coagulant(s).

Note: All major problems should be reported to the authorities and response duly followed up. Also, latest technology like streaming current detector (SCD) can be used by the operator to measure coagulated particle stability. This measurement is then used to establish a set point to control coagulant dosing as influent turbidity changes and assures a consistent effluent quality to monitor and control coagulants in water. SCD is an analyser instrument for measuring the net electric charge of particles after coagulant dosing.

5.4.5.16 Enhanced Coagulation

Enhanced coagulation refers to the process of increasing the removal rate of organic matter by increasing the dosage of coagulant and controlling the pH value under the premise of ensuring the removal of turbidity during the conventional coagulation treatment of water treatment.

Enhanced coagulation and flocculation improve the removal effect of natural organic matter (NOM) in conventional treatment, maximally removing the precursor of disinfection by-product (DBP), and ensuring that drinking water DBPs comply with drinking water Standard IS:10500 (2012).

Enhanced coagulation has the advantages of low investment, no need to construct new structures, no land occupation, and low operating costs, and no need of transformation of the original system.

At varying pH values, the coagulation process may suffer from less than optimum ions being formed in solution. pH that is too low may not allow the coagulation process to proceed, while high pH can cause a coagulated particle to redisperse. So, it is essential to monitor the pH of the water and conduct jar test to ascertain proper coagulation dosing.

5.4.5.17 Startup and Shutdown Procedures

a) Conditions

This is not a routine operating procedure in most of the plants. These procedures generally happen when the plant is shut down for maintenance. In some rare instances, shutdown may be required due to a major equipment failure.

b) Startup Procedures

1. Check the condition of all mechanical equipment for proper lubrication and operational status.
2. Make sure all chemical feeders are ready. There should be plenty of chemicals available in the tanks and ready to be fed to the raw water.
3. Collect a sample of raw water and immediately run a jar test using fresh chemicals from the supply of chemicals to the feeders.
4. Determine the settings for the chemical feeders and set the feed rates on the equipment.
5. Open the inlet gate or valve to start the raw water flowing.
6. Immediately start the selected chemical feed systems.
    - Open valves to start feeding coagulant chemicals and dilution make- up water.
    - Start chemical feeders.
    - Adjust chemical feeders as necessary.
7. Turn on the flash mixer at the appropriate time. You may have to wait until the tank or channel is full before turning on the flash mixer. Follow the manufacturer's instructions.
8. Start the sample pumps as soon as there is water at each sampling location. Allow sufficient flushing time before collecting any samples. Start the flocculators as soon as the first basin is full of water.
9. Inspect mixing chamber and flocculation basin. Observe formation of floc and make necessary changes.
10. Remove any debris floating on the water surface.
11. Perform water quality analysis and make process adjustments as necessary.
12. Calibrate chemical feeders.

Note: Do not allow any untreated water to flow through the plant.

c) Shutdown Procedures

1. Turn off chemical feeders.
2. Close raw water gate to flash-mix chamber or channel.
    - Shut down the chemical feed systems.
    - Shut off appropriate valves.
    - Flush or clean chemical feed lines if necessary.
3. Shut down flash mixer and flocculators as water leaves each process.
4. Shut down sample pumps before water leaves the sampling location.
5. Waste any water that has not been properly treated.
6. Lock out and tag appropriate electrical switches.
7. Dewater basins if necessary.
8. Drain all the water that has not been properly treated for the start of shutdown process.

Note:

- Do not dewater below-ground basins without checking groundwater levels.
- Close basin isolation gates or install stop-logs.
- Open basin drain valves.
- Be careful that the basin may not float or collapse depending on upward groundwater thrust, active earth pressure of soil or other conditions depending on the plant levels.
- Good records of actions taken during start/shutdown operations will assist the operator in conducting future shutdowns.

5.4.5.18 Laboratory Tests

Process control water quality indicators of importance in the operation of flocculation process include turbidity, alkalinity, chlorine demand, colour, pH, temperature, odour and appearance.

5.4.5.19 Safety Considerations

In the coagulation-flocculation processes, the operator will be exposed to a number of hazards such as:

- electrical equipment;
- rotating mechanical equipment;
- water treatment chemicals;
- laboratory reagents (chemicals);
- slippery surfaces caused by certain chemicals;
- flooding;
- confined spaces and underground structures such as valve or pump vaults (toxic and explosives gases, insufficient oxygen).

Strict and constant attention must be given to safety procedures. The operator must be familiar with general first-aid practices such as mouth-to-mouth resuscitation, treatment of common physical injuries, and first aid for chemical exposure (chlorine).

For more details, a reference may be made to Part B, Chapter 13: Safety Practices.

5.4.6 Sedimentation (Clarification)

To facilitate settling of settleable floc and effective removal from the process (in the form of sludge). Sedimentation (clarification) refers to the sequence of operations used to remove suspended solids (mineral and organic) from the raw water. The IS 10313 (1982, reaffirmed 2010) covers requirement of settling tank (clarifier equipment) for water treatment, which may be referred to. Sedimentation can be carried out in the following types of basins:

- Rectangular basins
- Circular basins
- Square basins
- High-rate settlers (tube settlers/plate settlers)
- Solid contact units (up-flow solid-contact clarification and up-flow sludge blanket clarification)
- Dispersed flotation systems to be added (DAF)

The details are described in Section 8.6 of Chapter 8: Conventional Water Treatment in Part A of the manual. Sedimentation basins generally have inlet, settling, sludge, and outlet zone.

There are a variety of designs for sedimentation tanks available. These include large rectangular tanks in which the water enters one side and leaves at the other end. This type is normally used at large conventional treatment works. Circular tanks with flat or cone-shaped bottoms are also used, especially at smaller works. Flocculated water enters the tank at a central distribution section and clarified water leaves the tank at collection troughs at the circumference of the tank. The design and flow conditions in a sedimentation tank must be such that the minimum amount of flocs leaves with the clarified water. Sedimentation is a suitable process for removal of flocs formed from silt and clay particles that settle readily. However, certain flocs are relatively light and do not settle readily and a process such as flotation must be used for their removal. Light flocs are formed when algae or organic matter is flocculated.

The flocs that settle in the sedimentation tank collect at the bottom of the tank as sludge from where it must be removed on a regular basis to prevent accumulation in the tank. If sludge is not regularly withdrawn according to operating schedules, the quality of the clarified water may deteriorate due to re-entrainment of sludge.

The purpose of sedimentation process is to remove suspended particles so as to reduce load on filters. If adequate detention time and basin surface area are provided in the sedimentation basins, solids removal efficiencies greater than 95% can be achieved. However, high sedimentation basin removal efficiencies may not always be the most cost-effective way to remove suspended solids.

The sedimentation process should be operated from the standpoint of overall plant efficiency. If the source water turbidity is only 3 mg/L, and the jar tests indicate that
0.5 mg/L of coagulant is the most effective dosage, then the sedimentation process may not remove a significant fraction of the suspended solids. On the other hand, source water turbidities are in excess of 50 mg/L, it will probably require a high coagulant dosage for efficient solids removal. In this case, the majority of the suspended particles and alum floc should be removed in the sedimentation basin.

The frequency of sludge removal is an important aspect to ensure the system's efficient operation. One of the factors that significantly impact the sludge removal frequency is the turbidity of the raw water.

To maintain optimal performance, removing the accumulated sludge regularly is crucial. The frequency of sludge removal depends on the turbidity of the raw water. When the raw water has high turbidity, indicating a higher concentration of suspended solids, sludge accumulates faster. In such cases, more frequent sludge removal is necessary to prevent excessive build-up, which can negatively affect the efficiency of the sedimentation/clarification process.

The design and capacity of the clarifier or sedimentation tank, as well as the treatment objectives, can influence the sludge removal frequency.

Ultimately, the specific sludge removal frequency should be determined based on a combination of factors, including raw water turbidity, settling characteristics of the suspended solids, system design, and treatment goals. Regular monitoring, operational experience, and potential laboratory analysis are essential for establishing an appropriate sludge removal schedule that maintains efficient sedimentation and clarification processes.

5.4.6.1 Operating Procedures

From a water quality standpoint, filter effluent turbidity is a good indication of overall process performance. However, one must monitor the performance of each of the individual water treatment processes, including sedimentation, in order to acquire the data of quality or performance changes. Normal operating conditions are considered to be conditions within the operating ranges of WTP, while abnormal conditions are unusual or difficult to handle conditions. In normal operation of the sedimentation process, one must monitor.

- Turbidity of the water entering and leaving the sedimentation basin and temperature of the entering water. Turbidity of the entering water indicates the floc or solid loading on the sedimentation process. Turbidity of the water leaving the basin reveals the effectiveness or efficiency of the sedimentation process. Low levels of turbidity are desirable to minimise the floc loading on the filter.
- Temperature of the water entering the sedimentation basin is important. As the water becomes colder, the particles will settle more slowly. To compensate for these changes, a jar test may perform so as to adjust the coagulant dosage to produce a heavier and thus a settling floc. Another possibility is to enforce longer detention times when water demand decreases.
- Visual checks of the sedimentation process should include observation of floc settling characteristics, distribution of floc at the basin inlet and clarity of settled water spilling over the launder weirs. An uneven distribution of floc, or poorly settling floc, may indicate that a raw water quality change has occurred or that the operational problems may have developed.

5.4.6.2 Operational Aspect

I. Main Operational Tasks

- Ensuring an even inflow and distribution of flocculated water into the tank. The distribution of flocculated water in the sedimentation tank is mainly determined by design. The operator must, therefore, observe flows and the nature of flocs. If it is evident that flow distribution problems exist, the operator must investigate possibleproblems such as blockages in channels or inlet pipes and clean if necessary.
- Ensure that the scraping mechanisms and moving bridge function properly. Maintenance must be carried out according to schedule to ensure proper functioning. Regular visual inspections are also necessary to detect possible mechanical problems. If mechanical problems occur, the equipment must be stopped and maintenance staff called in.
- Sludge must be pumped regularly from the tank according to operating instructions. If sludge is left too long in the tank, it may become too thick and cause pump problems. Alternatively, settled sludge may be entrained and cause a deterioration in settled water quality. If sludge is pumped too frequently, the sludge may become very thin, resulting in high water losses and rapidly filling of sludge dams or lagoons.
- The sides and overflow weirs of the sedimentation tanks must be kept free from algal and other growths by regular brushing and cleaning. Algal growths may cause taste and odour problems and also create a poor impression of the operation and control.
- The turbidity of the overflow from each tank must be determined on a regular basis. If the turbidity exceeds set values, the cause for poor performance must be determined

and corrective action taken. Possible causes include an increase in inflow to the sedimentation tank as a result of increased production or due to problems with flow distribution between tanks. Other possible causes include too low pumping frequency of sludge or wind or density currents.

- In case of poor performance, check inflow volume, calculate upflow velocity, check inflow distribution, check coagulation, check flocculation and correct where necessary.

II. Process Actions

In rectangular and circular sedimentation basins, when sedimentation is working well, the floc will only be visible for a short distance. When the sedimentation is poor, the floc will be visible for a long distance beyond the inlet.

In upflow or solid-contact clarifiers, if the sludge blanket is of normal density (measured as milligrams of solids per litre of water) but if it is very close to the surface, more sludge should have to be formed. If the blanket is of unusually light density, the coagulation-flocculation process (chemical dosage) must be adjusted to improve the performance.

With any of the sedimentation processes, it is useful to observe the quality of the effluent as it passes over the launder weir. Flocs coming over at the end of the basin are indicative of density currents, short circuiting, and sludge blankets that are too deep or high flows. The clarity of the effluent is also a reliable indicator of coagulation- flocculation efficiency.

Process equipment should be checked regularly to assure adequate performance. Proper operation of sludge removal equipment should be verified each time the equipment is operated, since sludge removal discharge piping systems are subject to clogging. Frequent clogging of sludge pipe requires increasing frequency of sludge removal equipment and this can be diagnosed by performing sludge solids volume analysis in the laboratory. A summary of routine sedimentation process actions is given in Table 5.3.

Table 5.3: Summary of Routine Sedimentation Process Actions

1. Monitor Process Performance and Evaluate Water Quality Conditions	Location	Frequency	Possible Operator Actions
Turbidity	Influent/Effluent	At least once every 8-hour shift	1. Increase sampling frequency when process water quality is variable.
Temperature	Influent	Occasionally	2. Perform jar tests. 3. Make necessary process changes: a) Change coagulant dosage. b) Adjust flash mixer/flocculator mixing intensity. c) Change frequency of sludge removal. d) Chkange coagulant.

2. Make Visual Observations	Location	Frequency	Possible Operator Actions
Floc settling characteristics Floc distribution Turbidity (clarity) of settled water	First half of basin Inlet Launders of settled water conduit	At least once per 8-hour shift At least once per 8-hour shift At least once per 8-hour shift Note: Depends on size of plant	1. Perform jar tests. 2. Make necessary process changes: a) Change coagulant dosage. b) Adjust flash mixer/flocculator mixing intensity. c) Change frequency of sludge removal. d) Change coagulant.
3. Check Sludge Removal Equipment	**Location**	**Frequency**	**Possible Operator Actions**
Noise, Vibration, Leakage, Overheating	Various	Once per 8-hour shift	1. Correct minor problems. 2. Notify others of major problems.
4. Operate Sludge Removal Equipment	**Location**	**Frequency**	**Possible Operator Actions**
Perform normal operations sequence Observe conditions of sludge being removed	Sedimentation basin	Depends on process conditions (may vary from once per day to several days or more)	1. Change frequency of operation: a) If sludge is too watery, decrease frequency of operation and/or pumping rate. b) If sludge is too dense, bulks, or clogs discharge lines, increase frequency of operation and/or pumping rate. c) If sludge is septic, increase frequency of operation and/or pumping rate.
5. Inspect Facilities	**Location**	**Frequency**	**Possible Operator Actions**

Check sedimentation basins Observe basin water over launder weirs Observe basin water surface Check for algae build-up on basin walls and launders	Various Various	Once every 8- hour shift Once per 8-hour shift Once per 8-hour shift Occasionally	Report abnormal conditions. Make flow changes or adjust launder weirs. Remove debris from basin water surface.

Note: All major problems should be reported to the competent authorities and response duly followed.

III. Operational Problems

Operational problems associated with sedimentation basins typically relate to ineffective sludge removal or short circuiting. Ineffective sludge removal is commonly associated with equipment problems or inadequate sludge removal practices. Short circuiting is typically the result of improper inlet or outlet design, it can also be the result of wave action, density currents, or temperature currents. Common operational and maintenance problems and troubleshooting guides are as follows:

- Operational problems with sludge collection equipment may include the shear pins or motor overloads or both, generally due to improper sludge removal. Rapid checks include removal of sludge, ensuring proper shear pin installation, motor overload setting, and also to remove debris in the basin.
- Sludge withdrawal with low solids concentrations may result from an excessively rapid removal rate or improperly operated sludge collection mechanism. Checks include decreasing the removal rate and to ensure proper operation of sludge collection equipment.
- Clogged sludge withdrawal piping can be the result of insufficient sludge withdrawal, therefore, increases the removal rate.
- High effluent turbidity or floc carryover may result from an improper coagulation process. High turbidity or floc carryover may also result from short circuiting in the sedimentation basin. Possible corrective measures include inlet and outlet baffles. Tracer studies help in identifying short circuits.
- Algae build up on basin walls or weirs may create taste and odour problems. Regular cleaning of basin walls, maintaining a residual disinfectant in the basin, and restricting algae growth are required.

A summary of sedimentation process problems and remedial measures are given in Table 5.4.

Table 5.4: Sedimentation Process Troubleshooting

1. Source Water Quality Changes	Operator Actions	Possible Process Changes
Turbidity Temperature Alkalinity pH Colour	1. Perform necessary analysis to determine extent of change. 2. Evaluate overall process performance. 3. Perform jar tests.	1. Adjust coagulant dosage. 2. Adjust flash mixer/flocculator mixing intensity. 3. Change frequency of

	4. Make appropriate process changes (next column). 5. Increase frequency of process monitoring.	sludge removal (increase or decrease). 4. Increase alkalinity by adding lime, caustic soda, or soda ash. 5. Change coagulant.
2. Flocculation Process Effluent Quality Changes	**Operator Actions**	**Possible Process Changes**
Turbidity Alkalinity pH	1. Evaluate overall process performance. 2. Perform jar tests. 3. Verify performance of coagulation flocculation process. 4. Make appropriate process changes (next column).	1. Adjust coagulant dosage. 2. Adjust flash mixer / flocculator mixing intensity. 3. Adjust improperly working chemical feeder. 4. Change coagulant.
3. Sedimentation Basin Changes	**Operator Actions**	**Possible Process Changes**
Floc Settling Rising or floating Sludge	1. Observe floc settling characteristics: a. dispersion b. size c. settling rate 2. Evaluate overall process performance. 3. Perform jar tests. a. Assess floc size and settling rate. b. Assess quality of settled water (clarity and colour). 4. Make appropriate process changes (next column).	1. Adjust coagulant dosage. 2. Adjust flash mixer / flocculator mixing intensity. 3. Change frequency of sludge removal (increase or decrease). 4. Remove sludge from basin. 5. Repair broken sludge rakes. 6. Change coagulant.
4. Sedimentation Process Effluent Quality Changes	**Operator Actions**	**Possible Process Changes**
Turbidity Colour	1. Evaluate overall process performance. 2. Perform jar test. 3. Verify process performance: Coagulation-flocculation process.	1. Change coagulant. 2. Adjust coagulant dosage. 3. Adjust flash mixer/flocculator mixing intensity. 4. Change frequency of

	4. Make appropriate process changes (next column).	sludge removal (increase or decrease).
5. Up-flow Clarifier Process Effluent Quality Changes	**Operator Actions**	**Possible Process Changes**
Turbidity Turbidity caused by sludge blanket coming to top due to rainfall on watershed	1. See no. 4 above. 2. Open main drain valve of clarifier.	1. See no. 4 above (sedimentation process). 2. Drop entire water level of clarifier to bring the sludge blanket down.

Note: All major problems should be recorded for information to the competent authorities and compliance duly followed up.

5.4.6.3 Equipment

a) **Types of support equipment**

The operator will need to be thoroughly familiar with the O&M instructions for each specific equipment.

- Rapid mixer
- Lime mixer
- Submersible wastewater pump (sludge tank)
- Level control system for sludge tank
- Solution metering pump for alum dosing
- Slurry metering pump for lime dosing
- Alum circulation pump (for alum mixing)
- Overhead bridge crane (for chemical house)
- Control room equipment (flowmeter, differential pressure transmitter, integrator, differential pressure regulator, plant monitor panel, etc.)
- Flowmeters and gauges
- Valves
- Control systems
- Laboratory equipment
    - Water quality monitors such as turbidity meters, jar test apparatus, chlorine titrimeter, chlorine colour comparator, pH/ion meter, etc.
    - Spectrophotometer
    - Incubator
    - Autoclave
    - Hot plate
    - Hot plate magnetic stirrer
    - Steaming water bath
    - Muffle furnace
    - Water distilling

  - o Vacuum pump
  - o Vacuum manifold
- Sludge removal equipment
- Sludge and backwash pumps
- Sump pumps

b) **Electrical equipment**
- Avoid electric shock.
- Avoid grounding yourself in water or on pipes.
- Ground all electric tools.
- Use a lock out and tag system for electric equipment or electrically driven mechanical equipment.

c) **Mechanical equipment**
- Keep protective guards on rotating equipment.
- Do not wear loose clothing around rotating equipment.
- Keep hands out of valves, pumps, and other equipment.
- Clean up all lubricant and sludge spills.

d) **Open surface water-filled structures**
- Use safety devices such as handrails and ladders.
- Close all openings.
- Know the location of all life preservers.

e) **Valve and pump vaults, sumps**
- Ensure that all underground or confined structures are free from hazardous atmosphere (toxic or explosive gases, lack of oxygen).
- Work only in well-ventilated structures.
- Take proper steps against flooding.

f) **Equipment operation (inadequate) Check the following:**
- Proper lubrication and operational status of each unit.
- Excessive noise and vibration, overheating and leakage.
- Pumps suction and discharge pressure.
- All incidents, regardless of severity, must be investigated and lessons learnt are used for prevention. Formal investigation of serious incidents must be carried out. Accountability at all levels, from staff to management must be owned.

5.4.6.4 Start Up and Shutdown Procedures

In the event of requirement for shut down or startup of processes on account of maintenance or a major equipment failure, proper procedures must be followed as per recommendations of the manufacturer of the plant and equipment. The procedures, in general, are given below:

a) **Startup procedure**

1. Check operational status and mode of operation of equipment and physical facilities. Check that basin valves are closed.

Check that basin isolation gates are closed.

Check that launder weir plates are set at equal elevations.

Check to ensure that all trash, debris, and tools have been removed from basin.

2. Test sludge removal equipment.
   Check that mechanical equipment is properly lubricated and ready for operation. Observe operation of sludge removal equipment.
3. Fill sedimentation basin with water. Observe proper depth of water in basin.
   Remove floating debris from basin water surface.
4. Start sample pumps.
5. Perform water quality analyses.
6. Operate sludge removal equipment. Be sure that all valves are in the proper position.

b) **Shutdown procedures**

1. Stop flow to sedimentation basin. Install basin isolation gates.
2. Turn off sample pump.
3. Turn off sludge removal equipment.
   Shut off mechanical equipment and disconnect where appropriate. Check that valves are in proper position.
4. Lock out electrical switches and equipment.
5. Dewater basin if necessary.
   Ensure that the water table is not high enough to float the empty basin. Open basin drain valves.
6. Grease and lubricate all gears, sprockets, and mechanical moving parts which have been submerged immediately following dewatering to avoid seize up.

5.4.6.5 Preventive Maintenance

The following preventive maintenance procedures are necessary forsatisfactory operation of the sedimentation facility:

- Cleaning of basins annually to remove any accumulated sludge and algal growth.
- Lubrication of the sludge collection equipment as recommended by the manufacturer.
- Testing the sludge collection overload devices annually.
- Testing the solids content in the sludge withdrawal line daily.
- Turbidity of effluent may be checked on a regular basis and whenever the water quality or flow rate changes.

5.4.6.6 Sludge Scrapper Bridge

The purpose of the sludge scraper bridge is to collect and remove settled sludge from the bottom of the clarifier, ensuring the continuous and efficient performance of the system. It is equipped with scraper blades or flights that move along the tank’s floor, scraping the settled sludge towards a collection point. The collected sludge is then discharged from the clarifier through designated outlets or pipes.

Scraper blades are typically made from durable and corrosion-resistant materials to withstand the harsh environment and abrasive nature of the sludge being scraped. The scraper blades push or guide the scraped sludge towards a collection point, such as a central hopper or an outlet pipe. Proper maintenance of the scraper blades is essential to ensure their efficient performance.

Regular inspections are carried out to check for any damage or wear on the blades. Worn-out or damaged blades are replaced, if necessary, to maintain optimal scraping efficiency.

Additionally, the tension or pressure applied by the scraper blades on the sludge is monitored and adjusted as needed. This ensures that the blades maintain proper contact with the sludge layer, maximising the effectiveness of the scraping process.

The O&M of the scrapper bridge in rectangular and circular clarifiers are as follows:

1. **Sludge scraper bridge for rectangular clarifiers:**
   - Operation: The sludge scraper bridge in a rectangular clarifier consists of a mechanical system that moves along the length of the tank, collecting and removing settled sludge. The operation involves the following steps:
     - The bridge is set in motion by a drive mechanism, typically a motor or gear system.
     - As the bridge moves, the attached scraper blades scrape the settled sludge toward a hopper at one end of the tank (collection point).
     - The collected sludge is then discharged from the clarifier through sludge outlets or discharge pipes.
   - Maintenance:
     - Regular inspection of the scraper blades and their attachment to the bridge to ensure they are intact and functioning properly.
     - Lubrication of the moving parts to minimise friction and ensure smooth operation.
     - Cleaning and clearing any debris or obstructions that may hinder the movement of the scraper bridge.
     - Monitoring and adjusting the tension of the scraper blade to maintain effective sludge scraping.
     - Periodic inspection of the drive mechanism, motor, and gearbox for any signs of wear or malfunction.
     - Regular calibration of the drive mechanism to maintain the desired speed and motion of the bridge.
2. **Sludge scraper bridge for circular clarifiers and clariflocculators:**
   - Operation: In circular clarifiers and clariflocculators, the sludge scraper bridge rotates around the central axis of the tank to collect and remove settled sludge. The operation involves the following steps:
     - The bridge is driven by a central drive mechanism, such as a rotating arm or motor.
     - The scraper blades attached to the bridge gradually scrape the settled sludge towards the centre of the tank.
     - A cone-shaped hopper or collection well located at the centre collects the sludge for removal.
     - The sludge is then discharged from the tank through sludge outlets or discharge pipes.
   - Maintenance:
     - Regular inspection of the scraper blades and their attachment to the bridge for any signs of damage or wear.
     - Lubrication of the rotating parts and bearings to ensure smooth operation.
     - Cleaning and clearing any obstructions or sediment build-up in the collection well or

hopper.

- Checking the alignment and balance of the bridge to prevent any excessive vibration or misalignment.
- Monitoring the central drive mechanism for proper functioning and addressing any issues promptly.
- Periodic calibration of the drive mechanism to maintain the desired rotational speed and motion of the bridge.

5.4.6.7 Tube/Plate Settlers

Tube settlers and plate settlers are widely utilised in water treatment processes to optimise the settling of suspended solids. The O&M of these settlers encompass the following key aspects:

Operation of Tube/Plate Settlers:

1. Installation: Tube settlers consist of closely spaced tubes, while plate settlers consist of closely spaced plates or inclined channels. During installation, they are positioned in the settling tank or clarifier, creating a large effective settling area.
2. Flow distribution: Proper flow distribution is essential for efficiently operating tube/plate settlers. The influent should be evenly distributed across the settling surface to ensure uniform flow through the tubes or plates.
3. Sedimentation: As the water flows through the tube settlers or over the plate settlers, suspended particles settle due to gravity. The inclined surfaces of the tubes or plates provide an extended settling path, allowing the particles to settle more effectively.
4. Clarified water collection: The clarified water flows upward through the tube settlers or plate settlers and collects in a separate compartment or launder. It is then collected for further treatment or discharge.

Maintenance of Tube/Plate Settlers:

1. Cleaning: Regular cleaning of tube settlers or plate settlers is crucial to maintain their effectiveness. Accumulated sediment and debris on the surfaces should be removed periodically to prevent clogging and ensure proper settling.
2. Inspection: Routine inspections are necessary to identify any damages or deformities in the tubes or plates. Bent or damaged elements should be replaced promptly to maintain optimal performance.
3. Scouring: In some cases, the settling surfaces may require scouring to remove stubborn deposits or biofilms. This can be done using high-pressure water jets or appropriate cleaning agents, as recommended by the manufacturer.
4. Repairs and replacements: If any significant damage or deterioration is observed, repairs or replacements should be carried out promptly to restore the functionality of the tube/plate settlers.
5. Flow monitoring: Monitoring the flow rate and distribution across the settlers is critical to ensure that the design parameters are met. Adjustments may be needed to optimise flow distribution and settling efficiency.
6. Regular maintenance checks: Other routine maintenance tasks include inspecting and maintaining the supports, seals, and connections of the tube settlers or plate settlers. Lubrication of any movable parts may also be necessary.

Ensuring the proper operation and regular maintenance of the tube/plate settlers are imperative for achieving optimal performance and prolonging their lifespan. Proactive maintenance shall be carried out as per guidelines provided by the manufacturer.

5.4.6.8 Safety Considerations

Failure to follow established safety practices, and lack of a safety policy are the main causes of most operator injuries. Important workplace safety plans that are to be strictly followed are the safety data sheet (SDS) notebook, emergency response plan, spill prevention plan, O&M plan, and standard operating procedures (SOPs).

Engineering controls are the primary method for hazard control. Work procedures are the secondary method for hazard control. Personal protective equipment (PPE) is used when other controls are not feasible or are inadequate.

5.4.6.9 Employee Training

The most important component of safe chemical management.

- Training must be thorough, frequent, and focused on specific work tasks.
- Management must support training by providing adequate time and funding.
- Supervisors must lead by example.

5.4.6.10 Emergency Management

- Prepare for and prevent emergencies (fires, spills/releases, and injuries).
- Emergency response must be part of basic work procedures and employees must be trained (evacuation, fire brigade, spill response, and medical response).

For more details, refer to preventive maintenance of Part B, Chapter 13: Safety Practices of this manual.

Such programmes are designed to assure the continued satisfactory operation of treatment plant by reducing the frequency of breakdown failures. Typical functions include:

1. Keeping electric motors free of dirt and moisture.
2. Assuring good ventilation.
3. Checking pumps and motors for leaks, unusual noise and vibrations, overheating or signs of wear.
4. Maintaining proper lubrication and oil levels.
5. Inspecting alignment of shafts and couplings.
6. Checking bearings for overheating and proper lubrication.
7. Checking for proper valve operation.
8. Checking for free flow of sludge in sludge removal collection and discharge systems.
9. Good housekeeping.

5.4.6.11 Record Keeping

Maintain daily operations log of process performance and water quality characteristics and keep the following records:

1. Influent and effluent turbidity and influent temperature.
2. Process production inventory (amount of water processed and volume of sludge produced).

3. Process equipment performance (type of equipment in operation, maintenance procedures performed and equipment calibration).

5.4.7 Filtration

The filtration process is the passing of the water through a bed of fine material, such as sand, anthracite coal, or other fine granular material. The filter media can be uniform in sizing, but higher and more effective filter rates are attained by use of mixed media. The purpose of filtration is the removal of particulate impurities and floc from the water being treated. In this regard, the filtration process is the final step in the solids removal process which usually includes the pretreatment processes of coagulation, flocculation, and sedimentation. Various types of filtration processes are available which are explained in detail in Section 8.7 of Chapter 8: Water Treatment in Part A of the manual. A typical flow of treatment in rapid and slow sand filtration is shown in Figure 5.2.

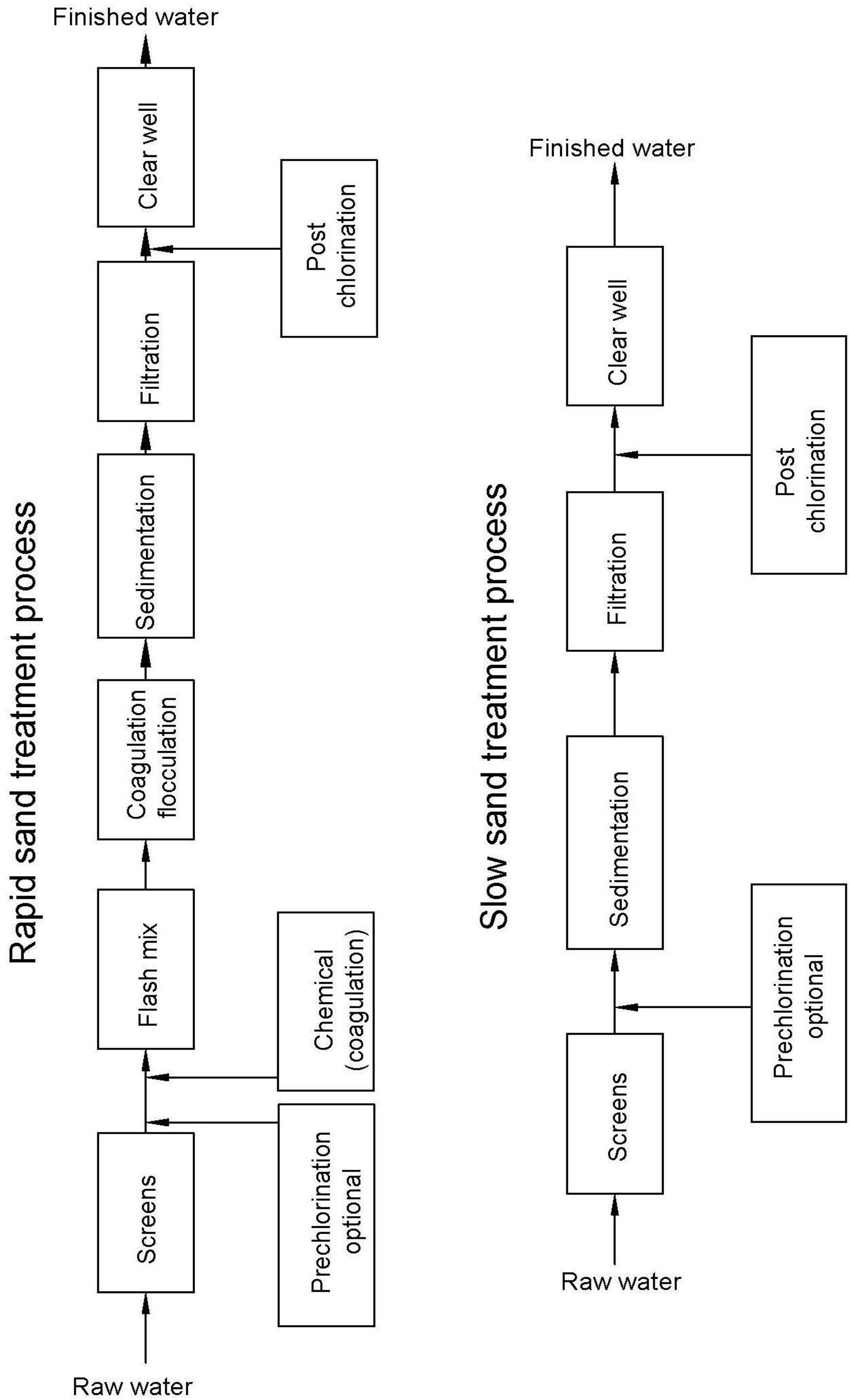


Figure 5.2: Filtration Processes

The filtration process is provided with varying degree of prior treatment depending upon the quality of water feed to them. Typical treatment processes are shown in Figure 5.3, Figure 5.4, and Figure 5.5.

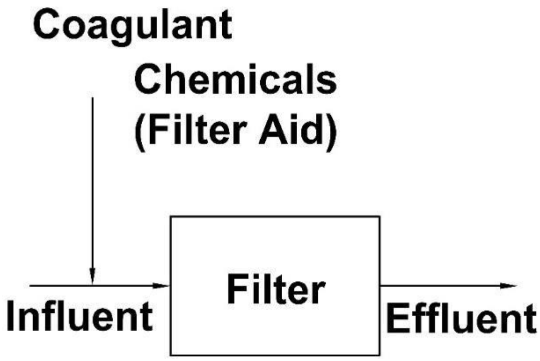


Figure 5.3: In-line Filtration

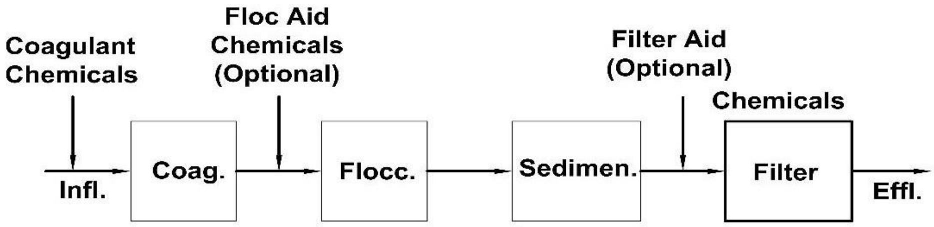


Figure 5.4: Conventional Filtration

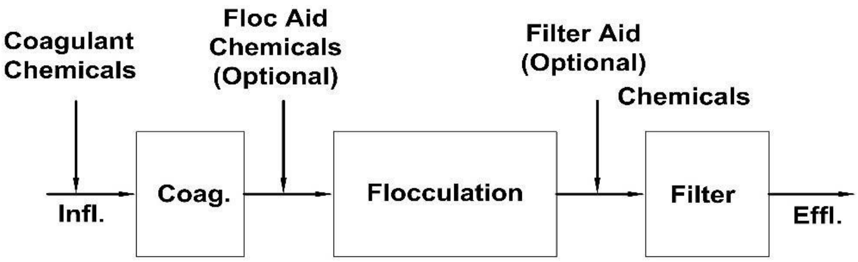


Figure 5.5: Direct Filtration

5.4.7.1 Slow Sand Filters

It may include plain sedimentation basins followed by the conventional filters. These filters require large areas of land and a correspondingly large quantity of filter media (sand) and base material (gravel). Cleaning of the filter is done by surface scrapping which may involve a lot of labour. A slow sand filter (SSF) is suitable when the availability of land, labour, and filter media are at a low cost. A distinguishing property of SSFs is the availability of a thin layer, called the schmutzdecke, which results on the surface of the sand bed and contains a large variety of biologically active microorganisms. It is a very simple and effective technique for purifying surface water. It will remove practically all of the turbidity from the water as well as most of the pathogens without the addition of chemicals. If the turbidity of raw water is high, then plain sedimentation would be required to reduce turbidity to some extent so that the fillers are not unduly loaded.

I. Filter Controls

The pipe work, valves, and devices used to regulate the operation of a filter should be properly planned. Adequate means must be available to:

- deliver raw water into the supernatant reservoir;
- remove scum and floating matter;
- drain off supernatant water prior to filter cleaning;
- lower water level in the bed;
- control the rate of filtration and adjust it as bed resistance increases;
- ensure that negative pressures cannot occur within the bed (the weir is the device usually used for this purpose);
- convey filtered water to the filter water tank;
- run filtered water to waste or to the inlet side of other filters during the ripening process;
- fill sand bed from below with filtered water (from other filters) after cleaning.

II. Operation

The operation of the filter is determined by the filtration rate, which is controlled at the effluent outlet. Inflow, which may be by gravity from a constant level reservoir, or by a pump, is adjusted so that the head of water in the supernatant reservoir remains constant at all times. Excessive raw water delivery will cause overflow through the scum outlets, while a reduction in the rate of inflow will cause the level in the supernatant water reservoir to drop; either condition should alert the operator to a defect in the mechanism controlling the supply of raw water.

The filtration rate is controlled by a single regulating valve on the effluent delivery. At the beginning of the filter run this will be partially closed, the additional resistance thereby provided being equal to that which will later build up within the filter bed. Day by day as the run continues this valve must be checked and opened fractionally to compensate for the choking of the filter and to maintain a constant filtration rate. In the early part of the filter run, the daily build-up of resistance will be almost imperceptible, calling for very little valve adjustment, but towards the end of the filter run the resistance will increase more rapidly, necessitating a more positive opening of the valve and signalling the impending need for filter cleaning.

To enable the operator to regulate the valve precisely, it is necessary to have some form of measuring device on the effluent outlet. Ventilators are provided as an integral part of the filter bed. It should be ensured that this function properly for supply of adequate air.

III. Control of Algal Growth

Excessive algal growth may cause trouble in the operation of open filters. Pretreatment by micro-strainers is one method of removing the algae contained in the raw water.

IV. Dissolved Oxygen

If the dissolved oxygen content of the raw water drops below the potential oxygen demand, anaerobic conditions may develop within the bed. To some extent, a reasonable growth of algae in the supernatant reservoir oxygenates the supernatant water. Where the composition of raw water or climate does not favour the growth of algae, or where chemical dosing or some other device has been used to remove or exclude them, it may be necessary to use other expedients to increase the dissolved oxygen content, such as aeration of the incoming raw water.

V. Water Quality

Samples of raw and treated water will have to be taken at regular intervals for analysis. In a large waterworks with its own laboratory, sampling will almost certainly be carried out daily, since the effluent analysis constitutes the only certain check that the filter is operating satisfactorily and the raw water analysis provides what is possibly the only indication of a change in quality that might adversely affect the efficiency of treatment. Field testing equipment may be used to measure water quality.

VI. Filter Cleaning

While the filter is in operation, a stage comes when the bed resistance increases so much that the regulating valve has to be fully opened for additional pressure and it is the right time to plan the cleaning of the filter bed since any further resistance is bound to reduce the filtration rate as well as the filtrate. Resistance accelerates rapidly as the time for cleaning approaches. Indicators may be installed showing the inlet and outlet heads, from which the head loss can be monitored regularly, this gives a clear picture of the progress of choking and the imminence of the end of the run. Without any measurement of the head loss the only true indicator of build-up of resistance is the degree of opening of the regulating valve, though the experienced operator may be able to recognise preliminary visual warnings in the condition of the filter bed surface. A slight deterioration in the effluent quality may be a reason for the need for cleaning.

To clean a filter bed, the raw water inlet valve is first closed, allowing the filter to discharge to the clear water well as long as possible (usually overnight). As the head in the supernatant reservoir drops, the rate of filtration rapidly decreases, and although the water above the bed would continue to fall until level with the weir outlet, it would take a very long time to do so.

Consequently, after a few hours, the effluent delivery to the clear water well is closed and the supernatant water outlet is run to waste through the drain valve provided.

When the supernatant water has been drained off (leaving the water level at the surface of the bed), it is necessary to lower the water within the bed still further, until it is some 100 mm or more below the surface. This is done by opening the waste valve on the effluent outlet pipe. As soon as the scum deposit is dry enough to handle, cleaning should start. If the filter bed is left too long at this stage, it is likely to attract scavenging birds that will not only pollute the filter surface but also disturb the sand to a greater depth than will be removed by scraping.

The cleaning of the bed may be carried out by hand or with mechanical equipment. Working as rapidly as possible, they should strip off the scum deposit from the surface sand, stack it into ridges or heaps, and then remove the waste material by barrow, hand cart, basket, conveyor belt, or another device.

After removal of the scrapings the bed should be smoothed to level surface. The quicker the filter bed is cleaned the less will be the disturbance of the bacteria and shorter the period of re-ripening. Provided they have not been completely dried out, the microorganisms immediately below the surface will quickly recover from having been drained and will adjust themselves to their position relative to the new bed level. In this event, a day or two will be sufficient for re-ripening.

Before the filter box is refilled, the exposed walls of the supernatant water reservoir should be well swabbed down to discourage the growth of adhering slimes and algae, and the height of the supernatant water drain and of the outlet weir must be adjusted to suit the new bed level. The water level in the bed is then raised by charging from below with treated water from the clear water well or from one of the other filters. As soon as the level has risen sufficiently above the bed surface to provide a cushion, the raw water inlet is gradually turned on. The effluent is run to waste until analysis shows that it satisfies the normal quality standards. The regulating valves on the effluent line will be substantially closed to compensate for the reduced resistance of the cleaned bed, and the filter will then be ready to start a new run.

During the cleaning operations, precautions must be taken to minimise the chances of pollution of the filter bed surface by the labours themselves. Such measures, as the provision of boots to be used can be disinfected in a tray of nascent bleaching solution prior to use in the filter bed. Hygienic personal behaviour must be rigidly imposed, and no labours with symptoms that might be attributable to water borne or parasitic diseases should be permitted to come into direct or indirect contact with the filter medium.

VII. Re-sanding

After several years of operation and, say, 20 or 30, scrapings the depth of filtering material will be dropped to its minimum designed level (usually 0.5 to 0.8 m above the supporting gravel, according to the grain size of the medium). In the original construction, a marker, such as a concrete block or a step in the filter box wall, is sometimes set in the structure to serve as an indication that this level has been reached and that re-sanding has become due.

During the long period of the filter, use/run some of the raw water impurities and some products of biochemical degradation would have been carried into the sand-bed to a depth of some 0.3 to 0.5 m according to the grain size of the sand. To prevent cumulative fouling and increased resistance this depth of sand should be removed before re-sanding takes place, but it is neither necessary nor desirable that it should be discarded. Instead, it is moved to one side, the new sand is added, and the old sand replaced on the top of the new, thus retaining much of the active material would be enable the re-sanded filter to become operational with the minimum re-ripening.

This process (of replacing old sand on the top of the new) known as “throwing over” is carried out in strips. Excavation is carried out on each strip in turn, making sure that it is not dug so deeply as to disturb the supporting gravel layers below. The removed material from the first strip is stacked to one side in a long ridge, the excavated trench is filled with new sand, and the adjacent strip is excavated, throwing the removed material from the second trench to cover the new sand in the first. The operation is illustrated in Figure 5.6. When the whole of the bed has been re-sanded, the material in the ridge from the first trench is used to cover the new sand in the last strip.

In areas where sand is expensive or difficult to obtain, the surface scrapings may be washed, stored, dried, and used for re-sanding at some future date. These scrapings must be washed as soon as they are taken from the filter, otherwise, being full of organic matter, the material will continue to consume oxygen, quickly become anaerobic, and putrefy yielding odd taste and odour-producing substances that are virtually impossible to remove during any further washing process.

Sand washing machines should be provided for the bigger plants. Wherever provided, these should be operated regularly to prevent accumulation of sand and also to keep the machine in working condition.

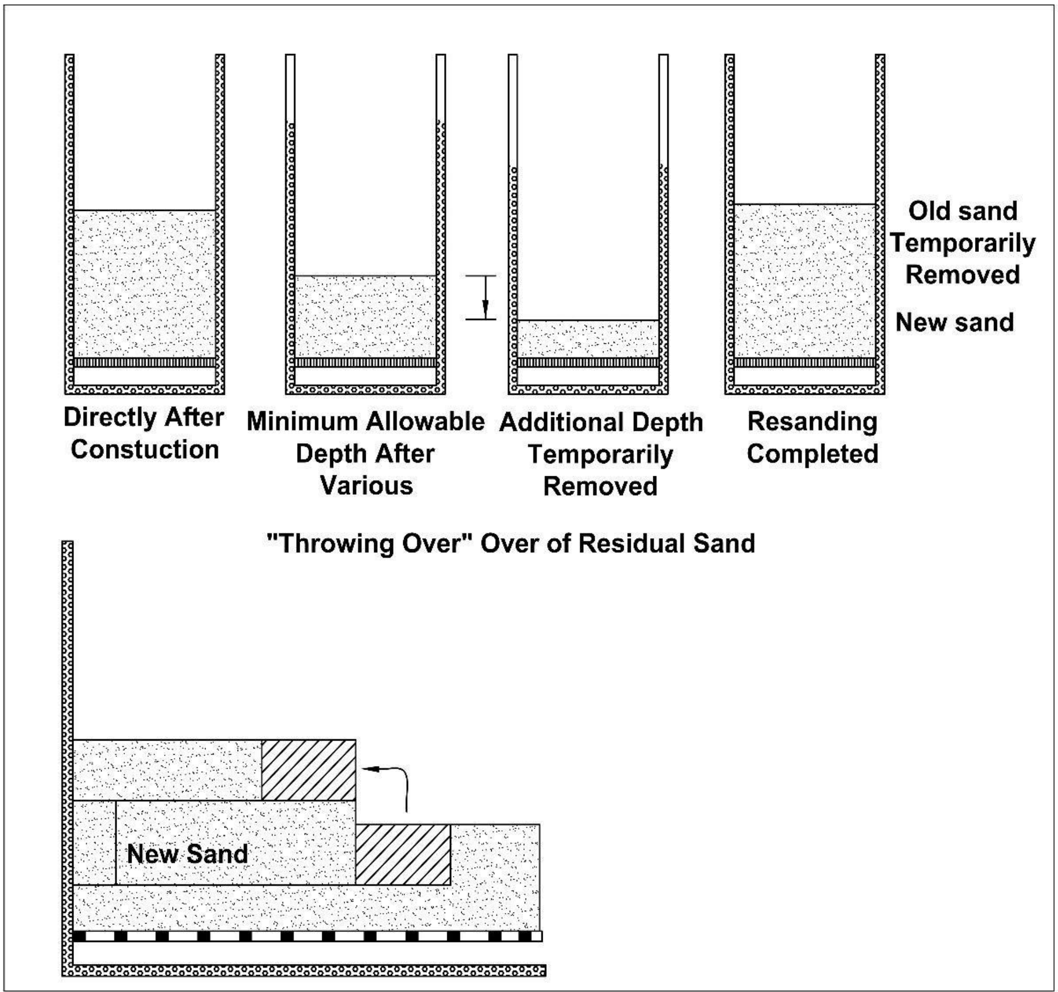


Figure 5.6: Re-sanding of a Slow Sand Filter

VIII. Augmentation of Existing Plant

Some of the existing slow sand filtration plants need augmentation. There is a tendency to abandon the old plants and substitute the same with rapid sand filtration plants. It is suggested that, wherever possible, the old slow sand filtration plants may be retained on account of the following reasons:

i) An SSF is less likely to go wrong under inexperienced operation.
ii) It does not require skilled attendance.
iii) Head consumed is less.
iv) It provides greater reliability of the removal of bacteria.
v) Operating costs may be less.
vi) Though it occupies a larger area than that of rapid gravity filtration system.

It is, however, adapted to waters low in colour, turbidity, and bacterial count. Under such circumstances, provision of a roughing filter as a pretreatment unit gives good results.

5.4.7.2 Rapid Sand Filters

Rapid sand filter (RSF) consists of a bed of sand and gravel that acts as a physical barrier, trapping and removing contaminants as water passes through. The filter operates at a relatively high flow rate, allowing for quick treatment of large volumes of water. To maintain its effectiveness, the filter bed is periodically cleaned through backwashing, where water is forced through the filter in the opposite direction to dislodge trapped particles. RSFs are commonly used in municipal WTPs and industrial processes to ensure the provision of clean and safe water.

I. Components of Rapid Sand Filter

The major parts of a gravity RSF are:

- Filter tank or filter box;
- Filter media;
- Gravel support;
- Underdrain system; and
- Wash-Water troughs.

Figure 5.7 shows a typical RSF water treatment with components. The filter is contained within a filter box, usually made of concrete. Inside the filter box are layers of filter media and gravel.

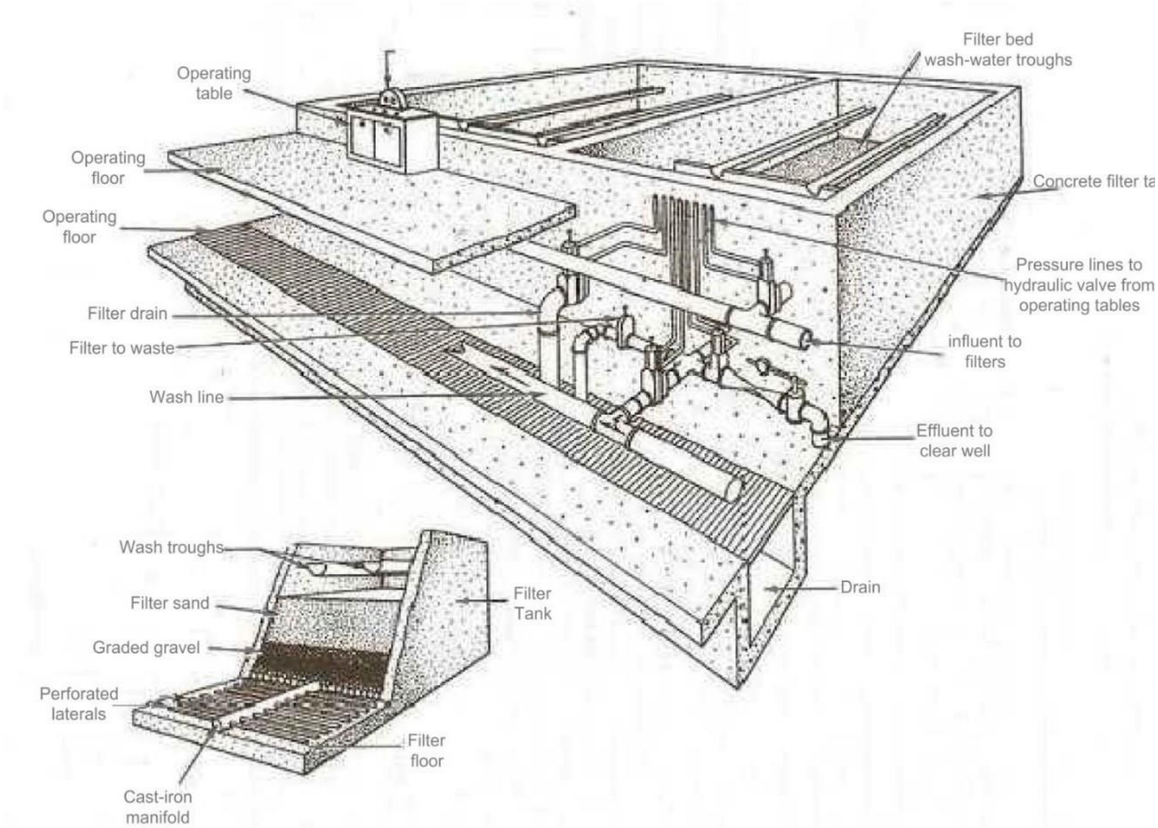


Figure 5.7: Typical Rapid Sand Filter

Below the gravel, a network of pipes makes up the underdrain system which collects the filtered water and evenly distributes the backwash water. Wash-water troughs help distribute the influent water and are also used in collecting the dirty washed water during backwashing.

In addition to the components mentioned above, most RSFs contain a flow controller, or filter control system, which regulates flow rates of water through the filter. Other parts, such as valves, a loss of head gauge, surface washers, and a backwash pump, are used while cleaning the filter.

Operation of an RSF during water filtration is similar to operation of an SSF. The influent water flows down through the sand and support gravel and is collected by the underdrain system, as shown in Figure 5.7 However, the influent water in an RSF is already relatively clear due to coagulation, flocculation, and clarification, so RSFs operate much more quickly than SSFs.

II. Operation

Filter Operation: A filter is usually operated until just before clogging or breakthrough occurs or a specified time period has passed (generally 24 hours).

Backwashing: After a filter clogs or breakthrough occurs or a specified time has passed, the filtration process is stopped and the filter is taken out of service for cleaning or backwashing.

Surface Wash: In order to produce optimum cleaning of the filter media during backwashing and to prevent mud balls, surface wash (supplemental scouring) is usually required. Surface wash systems provide additional scrubbing action to remove attached floc and other suspended solids from the filter media.

III. Operational Procedures

a) **The indicators of normal operating conditions**
The filter influent and effluent turbidities should be closely watched with a turbidity meter. Filter influent turbidity levels (settled turbidity) can be checked on a periodic basis at the filter or from the laboratory sample tap. However, the filtered effluent turbidity is best monitored and recorded on a continuous basis by an online turbidity meter.

b) **Process actions**
Follow the steps as indicated below:

- Monitor process performance.
- Evaluate turbidity and make appropriate process changes.
- Check and adjust process equipment (change chemical feed rates). Backwash filters.
- Evaluate filter media condition (media loss, mud balls, cracking). Visually inspect facilities.

c) **Important process activities and precautions**

1. Monitoring process performance is an ongoing activity. You should look for and attempt to anticipate any treatment process changes or other problems that might affect filtered water quality, such as a chemical feed system failure.
2. Measurement of head loss built up (Figure.5.8) in the filter media will give you a good indication of how well the solids removal process is performing. The total designed head loss from the filter influent to the effluent in a gravity filter is usually about 3 m. At the beginning of the filtration cycle, the actual measured head loss due to clean media and other hydraulic losses is about
0.9 m. This would permit an additional head loss of about 2.1 m due to solid accumulation in the filter.
3. The rate of head loss build up is an important indication of process performance. Sudden increase in head loss might be an indication of surface sealing of the filter media (lack of depth penetration). Early detection of this condition may permit you to make appropriate process changes such as adjustment of chemical filter aid feed rate

or adjustment of filtration rate.

4. Monitoring of filter turbidity on a continuous basis with an online turbidity meter is highly recommended. This will provide you with continuous feedback on the performance of the filtration process. In most instances, it is desirable to cut off (terminate) filter at a predetermined effluent turbidity level. Preset the filter cut off control at a point where you experience and tests show that breakthrough will soon occur (Figure 5.9).
5. In the normal operation of the filter process, it is best to calculate when the filter cycle will be completed on the basis of the following guidelines:
    - Head loss.
    - Effluent turbidity level.
    - Elapsed run time.

   A predetermined value is established for each guideline as a cut off point for filter operation. When any of these levels is reached, the filter is removed from service and backwashed.
6. At least once a year, one must examine the filter media and evaluate its overall condition. Measure the filter media thickness for an indication of media loss during the backwashing process. Measure mud ball accumulation in the filter media to evaluate the effectiveness of the overall backwashing operation.
7. Routinely observe the backwash process to qualitatively assess process performance. Watch for media boils (uneven flow distribution) during backwashing, media carry over into the wash-water trough, and clarity of the waste wash-water near the end of the backwash cycle.
8. Upon completion of the backwash cycle, observe the condition of the media surface and check for filter sidewall or media surface cracks. You should routinely inspect physical facilities and equipment as part of good housekeeping and maintenance practice. Correct or report the abnormal equipment conditions to the appropriate maintenance personnel.
9. Never bump up a filter to avoid backwashing. Bumping is the act of opening the backwash valve during the course of a filter run to dislodge the trapped solids and increase the length of filter run. This is not a good practice.
10. Shortened filter runs can occur because of air bound filters. Air binding will occur more frequently when large head losses are allowed to develop in the filter. Precautions should be taken to minimise air binding to avoid damage to the filter media.

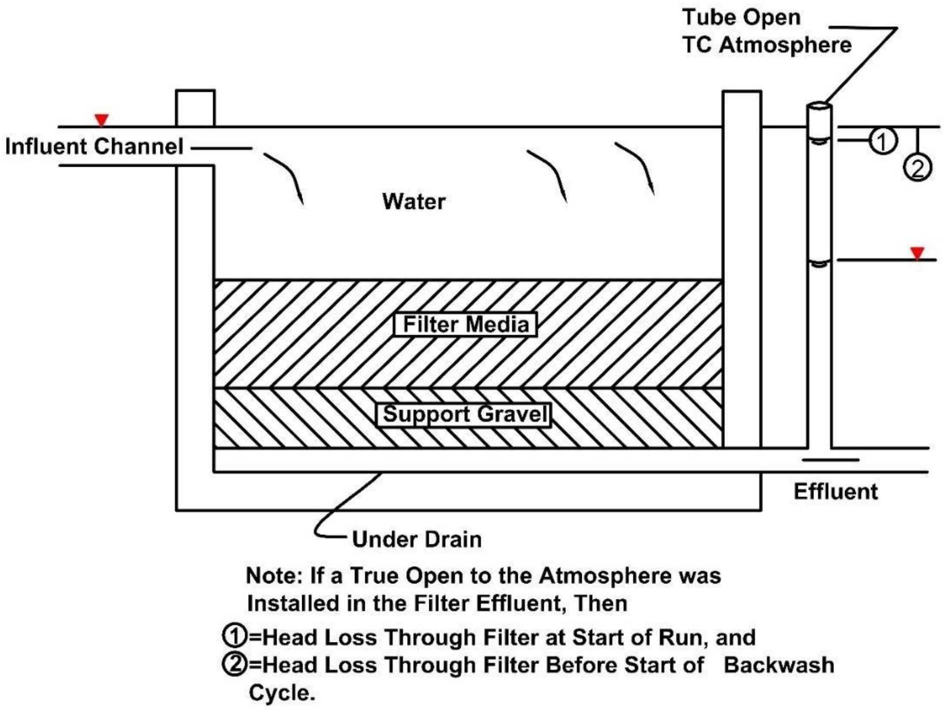


Figure 5.8: Measurement of Head Loss

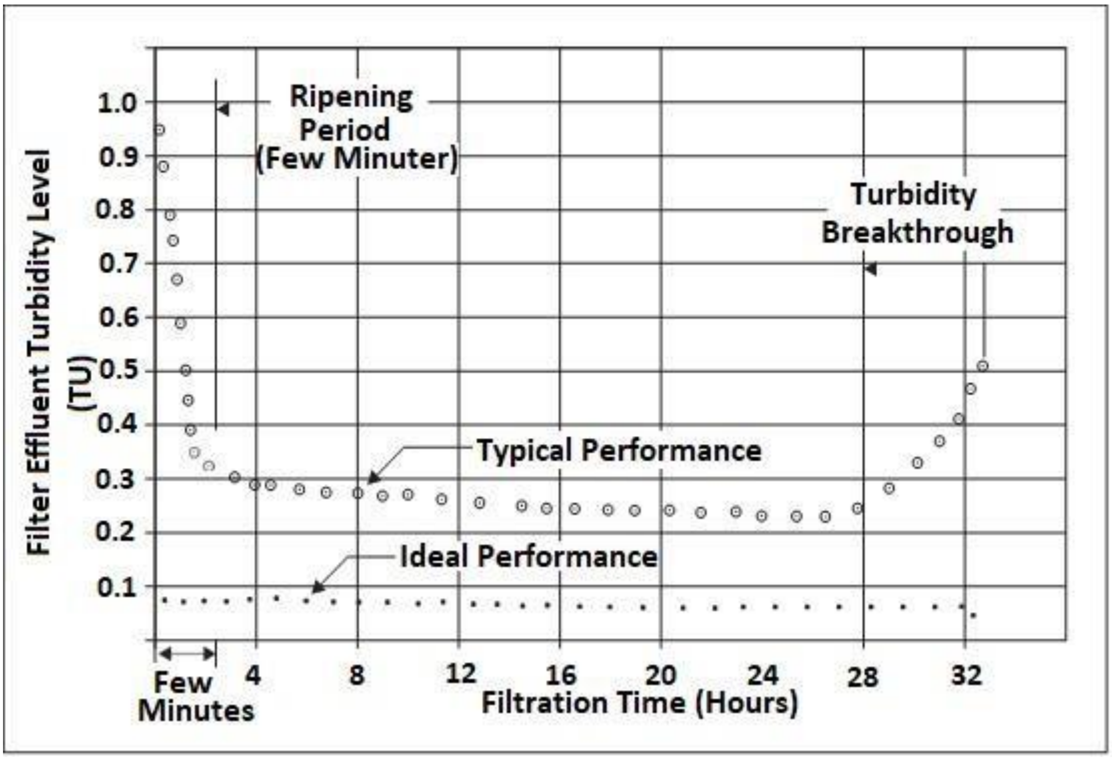


Figure 5.9: Typical Filter Turbidity Data

A summary of routine filtration process action is given in Table 5.5 and filtration process troubleshooting problems is given in Table 5.6.

Table 5.5: Summary of Routine Filtration Process Action

Monitor Process Performance and Evaluate Water Quality Conditions	Location	Frequency	Possible Operator Actions
Turbidity Colour Head loss	Influent/ Effluent Influent/ Effluent	At least once per 8- hour shift. At least once per 8-hour shift. At least two times per 8-hour shift.	1. Increase sampling frequency when process water quality is variable. 2. Perform jar tests. 3. Make necessary process changes: • Adjust coagulant dosage. • Adjust flash mixer/flocculator mixing intensity. • Change filtration rate. • Backwash filter. • Change chlorine dosage. • Change coagulant.
Operate Filters and Backwash	**Location**	**Frequency**	**Possible Operator Actions**
Put filter into service. Change filtration rate. Remove filter from service. Backwash filter. Change backwash rate.	Filter module	Depends on process conditions	See operating procedures (Section 5.11.2 (II))
Check Filter Media Condition	**Location**	**Frequency**	**Possible Operator Actions**
Media depth evaluation. Media cleanliness. Cracks or shrinkage.	Filter module	At least monthly.	1. Replace lost filter media. 2. Change backwash procedure. 3. Change chemical coagulants.
Make visual Observations of Backwash Operation	**Location**	**Frequency**	**Possible Operator Actions**
Check for media boils and media expansion. Check for media carryover into wash-water trough. Observe clarity of wastewater.	Filter module	At least once per day or whenever backwashing occurs.	Change backwash rate. Change backwash cycle time. Adjust surface wash rate or cycle time. Inspect filter media and support gravel for disturbance.
Check Filtration Process and			

Backwash Equipment Condition	Location	Frequency	Possible Operator Actions
Noise, Vibration, Leakage, Overheating	Various	Once per 8-hour shift.	Correct minor problems.
Inspect Facilities	**Location**	**Frequency**	**Possible Operator Actions**
Check physical facilities and algae on sidewalls and troughs.	Various	Once a day.	1. Remove debris from filter media surfaces. 2. Adjust chlorine dosage to control algae.

Note: All major problem should be reported to the competent authorities and response duly followed up.

Table 5.6: Filtration Process Troubleshooting

Source Water Quality Changes	Operator Actions	Possible Process Changes
Turbidity Temperature Alkalinity pH Colour Chlorine Demand	1. Perform necessary analysis to determine extent of change. 2. Assess overall process performance. 3. Perform jar tests. 4. Make appropriate process changes. 5. Increase frequency of process monitoring. 6. Verify response to process changes (be sure to allow sufficient time for change to take effect) 7. Add lime or caustic soda if alkalinity is low.	1. Adjust coagulant dosage. 2. Adjust flash mixer/flocculator mixing intensity. 3. Change frequency of sludge removal (increase or decrease). 4. Adjust backwash cycle (rate, duration). 5. Change filtration rate (add or delete filters). 6. Start filter aid feed. 7. Change coagulant.
Sedimentation Process Effluent Quality Changes	**Operator Actions**	**Possible Process Changes**
Turbidity or floc carryover	1. Assess overall process performance. 2. Perform jar tests. 3. Make appropriate process changes.	Same as source water quality changes.
Filtration Process Changes/ Problems	**Operator Actions**	**Possible Process Changes**
Head loss increase	1. Assess overall process	1. Adjust coagulant dosage.

Short filter runs media surface sealing Mud balls Filter media cracks, shrinkage filter not clean Media boils Media loss Excessive head loss	performance. 2. Perform jar tests. 3. Make appropriate process changes.	2. Adjust flash mixer/flocculator mixing media intensity. 3. Change frequency of sludge removal. 4. Adjust backwash cycle (rate, duration). 5. Manually remove mud balls. 6. Decrease filtration rate (add more filters). 7. Decrease or terminate filter aid. 8. Replenish lost media. 9. Clear underdrain openings of media, corrosion, or chemical deposits; check head loss. 10. Change coagulant.
Filter Effluent Quality Changes	**Operator Actions**	**Possible Process Changes**
Turbidity breakthrough Colour pH Chlorine	1. Assess overall process performance. 2. Perform jar tests. 3. Verify process performance: Coagulation and flocculation. Sedimentation process. Filtration process. 4. Make appropriate process changes.	1. Adjust coagulant dosage. 2. Adjust flash mixer/flocculator mixing intensity. 3. Change frequency of sludge removal. 4. Start filter aid feed. 5. Decrease filtration rate (add more filters). 6. Change chlorine dosage. 7. Change coagulant.

Note: All major problems should be reported to the competent authorities and response duly followed up.

IV. Augmentation of Rapid Sand Filtration Plants

Augmentation of an existing rapid sand filtration plant can be carried out by converting the conventional filtration process to variable declining rate filtration with dual media filter units. The filter unit will, however, require additional depth. Special precautions are required to strictly adopt the specifications of the two filter media regarding effective size and specific gravity. During operation, a special watch has to be kept to avoid intermixing of the two media.

V. Startup and Shutdown Procedures

a) Routine Procedure

Most plants keep all filters online except for backwash and in service except for maintenance. Filters are routinely taken offline for backwashing when the media becomes clogged with particulates, turbidity breakthrough occurs, or demands for water are reduced.

b) Startup and Shutdown Procedures

1. Filter checkout procedures

- Check operational status of filter.
- Ensure that the filter media and wash-water troughs are clean of all debris such as leaves, twigs, and tools.
- Check and ensure that all access covers and walkway gratings are in place.
- Make sure that the process monitoring equipment, such as head loss and turbidity systems, are operational.
- Check the source of backwash to ensure that it is ready to go.

2. Guideline for filter backwash

- Close the influent valve but continue the water treatments filter in operation until the water level drops to a point about 15 cm above the sand. This conserves the settled water and also permits inspection of the filter sand.
- Close the effluent valve.
- Inspect the water filter for mud balls, cracks, mounds, or evidence that the sand is drawing away from the sidewalls.
- Open the drain valve. This may be done any time after the water on filter is below the wash-water gutter.
- Open the wash-water valve gradually during a period of 45 to 60 seconds to the point where expansion is about 15%, or flow is about 400 Lpm/m^2. This prevents wash water from entering so fast that the compacted surface sand is lifted as a body until a portion cracks and causes high horizontal flow towards the crack, this flow carrying the cleaner bottom sand and pea gravel with it.
- The backwash water must have enough velocity and volume to agitate the sand and carry away the foreign matter which has collected there.
- Backwashing should begin slowly. If begun too quickly, backwash water can damage the underdrain system, gravel bed, and media due to the speed of the water. Beginning backwashing too quickly will also force air bound in the filter out, further damaging the filter.
- Wash at a low rate for about 3 minutes, to provide ample time for the sand grains to impinge on one another and dislodge the floc.
- Open the wash-water valve that gives the maximum sand expansion desired, such as 40%, and continue for about 1 minute or until the wash water appears to be relatively clear and the agitated sand can be observed.
- The dirty backwash water is collected by the wash troughs and can be recycled after sedimentation to the beginning of the plant or can be allowed to settle in a tank, pond, or basin.
- Close the wash-water valve after the cleaning.
- Close the drain valve.
- Open the influent valve slowly, so as to avoid undue turbulence and disturbance of the sand.
- Open the influent valve wide when the water level reaches the normal level, then open the filtered water outlet valve.

3. Backwash procedure

i) **Filters should be washed before placing them into service.**

The surface wash system should be activated just before the backwash cycle starts to aid in removing and breaking up solids on the filter media and to prevent the development of mud balls. The surface wash system should be stopped before completion of the backwash cycle to permit proper settling of the filter media.

A filter wash should begin slowly for about 1 minute to permit purging (removing) of an entrapped air from the filter media, and also to provide uniform expansion of the filter bed. After this period, the full backwash rate can be applied. Sufficient time should be allowed for cleaning of the filter media. Usually, when the backwash water coming up through the filter becomes clear, the media is washed. This generally takes from 3 to 8 minutes. If flooding of wash-water troughs or carryover of filter media is a problem, the backwash rate must be reduced.

ii) Procedure for backwashing a filter is as follows (Figure 5.10):

- Log length of filter run since last backwash.
- Close filter influent valve (V-1).
- Open drain valve (V-4).
- Close filter effluent valve (V-5).
- Start surface wash system (open V-2).
- Slowly start backwash system (open V-3).
- Observe filter during washing process.
- When wash water from filter becomes clear (filter media is clean), close surface wash system valve (V-2).
- Slowly turn off backwash system (close V-3).
- Close drain valve (V-4).
- Log length of wash and the quantity of water used to clean filter.

c) Filter Startup Procedures

- Start filter.
- Slowly open influent valve.
- When proper elevation of water is reached on top of filter, filter effluent valve should be gradually opened. This effluent control valve should be adjusted itself to maintain a constant level of water over the filter media.
- Waste some of the initial filtered water if such a provision exists.
- Perform turbidity analysis of filtered water and make process adjustments as necessary.

d) Filter Shutdown Procedures

- Remove filter from service by closing influent valve and closing effluent valve.
- Backwash filter.
- If filter is to be out-of-service for a prolonged period, drain water from filter to avoid algal growth.
- Note status of filter in operations log.

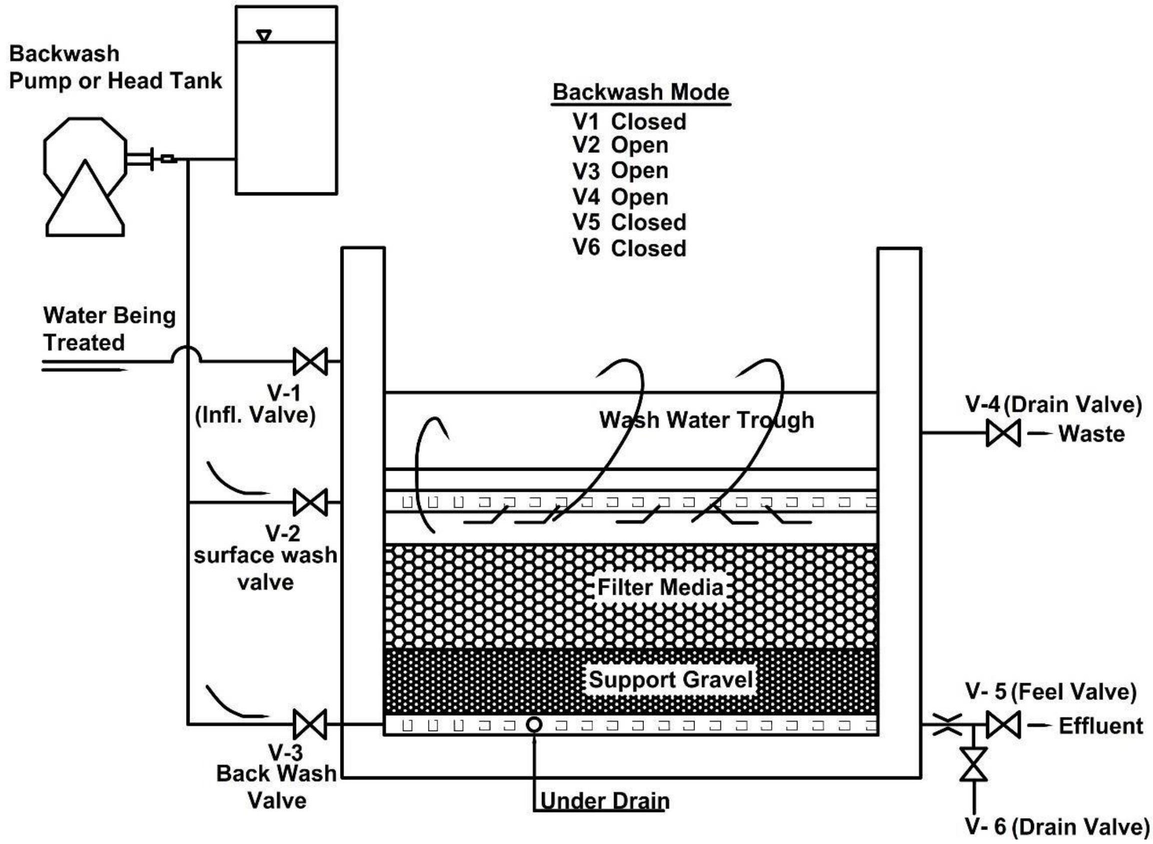


Figure 5.10: Backwash Operation

VI. Support Equipment

The operator must be familiar with the O&M instructions for each specific equipment item or control system.

a) **Types of Equipment**

1. Filter control valves.
2. Backwash and surface wash pumps.
3. Flowmeter and level/pressure gauges.
4. Water quality monitors such as turbidity meters.
5. Process monitors (head loss and water level).
6. Mechanical and electrical filter control systems.

b) **Equipment Operation**

Before starting a piece of mechanical equipment, such as a backwash pump, be sure that the unit has been serviced on schedule and its operational status is known.

After startup, always check for excessive noise and vibrations, overheating, and leakage (water, lubricants). When in doubt about the performance of a piece of equipment, refer to manufacturer's instructions.

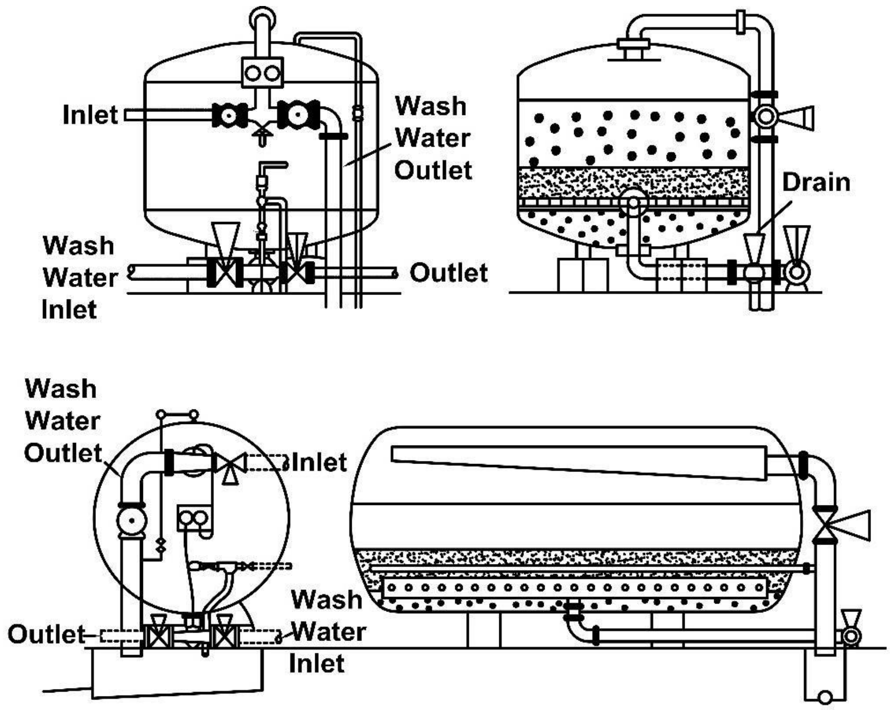
Periodic calibration and maintenance of the equipment is necessary.

VII. Other Categories of Filters

There are a number of other categories of filtration plants that are not commonly used. Among these, pressure filters are used for small treatment plants or industries. Roughing filters may be used to reduce the load on the treatment plants. Small streams of water in the catchment areas may carry large quantity of particles and floating matter, particularly during monsoon period. Introduction of the roughing filters will ensure entrapping of such undesirable material prior to the storage structures of the treatment units.

5.4.7.3 Pressure Filters

Pressure water treatment filter is an RSF contained under pressure in a closed tank (steel, GRP, etc.), which may be vertical or horizontal, depending on the space available. Similar to gravity filters, the media in pressure filter is usually sand or a combination of media also called multimedia filters. Filtration rates are similar to gravity filters. Figure 5.11 shows the details of vertical and horizontal pressure water treatment filters.



Pressure Filters: Vertical Pressure Filter. Bottom: Horizontal Pressure Filter

Figure 5.11: Details of Vertical and Horizontal Pressure Filter (Top: Vertical pressure filter, Bottom: Horizontal pressure filter)

These filters are commonly used for iron and manganese removal from groundwater, which is first aerated to oxidise the iron or manganese present, then pumped through the filter to remove the suspended material. Pressure filters are also used in swimming pool for recirculation water treatment.

Regardless of the method of control, the water filter eventually fills with suspended material. At some time, usually after 15 to 30 hours, it will need to be backwashed similar to RSF to clean the media and restore the normal rate of filtration.

The water passes through the sand and emerges from the filter under a pressure greater than atmosphere.

Pressure filters are used primarily in small plants and in industries where the raw water is received, and the filtered water is discharged, under pressure.

Operation
The filter is operated similar to a gravity-type filter except that the coagulated water is applied directly to the filter without mixing, flocculation, or conditioning. Automatic filters are available in which the valves are manipulated automatically to backwash at a predetermined time or head loss. It is to be noted that the head loss through the filter is approximately the same as through a gravity filter. The term “pressure filter” does not imply that water is pumped through the filter under a high-pressure loss.

The coagulant, normally, is applied under pressure in the influent line to the filter, the influent water dissolving the alum as it enters the filter.

Following drawbacks have been noticed in the working of the pressure filters. Efforts should be made during their maintenance to avoid the same.

- There is no scope for proper formation of the flocs, the entrapment of the unsettle-able and colloidal particles, and independent settlement of the settleable solids.
- The filter media becomes mixed up due to the water pressure. Cracks develop within the filter sand media and serious piping develops within the entire media.
- Due to intermixing of the media, the under-drainage system gets damaged.
- The behaviour of the filter operation cannot be examined properly.

5.4.7.4 Roughing Filters

Some solid particles suspended in water are so small and light that they do not settle in a normal sedimentation tank and flow into the filter leading to increase difficulty of their cleaning. Roughing filters are used as a preliminary treatment step to remove solid matters which would, otherwise, impair the operation of the conventional filters. It typically consists of a coarse filter media, such as gravel or crushed stones, arranged in a bed. As water passes through the filter, the coarse media acts as a physical barrier, effectively trapping and removing larger particles.

These may be of horizontal flow or vertical flow. When used as pretreatment units in SSF, the plant can handle raw water of higher turbidity, colour, and bacterial count.

When installed in a catchment area it reduces the load on the conventional plant by arresting courser impurities and floating matter.

Performance Capabilities of Rapid Sand Filters
For RSFs performance standards may be based on the following criteria:

a) The filtrate should be clear with the turbidity of 1 NTU or less.
b) The filtrate should be free from colour (with 3 or less on the cobalt scale).
c) The filter runs should normally be not less than 24 hours with a loss of head not exceeding 2 m.
d) For an efficient filter, the wash-water consumption should not exceed 2% of the quantity filtered in between washing (calculated over one year of operation period).

5.4.7.5 Operational Problems

- Improper operation of filtration units can result in poor quality of finished water and damage to the filter bed. In order to ensure proper operation, operators must continually monitor the operation of the filter units. The filtered water turbidity and the head loss through each filter unit are of particular interest.

- The filters must be backwashed as soon as either the filtered water turbidity or the head loss through a filter unit reaches a preset maximum value. Also, if a filter unit has been idle for a period of time, it should be thoroughly backwashed prior to its being put back into service.
- Improper filter backwashing may cause inadequate filter cleaning and possible damage to the unit. If the backwash water is introduced too rapidly, the filter bed can be disturbed, or, in extreme cases, the filter bottom can be damaged. In order to reduce the chances of damage to the filter beds from improper backwashing techniques, most filter systems utilise automatic backwash controls.
- The two most common problems encountered in filter operation are mud ball formation and air binding. Mud ball formation is usually the effect of improper backwashing techniques, but improper media selection can also be the cause. Single medium filters historically show a greater tendency to form mud balls than do properly designed dual media and mixed media filters. Surface wash, sub-surface washing, or air scouring of filters before and during backwash also reduces the tendency to form mud balls in the filter bed.
- Once mud balls have formed in a filter bed, the most effective means of removing them is to remove the filter media and either replace it or thoroughly clean the media before placing them back into the bed. Once mud balls have begun to form in a filter bed, they will usually grow larger.
- Air binding of filter beds is usually caused by improper hydraulic design of the filter system. Possible solutions to air binding are (i) replacing the filter media with one with a different gradation, (ii) reducing the maximum flow rate through the filter, and (iii) inducing additional hydraulic head in the filter effluent, to raise the hydraulic gradient in the filter bed.
- Frequently observed problems in filter beds

  Problems in filter operation and performance can arise from either poor design or poor operation. However, in the last two decades, a lot of advances in the engineering design of filters, filter controls, and appurtenances have made water filtration an inherently stable, efficient, and reliable unit treatment process.

Some potential filter problems are as follows:

a) Surface clogging and cracking
b) Short runs due to rapid increases in head loss
c) Short runs due floc breakthrough and high effluent turbidity
d) Variations in effluent quality with changes in applied water flow rate or quality
e) Gravel displacement or mounding
f) Mud balls
g) Growth of filter grains, bed shrinkage, and media pulling away from side walls
h) Sand leakage
i) Negative head and air binding
j) Air leakage into system
k) Non-uniform air scour operation
l) Defunct rate of flow controllers

m) Failed underdrain systems which can cause sink holes, depressions, or mounds
n) Floc accumulating on the surface of the media causing short filter runs.

5.4.7.6 Brief Troubleshooting Guide

Condition I: High head loss through a filter unit or filter run

Possible cases are:

- Filter bed in need of backwashing
- Air binding
- Mud balls in the filter bed
- Improper rate of flow controller operation
- Clogged under drains
- Improper media design: too small (or) too deep
- Floc strength too strong – will not penetrate media

Condition 2: High effluent turbidity

Possible cases are:

- Filter bed in need of backwashing
- Rate of flow too high
- Improper rate of flow controller operation
- Disturbed filter bed
- Mud balls in the filter bed
- Air binding
- Inappropriate media size or depth
- Low media depth (caused by loss during backwash)
- Floc too small or too weak caused by improper chemical pretreatment.

As a coating builds and penetrates into the filter bed, the head loss across the filter becomes greater until the flow rate is greatly reduced. At this time, the filter must be backwashed to cleanse the media of the floc and particulate matter with following checks:

- The filter control valves should be checked routinely for proper operation and any leakage.
- The filter media should be examined annually to evaluate its overall condition, i.e.:
  - Is the media uniformly graded and distributed?
  - Is there the proper depth of each gradation of media?
- Expose the underdrain system to check if the holes or nozzles are clogged.
- The backwash and surface wash pumps should be checked and lubricated according to the manufacturer's recommendations.
- The surface wash equipment, including nozzles, should be checked periodically for free operation and proper position over the media.

5.4.7.7 Preventive Maintenance Procedures

Preventive maintenance programmes are to assure the continued satisfactory operation of treatment plant facilities by reducing the frequency of breakdown failures.

Routine maintenance functions include:

- Keeping electric motors free of dirt, moisture, and pests (rodents and birds).
- Assuming good ventilation (air circulation) in equipment work areas.
- Checking pumps and motors for leaks, unusual noise, and vibrations or overheating.
- Maintaining proper lubrication and oil levels.
- Inspecting for alignment of shafts and couplings.
- Checking bearings for overheating and proper lubrication.
- Checking the proper valve operation (leakage or jamming).
- Checking automatic control systems for proper operation.
- Checking air/vacuum relief systems for proper functioning, dirt, and moisture.
- Verifying correct operation of filters and backwashing cycles by observation.
- Inspecting filter media condition (look for algae and mud balls and examine gravel and media for proper gradation).
- Inspecting filter underdrain system (be sure that the underdrain openings are not becoming clogged due to media, corrosion, or chemical deposits).

5.4.7.8 Safety Considerations

a) Electrical Equipment

1. Avoid electric shock (use preventive gloves).
2. Avoid grounding yourself in water or on pipes.
3. Ground all electric tools.
4. Lock out and tag electrical switches and panels when servicing equipment.

b) Mechanical Equipment

1. Use protective guards on rotating equipment.
2. Don't wear loose clothing around rotating equipment.
3. Make sure of proper lighting arrangements (not to cause stroboscopic effects).
4. Keep hands out of energised valves, pumps, and other pieces of equipment.
5. Clean up all lubricant and chemical spills (slippery surfaces cause bad falls).

c) Open Surface Filters

1. Use safety devices such as handrails and ladders.
2. Close all openings and replace safety gratings when finished working.
3. Know the location of all life preservers and other safety devices.

d) Valve and Pump Vaults, Sumps, Filter Galleries

1. Ensure that all underground or confined structures are free of hazardous atmospheres (toxic or explosive gases, lack of oxygen) by checking with gas detectors.
2. Only work in well-ventilated structures (use air circulation fans). For more details, refer to Chapter 13: "Safety Practices", Part B of this manual.

5.4.7.9 Record Keeping

The following are the basic records that must be maintained:

1. The date of each cleaning (commencement).
2. The date and hour of return to full service (end of re-ripening period).
3. Raw and filtered water levels (measured each day at the same hour) and daily loss of head.
4. The filtration rate, the hourly variations, if any.
5. The quality of raw water in physical terms (turbidity, colour) and bacteriological terms (total bacterial count, E. coli) determined by samples taken each day at the same hour.
6. The quality of raw water in chemical terms, as per prescribed schedule.
7. The same quality factors of the filtered water.
8. Any incidents occurring, e.g., plankton development, rising scum debris, and unusual weather conditions.

Maintain a daily operations log of process performance data and water quality characteristics. Accurate recording of the following items should be maintained.

1. Process water quality (turbidity and colour).
2. Process operation (filters in service, filtration rates, loss of head, length of filter runs, frequency of backwash, backwash rates, and UFRV).
3. Process water production (water processed, amount of backwash water used, and chemicals used).
4. Percentage of water production used to backwash filters.
5. Process equipment performance (types of equipment in operation, equipment adjustments, maintenance procedures performed, and equipment calibration).

A typical daily operating record for a WTP is shown in Table 5.7.

Table 5.7: Filters Daily Operating Record

No	Time		Hours operated			Head loss		Wash		Physical condition of filters
	Start	Stop	Today	Previous	Total	Start	Stop	Min.	KL	
No. of filters washed						Average filter rate				
Average run-hours						Maximum hourly rate				
Total wash water						Total water filtered				
Percent of water filtered						No. of filters operating				
Average time of wash-min.						Filters out per wash-min.				
						Shift				
						Operator				

5.4.8 Disinfection

Water can be disinfected by heat, radiation, or chemical treatment; however, the only widely accepted method is chemical treatment. Chlorination usually is accomplished by either gas chlorinators, hypo-chlorinators, or chlorine dioxide generators. The details of disinfection are described in Chapter 9: “Disinfection”, Part A of the manual.

The disinfection of potable water is almost universally accomplished by the use of gaseous chlorine or chlorine compounds, because of the limitations of other procedures, for example, ozone, ultraviolet light, chlorine dioxide, etc. Chlorine is easy to apply, measure, and control. It persists reasonably well and it is relatively inexpensive.

5.4.8.1 Chlorination

The primary objectives of the chlorination process are disinfection, taste, and odour control in the system, preventing the growth of algae and other microorganisms that might interfere with coagulation and flocculation, keeping filter media free of slime growths and mud balls, and preventing possible built up of anaerobic bacteria in the filter media, destroying hydrogen sulfide, and controlling sulphurous taste and odour in the finished water, removing iron and manganese, and bleaching of organic colour.

It can also be used for flushing pipeline before it is brought into operation after carrying out repairs, etc. However, in such case, chlorinator is adjusted to apply chlorine or hypochlorite solution at the rate of 50 ppm. Heavily chlorinated water should be allowed to stand in the pipeline for at least 30 minutes and preferably for 12 hours before being replaced with potable water.

I. Principles of Chlorination

- Chlorine reacts with water to form hypochlorous acid (HOCl) and hydrochloric acid (HCl). This hydrolysis reaction is reversible. The hypochlorous acid dissociates into hydrogen ions (H^+) and hypochlorite ions (OCl^-), free available chlorine is hypochlorous acid and hypochlorite ions.
- This free available chlorine can react with compounds such as ammonia, proteins, amino acids, and phenol which may be present in the water, forming chloramines and chloro-derivatives which constitute the combined chlorine.
- Chlorination in presence of humic acid and fulvic acid forms trihalomethane (THM) which is a health hazard.
- The combined available chlorine has fewer disinfecting properties as compared to free available chlorine.

II. Methods of Application

Disinfection is carried out by applying chlorine or chlorine compounds. The methods of application are as follows:

1. Preparing weak solution by bleaching powder, HTH, etc.
2. Preparing weak solution by electrolysing brine solution.
3. By adding chlorine either in the form of gas or solution prepared from dissolving chlorine gas in small feed of water.

5.4.8.2 Bleaching Powder

Bleaching powder or calcium hypochlorite is a chlorinated lime, which contains about 25% to 34% of available chlorine by weight. Chlorine being a gas is unstable and as such it is mixed with lime to retain its strength for a longer period, as far as possible. The bleaching powder is hygroscopic in nature. It loses its chlorine strength rapidly due to storage and hence should not be stored for more than three months. The method of chlorination by bleaching powder is known as hypo-chlorination.

The calcium hydroxide settles as precipitate. The combined action of hypochlorous acid and hypochlorite ion brings about the disinfection of water.

I. Solution Preparation

i) The concentrated solution of bleaching powder is prepared in one or two tanks of capacity suitable for 24 hours requirement.
ii) The tank inside should be of glazed tiles or stoneware and should be covered.
iii) The powder is first put on a perforated slab placed longitudinally inside the tank at a higher level, with respect to bed level of tank.
iv) Water is sprinkled on the powder through a perforated pipe above this perforated slab. The solution of bleaching powder and water now enters the tank.
v) The solution is rotated for thorough mixing of powder with water by a hand driven/motor-reduction gear operated slow speed stirrer.
vi) The precipitates of calcium hydroxide settle at the bottom of the tank. The supernatant water, which contains OCl^-, Cl^-, is now ready for use as disinfectant.

II. Dosing of Solution

i) The solution is discharged to a small measuring tank at a lower level through PVC pipe or any other material resistant to chlorine. The level of water in this tank is maintained constant through a float valve. A micrometer orifice valve discharges the solution at any pre-set rate, by adjustment on the scale fitted on it. The solution is dosed to the clear water channel by gravity at the time of entry to clear water reservoir. The waste precipitates at the bottom of tanks are taken out occasionally by scour valve. The system is shown in Figure 5.12.
ii) The dose has to be monitored properly, depending on the desired residual chlorine required in clear water reservoir.

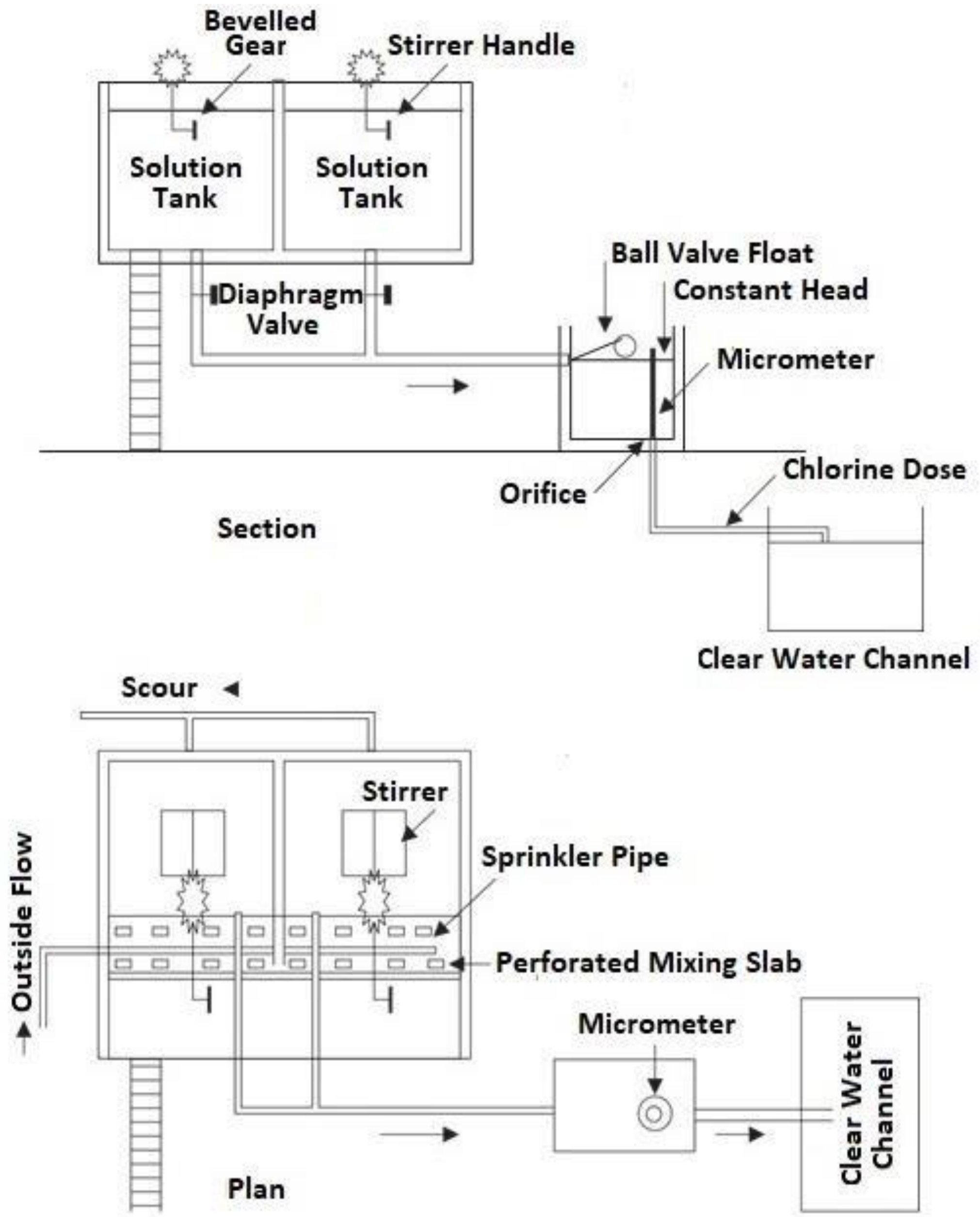


Figure 5.12: Typical Bleaching Solution Dosing

III. Precautions

i) The operating personnel should use hand gloves, aprons, and other protective apparel, while handling and mixing.
ii) The valves, stirrer, tanks, and plumbing arrangements require renovation every 6 months or so.

IV. Engineering Control of Hazards

Careful consideration should be given to methods of handling chlorine shipping containers. Ceilings high enough for overhead hoists and floors of sufficient area for ease in handling mechanical equipment should be provided. Storage and use areas should be properly ventilated so as to minimise the possible accidental reaction of chemicals, which is based on their previously noted characteristics. Piping systems should be as simple as possible with a minimum number of joints; they should be well supported, protected against temperature extremes, and adequately sloped to allow proper drainage.

Long pipelines for liquid chlorine should be avoided. Sections of pipelines that can be isolated or shut off at both ends (such as by valves) must be provided with a suitable expansion chamber to avoid possible hydrostatic rupture due to pressure and volume increase accompanying high temperatures. Condensation or re- liquefaction can occur in chlorine gas lines that pass-through areas where the temperature is below the temperature-pressure equilibrium indicated on the chlorine vapour pressure curve. It can be prevented by supplying properly controlled heat or by reducing the pressure. The temperature of chlorine containers and gas pipelines should be lower than the temperature of the chlorinator to prevent condensation; if chlorine gas condenses, the chlorine will be re-liquefied and result in erratic chlorinator operation. Chlorine pipelines removed from service for even very brief periods should be closed in a suitable manner to preclude the entrance of moisture, which will cause serious corrosion problems.

Equipment cleaning and repair should be performed under the direction of thoroughly trained personnel who are fully familiar with all the hazards and the safeguard necessary for the safe performance of the work. All precautions pertaining to education, protective equipment, and health and fire hazards should be reviewed and understood. Repair to chlorine systems should not be undertaken while the system is in operation and while piping systems are in service. Chlorine pipelines and equipment should be first purged with dry air as a safeguard to health; this is especially important where cutting or welding operations are undertaken because iron and steel will ignite in presence of chlorine at about 235 °C. Immediate drying of a chlorine pipeline into which water or moisture has been introduced or which has been opened for repairs is essential if corrosion is to be prevented.

Piping Systems

Moist chlorine unlike dry gas or liquid chlorine is highly corrosive. Pipelines, valves, and other fittings through which dry chlorine passes should be tightly closed when not in use to prevent absorption of the moisture from the air, dry chlorine gas or liquid chlorine under pressure should be conveyed through extra heavy wrought iron or steel pipe or flexible annealed copper tubing tested for 35 kg/cm^2 working pressure. The discharge line from the chlorine container should be flexible and slopping upwards, especially when chlorine is discharging in the liquid state. Long pipelines should be avoided. Hard rubber, silver, or platinum tubing is necessary for the conveyance of moist chlorine gas or aqueous chlorine solutions at low pressure.

To prevent condensation of gas, piping systems and control equipment should be at the same or a higher temperature than the chlorine container. Chlorine gas lines are preferably located overhead rather than along with the floor, to take advantage of the warmer ambient temperature. For liquid chlorine piping systems, conditions that contribute to vaporisation should be avoided.

Connections are flanged, the facing should be of “small tongue and groove” type. Gaskets should be made of antimony lead (with 2% to 3% antimony) or asbestos sheet. Rubber gaskets are not suitable. Screwed fittings should be of forged steel construction.

Pressure indicators in the system have “Teflon” diaphragms or silver foil protectors. Pressure reducing valves may be of bronze or silver-plated body with silver diaphragm or of “Monel metal” with a Teflon diaphragm.

5.4.8.3 Conventional Chlorination

The conventional chlorination facility, i.e., adding chlorine for disinfection of water treatment, consists of three essential parts:

1) Chlorine supply system
2) Metering system
3) Diffuser system

In addition to above, there are ancillary equipment, safety equipment, metering and control instrumentation, and chlorine residual analysers.

I. Chlorine Supply System

a) Chlorine Gas Supply System

In gas supply system if the header run passes through an area where ambient temperature may fall below the temperature of the gas leaving the supply containers, it is necessary to install a pressure reducing valve in the gas supply system. This valve prevents re-liquefaction of the gas downstream of it. It is also a good practice to install liquid chemical trap upstream of the valve. The trap will serve to prevent liquid chemical from entering and flashing across the valve seat resulting in poor pressure regulation (Figure 5.13).

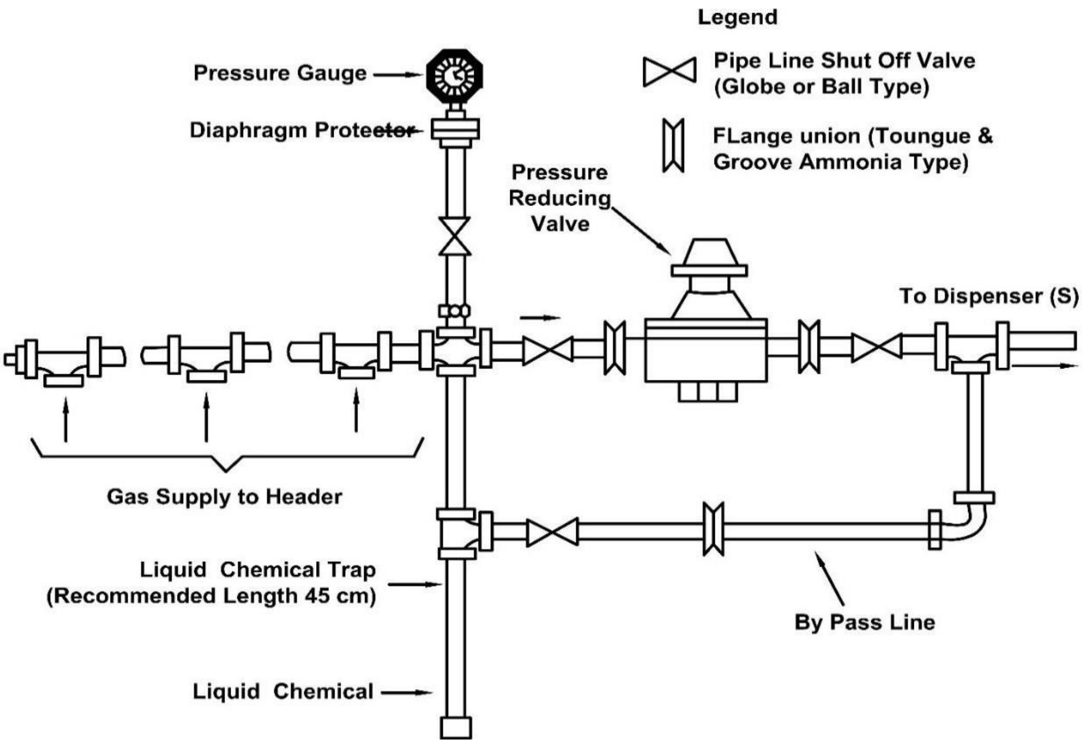


Figure 5.13: Gas Supply System

b) Evaporator Supply System or Liquid Chlorine Supply System

By means of an evaporator, liquid chlorine is converted into gaseous form. The details of evaporator have been discussed in Section 9.5 (and its sub parts) of Chapter 9: Disinfection, Part A of this manual.

Chlorinator operates the evaporator as per its chlorine requirement. If the chlorine requirement gets reduced, the pressure in the evaporator increases, causing liquid chlorine level to reduce, thereby reducing its area, which in turn reduces heat transfer. On the contrary, if the chlorine requirement increases, the pressure in the evaporator decreases. As a result, more liquid is pushed into the evaporator where it is evaporated at a higher rate (Figure 5.13).

c) Chlorine Gas Filter

Small chlorinators usually have same sort of built-in chlorine filter. However, any installation using ton containers (tonners) should have a chlorine gas filter as close as possible to the last cylinder, and always upstream of any external reducing valve. Commonly used material for this purpose is glass wool.

d) External Chlorine Pressure Reducing Valve

Any installation using the variable vacuum system for automatic control requires such a valve to reduce the chlorine supply pressure to 2 to 2.75 kg/cm^2 ahead of the chlorinator to ensure the maximum possible accuracy of the control system. Further, this valve also reduces the pressure in the chlorine supply header to prevent re-liquefaction of the gas in the header between the last cylinder connected and the chlorinator (Figure 5.13).

II. Metering System: Chlorinator

A chlorinator is a device for feeding chlorine to a water supply. It also serves as a gas metering device. Chlorinators are classified into two categories:

- Pressure type
- Vacuum type

A. Pressure-type Chlorinator

It consists of a stop valve, gas filter, pressure reducing valve, regulating valve, an orifice tube with manometer and moisture seal.

The pressure type may be further classified into two groups on the basis of gas or solution feed.

a) Dry Feed Type

These are not used in water treatment presently due to safety reasons.

b) Aqueous Solution Feed Type

It has been established that the only satisfactory method of applying chlorine gas to water is to dissolve the measured feed of gas in a minor flow of water which is then added to the main bulk of the water. For this purpose, three distinct types of solutionisers are available. In these systems, a minimum of 1500 litres of water is required per kilogram of chlorine for making chlorine solution. If the pressure is increased, the quantity required for making the solution is decreased. The temperature of the water used for preparing the solution must be more than 10°C. If the temperature of the water is less, it must be heated by safe methods before using for solution.

- Gravity feed or absorption tower feed type.
- Application of the chlorine into a main under pressure, i.e., Injector Solutioniser.

i. Gravity Feed

This can be used where the hydraulic gradient at the point of injection is below the level of the base of the tower. The tower is an ordinary tubular vessel filled with pebbles for percolation of water. A perforated tray is kept at the top of the tower to have an even distribution of water. A perforated PVC or ebonite tube is situated centrally in the tower for efficient and uniform distribution of gas. The water while trickling absorbs the gas and the resulting chlorinated water is delivered through an outlet at the base of the tower. Further, it is conveyed to the point of application by a rubber hose. For more details, refer to Section 9.10 of Chapter 9: Disinfection, Part A of this manual.

ii. Injector Solutioniser

It serves the dual purpose of the conversion of chlorine gas into a chlorine solution and of injecting it into water mains under a hydraulic pressure. The metered gas is introduced to a water-sealed cavity surrounding the injector. The water emerging with high velocity from the jet of injector absorbs chlorine gas due to partial pressure developed around the throat. The resulting solution is passed through a recovery zone to regain the pressure and subsequently injected into water mains (Figure 5.14).

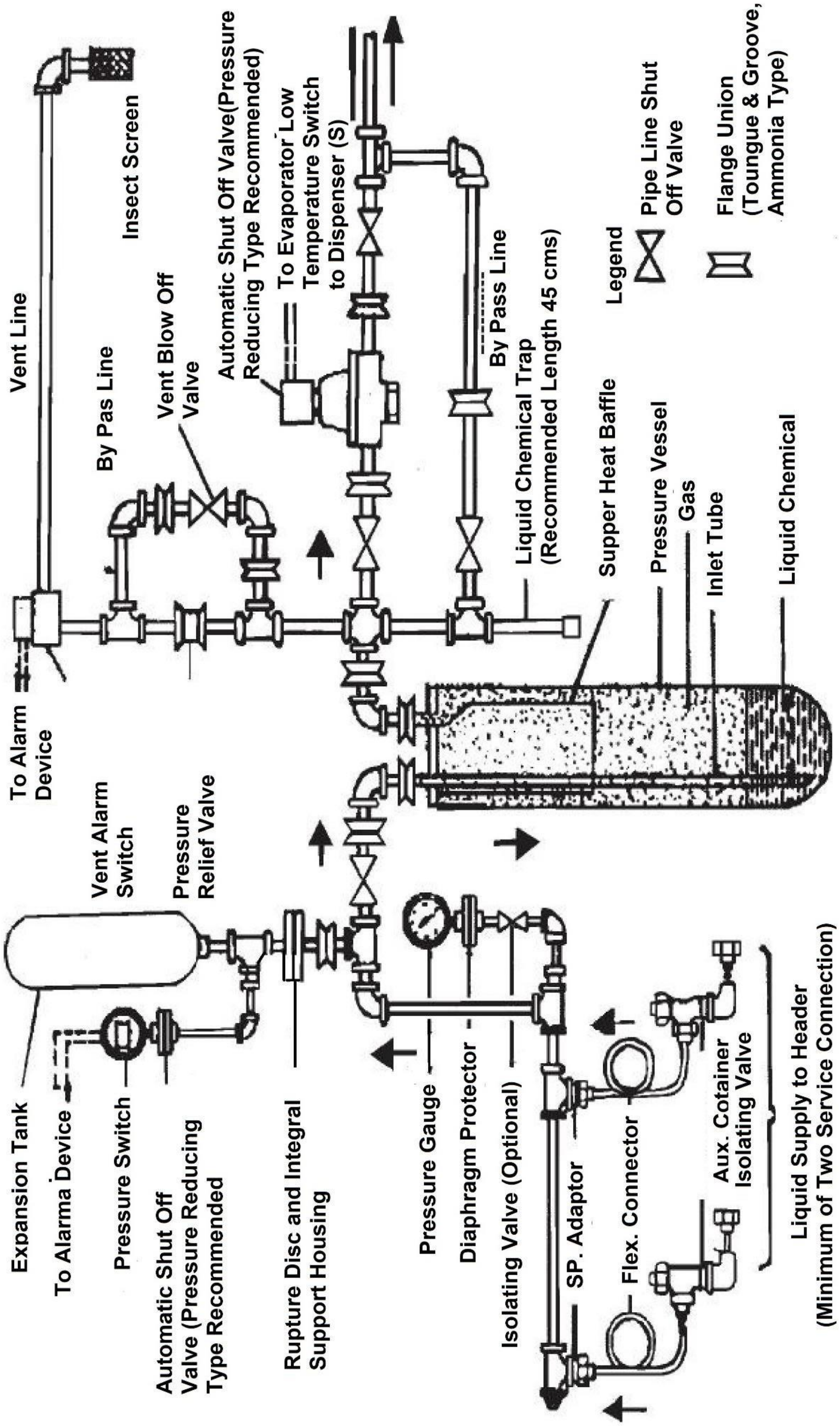


Figure 5.14: Liquid Withdrawal System

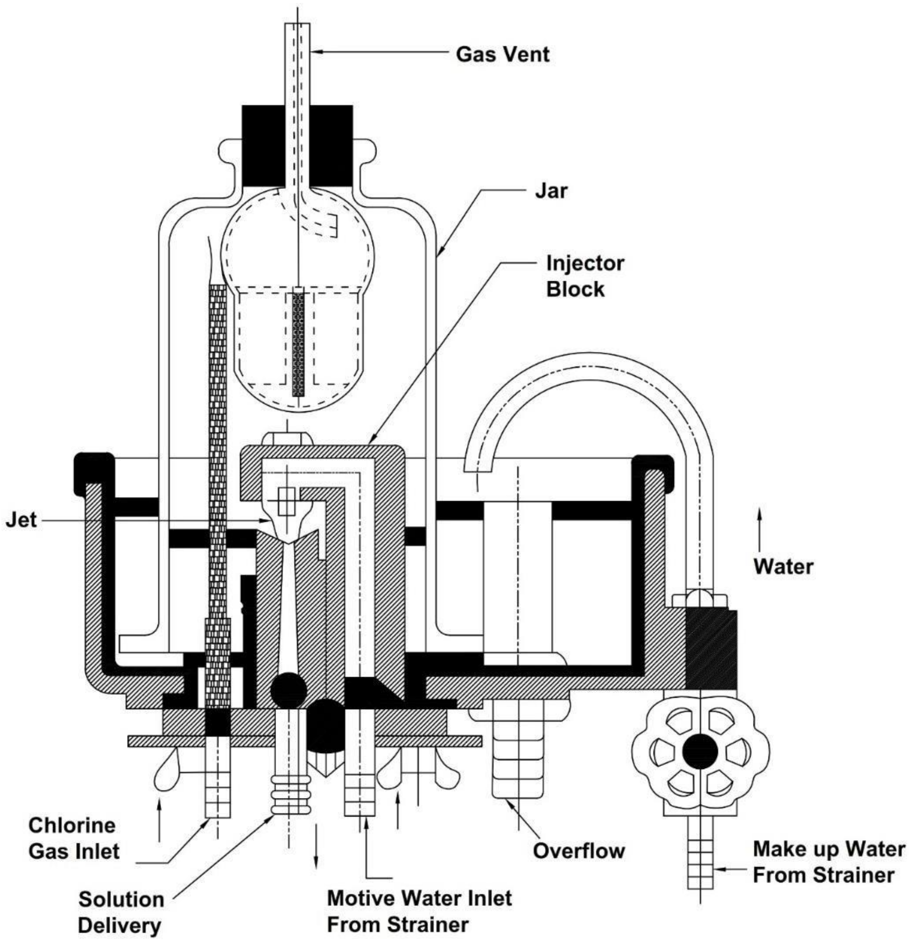


Figure 5.15: Chlorine Gas Apparatus Injector (Pressure Type) Solutioniser

From Figure 5.15, it can be observed that the makeup water connection maintains the seal of the water across the injector. Hence, chlorine does not leak through the jar unless pressure in the jar is increased. For letting the gas outside a gas vent is provided through HCl seal. This arrangement also serves the purpose of vacuum breaking in the system.

1. Operation of Pressure Chlorinator with Aqueous Solution – Gravity Feed Type

a) Startup

1) Turn on and adjust the water supply to the solutioniser.
2) With all cylinder connecting valves and regulating valves closed, open one cylinder valve and check the joint for leakage.
3) Slowly open the cylinder connecting valve and stop valve (when fitted). Check for leaks.
4) Open the cylinder connecting valves on any other cylinders that are to be brought into use if connected in parallel. After checking the joints for leakage, open the cylinder valves.
5) Slowly open the regulating valve until the meter indicates the required rate of discharge.

b) Shutting down

1) Close the cylinder valve and wait until the meter reading returns to zero.
2) Close stop valve when meter shows zero.

3) Shut off the water supply to the tower.

2. Operation of Pressure Chlorinator with Aqueous Solution-Injector Solutioniser Type

a) Startup

Carefully check all connections and ensure that all unions and hose clips are in order.

- Close the stop valve in the operating water supply and open the regulating cock when one is fitted in series with it. A regulating cock is incorporated except when a booster pump or pressure reducing valve is used.
- If the water pressure is to be "boosted", start the pump.
- Open the water stop valve to the full extent immediately. It is important to open this valve quickly in order to apply full pressure as soon as possible.
- The makeup water valve on the side of the tray should next be set so that there is a small surplus of water passing over the overflow tube.
- Close the chlorine regulating valve and stop valve if fitted and also the cylinder connecting valve. Open cylinder valve slowly and check the union joint on the cylinder for leakage.
- In the case of leakage attend to the same and set right the union joint.
- Slowly open the cylinder connecting valve attached to this cylinder and test for leakage at all joints between the cylinder connecting valves and the control panel.
- Open the chlorine stop valve (when fitted) and test for leaks up to the chlorine regulating valve.
- Open the cylinder connecting valves on the remaining cylinders. Test the unions on the cylinders for leakage.
- Open the chlorine regulating valve very slowly until the required rate of flow is indicated by the meter.
- The following conditions should then be noticed in the injector unit.

  1) The acid in the pressure released bulb should have risen about 6 mm to 12 mm up inside the inner tube.
  2) The quantity of water passing over the overflow should have increased slightly and there should be further increase if the flow of chlorine is set at a higher rate.

- It may then be possible to reduce the quantity of water by the injector, by reducing the pressure, either by throttling the regulating cock, by lowering the discharge pressure from the water supply pressure- reducing valve, or by adjusting the pressure at which the by-pass type pressure relief valve comes into operation, according to the water supply arrangement incorporated. Such an adjustment is indicated when the suction created by the injector makes it impossible to maintain the seal in the tray. The adjustment should be made with the maximum flow of chlorine and when the pressure against which the injector is operating is also at maximum, i.e., when the operating conditions are most exacting. The minimum suitable operating pressure is the one that can deal with the chlorine without forcing the acid from the lower part of the pressure release into the upper part. When this condition arises, the acid seal is broken and chlorine is allowed to escape via the vent pipe.

  - Following the adjustment of operating water supply, temporarily shut off the chlorine and, if necessary, reset the make-up water valve until there is again a small surplus passing over the overflow. This volume is not critical from an operating point of view, but it is desirable to avoid undue wastage of water.

b) Shutting down

1) Close the chlorine stop valve (or other cylinder connecting valve when there is no stop valve) and wait until the meter reading returns to zero.
2) Shut off the water supply to the solutioniser by means of the stop valve, and stop the booster pump when one is used for the supply.

Note: For a prolonged stoppage, close the cylinder valves and then the cylinder connecting valves before closing the stop valve.

B. Vacuum-type Chlorinator

In this type of chlorinator, chlorine is handled below the atmospheric pressure. The vacuum system has several advantages:

- It is the easiest method of dissolving chlorine in water.
- Chlorine is easily handled when in solution.
- This is the most accurate way of metering chlorine gas since a constant density is maintained under vacuum and it is not affected by ambient temperature changes.
- Operation under vacuum is safer than operating under pressure.
- A metering system can be easily designed to stop automatically if the vacuum should fail.

It consists of a gas filter, pressure regulating valve, variable area flowmeter (rotameter), vacuum regulating valve, pressure vacuum relief valve, drain valve, and injector assembly (Figure 5.16).

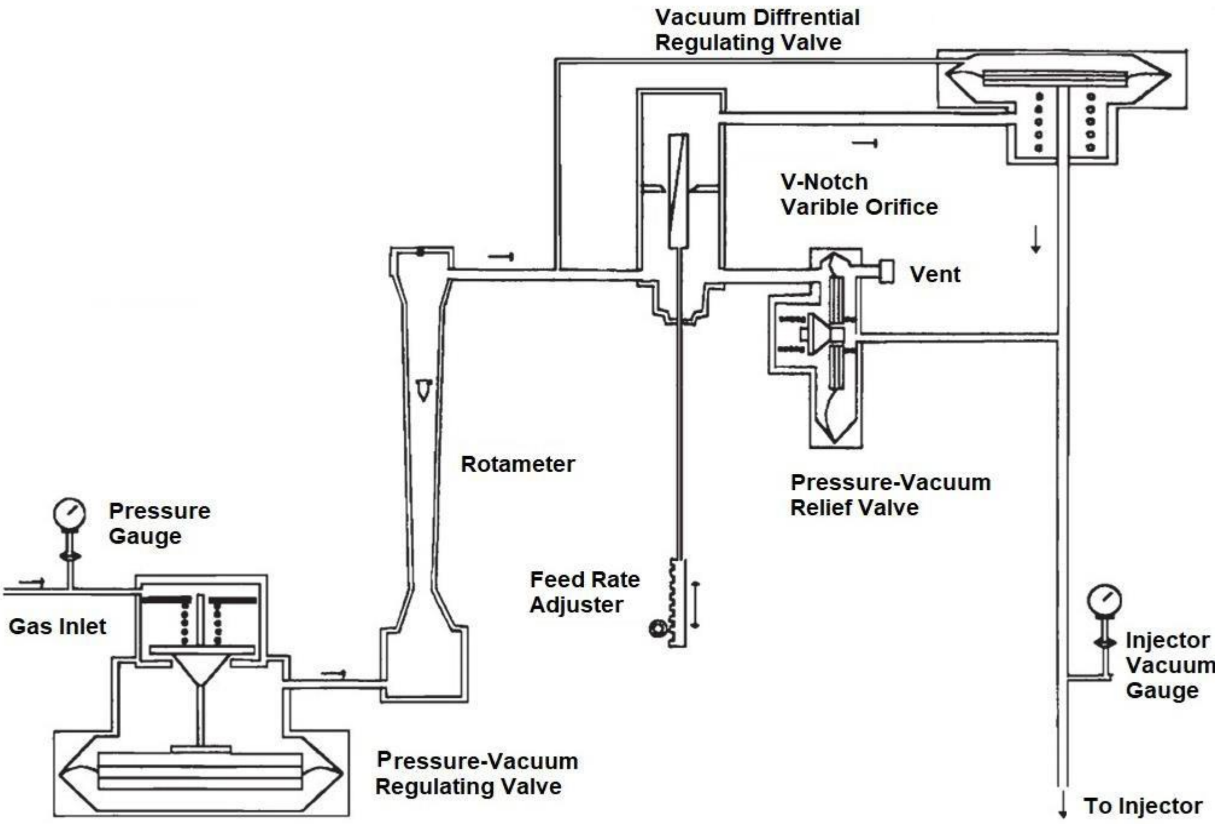


Figure 5.16: Typical Chlorinator

A comparison between the chlorinators is given in Table 5.8.

Table 5.8: Comparison of Chlorinators

S. No.	Description	Pressure-type Chlorinator			Vacuum-type Chlorinator	
		Dry feed	Aqueous solution feed			
			Gravity Feed	Injector Solutioniser	Kith Differential Vacuum Regulator	Sonic Flow Type
1	Rate of feed (maximum)	230 kg/d	230 kg/d	230 kg/d	4800 kg/d	240 kg/d
2	Water requirement per kilogram of chlorine (minimum)	Nil	1500 L	Less than 1500 L but more than 300 L	300 L	300 L
3	Accuracy	Low	Low	Low	High	High
4	Flowmeter	Manometer	Manometer	Manometer	Rotameter	Rotameter
5	Pressure at point of application	0.7 kg/cm^2 (maximum)	0.7 kg/cm^2 (maximum)	More than 0.7 kg/cm^2	More than 0.7 kg/cm^2	More than 0.7 kg/cm^2
6	Energy requirement	Low	Low	Moderate	Moderate	High
7	Maintenance	Extensive	Extensive	Extensive	Moderate	Less
8	Status	Not in production	Not in production	Not in production	In production	In production
9	Remarks	Not suitable below 10ºC water. It is used when the quality of water for making solution is not good. It is less safe.	Suitable below 10ºC provided water for making the solution is beyond 10ºC. It is used when the quality of water for making solution is good. It is less safe.	Suitable below 10ºC provided water for making the solution is beyond 10ºC. It is used when the quality of water for making solution is good. It is less safe.	Suitable below 10ºC provided water for making the solution is beyond 10ºC. It is used when the quality of water for making solution is good. It is more safe.	Suitable below 10ºC provided water for making the solution is beyond 10ºC. It is used when the quality of water for making solution is good. It is more safe.

If the system is designed for chlorine gas withdrawal, the following procedure for starting up the system is adopted.

C. Startup of Gas Chlorine System

1) First, start the booster pumps and make certain that the hydraulic conditions are satisfactory. For that purpose, see the delivery water pressure and injector vacuum gauge reading. If the conditions are satisfactory, the vacuum gauge should show reading above 590 mm of Hg. If the chlorinator is not equipped with vacuum gauge, remove the tubing at the injector vacuum inlet and place a hand over the opening. If the injector is performing properly, the suction will be felt instantly on the portion of the hand over the opening. But it is advisable to have a vacuum gauge for proper operation of the plant with safety.
2) Check that all the chlorine valves on the supply line to chlorinators are closed.
3) When the injector system is functioning properly, open the valve of chlorine cylinder partially to allow the gas. Chlorine container should be connected to the system and kept ready before starting the plant.
4) Verify that all of the tubing, manifold, and auxiliary valve connections are correct and that all union joints are properly gasketed. Check the leakage with ammonia stick and if there is any leakage, close the cylinder valve immediately and attend to the leaking joint to make it leak proof.
5) Check all the joints between cylinder valve to end. Figure 5.17 shows the cylinder mounted chlorinator.
6) Open the chlorine valve slightly to injector and check all the tubing and components of chlorinators for leakage. Attend, if necessary, by closing inlet valve. If there is no leak, then the chlorinator is ready for further testing.
7) Open fully the chlorinator gas inlet valve and check the chlorinator for range, automatic control and so on.
8) If at any stage leakage of chlorine is found, close the cylinder valve. Allow the gas in the system to be consumed through injector and then attend for leaking joints.
9) If the leakage is due to missing gaskets, etc., close the cylinder valve. Leave the site immediately for a safe area. With the help of breathing apparatus carry out the gas evacuation procedure through the chlorinators.
10) After all leaks have been corrected, the next step will be to see that the chlorinator will reach its maximum capacity as specified. This is the most important operative criteria of the chlorinator installation.

    i) If the chlorinator is not giving specified dose check for injector vacuum and chlorine pressure in the system and attend to the defects. The fault is normally in the hydraulics of the injector system. The next likely place is within chlorinator itself. A malfunction in either place is reflected by a low vacuum reading on the injector vacuum gauge.The first step in this case is to check the vacuum leak within the chlorinators. If the leak is major, it can be discovered by shutting off the injector water suddenly and using ammonia on all the joints. This sudden removal of vacuum will create slight pressure and chlorine will be expelled into atmosphere. Very small leak will not show up in this procedure.
    ii) Then check for “O” ring seal in the metering tube, vacuum relief valve, and check for defective spring or seat, etc., and attend to it.

11) Vacuum will be affected due to long vacuum line between injector and chlorinator. If this is filled with air, the large amount of air reduces injector vacuum. Moreover, if this line is leaking, it will also reduce the vacuum.
    Like a long vacuum line, a long chlorine solution line will also affect the injector vacuum. The air in this line, therefore, needs to be removed.
12) Defective injector may also affect vacuum.

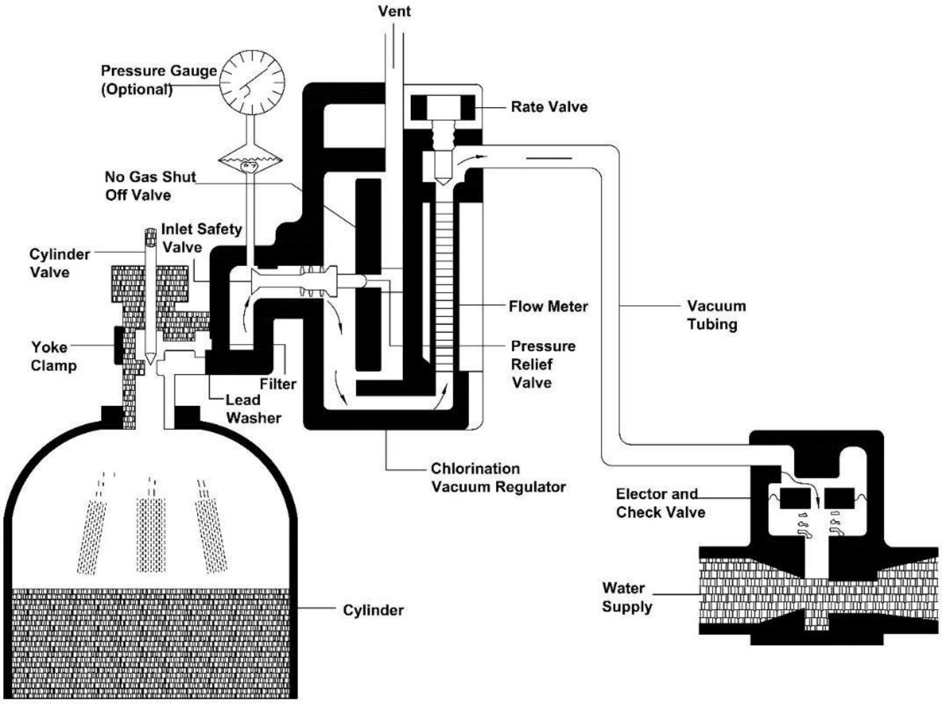


Figure 5.17: Cylinder Mounted Chlorinator

D. Startup of Liquid Chlorine System

If the system is designed for liquid withdrawal, the following procedure should be adopted for starting it up.

The procedure for startup on a liquid system is similar to gas system except for the role of evaporator. The evaporator is an extension of chlorine container system. Whatever happens in the container reflects into the evaporator pressure changes. The danger existing in liquid system is the possibility of trapping liquid chlorine in a pipeline. If this occurs and there is a significant rise in the ambient temperature, the liquid chlorine will expand and rupture the pipeline. For this reason, the liquid line between the evaporator and chlorine supply system should always remain open while the evaporator is operating. From safety point of view, rupture disc system with expansion chamber is provided on this line.

The first step preparatory for starting up a liquid system is to verify that the system is dry, because the moisture after coming in contact with liquid chlorine and metal of container forms ferric chloride which will pass through the chlorine control mechanism with stoppage of chlorine. Whenever this occurs, the entire chlorine system must be flushed with water and thoroughly dried. In addition to this, chlorination equipment must be dismantled and cleaned.

When the operator is convinced that the chlorine supply system is clean and dry, the next step is to start up the evaporators. This is done by filling the water bath and adjusting the control devices. When the water bath reaches 65 °C temperature, the chlorine pressure-reducing valve and shut-off valve will open, and the system is ready for operation. When the water temperature reaches 82 °C, start the injector water system and follow the procedure mentioned in the gas system.

III. Chlorination Plant Stopping Procedure

Stopping the chlorination system is also important in order to avoid chlorine leakages as well as for the system safety. The procedure is as follows:

1) Shut off the chlorine supply system.
2) When the chlorine pressure gauge reaches zero remove the cylinder connection and allow the air to evacuate all the residual chlorine gas in the system while the injector is still in operating condition.
3) After the chlorine has been purged to the satisfaction of the operator, the injector system may be shut down.
4) Connect the openings with plastic plugs.
5) For liquid system, the chlorine in the evaporator shall be completely consumed.
6) Then close the heater supply to the evaporator.

IV. Maintenance of Chlorination Equipment

Chlorine being hazardous chemical, its operating machinery should be properly maintained. In view of this, it is advisable to carry out preventive maintenance of all these equipment keeping in mind the followings for effective maintenance management programme.

1) Deploy trained personnel.
2) Prepare daily schedule:
   - Check chlorine leakage by ammonia torch.
   - Check exhaust fans working.
   - Check rotameter functioning.
   - Carry out physical verification of stock and position of tonners.
   - Check position of safety equipment.
   - Check vacuum of chlorinator.
3) Quantify the work.
4) Use of work permit system. A written work permit system is essentially a document which identifies the plant to be worked on and details precautions to be taken before a work can start. It predetermines the safe procedure and is a clear record of the hazards that have been anticipated defining the appropriate precautions to be taken to avoid them. It is also a statutory requirement.
5) Keep equipment record, i.e., history cards.
6) Analyse and plan every job.
7) Forecast yearly and monthly maintenance programme.
8) Prepare checklists for different types of preventive maintenance.
9) Set up a manpower control.
10) Set up a preventive maintenance programme.
11) Use budgetary control – yearly and monthly budget.
12) Provide material control.
13) Always use recommended spares.
14) Plan plant shutdowns.
15) Establish major overhaul procedures.
16) Develop standard practices.
17) Improve efficiency of the equipment.

18) Train the supervisors.
19) Train the maintenance staff.
20) Analyse performance and cost.

Since the properties of chlorine differ in liquid form, gaseous form, and solution form, suitable material has to be selected for various components of chlorine equipment (refer to **Annexure 5.1** for materials). The suggested maintenance of chlorine equipment in aqueous solution is given in Table 5.9 and in vacuum type is given in Table 5.10.

Table 5.9: Suggested Maintenance of Chlorine Equipment Pressure Chlorinator – Aqueous Solution Feed Type

S. No.	Name of Item	Period	Action Needed
1	Chlorine leakage	Daily	Inspect and take necessary action
2	Pebbles in tower	15 days	Clean with water
3	Calcium chloride	1 month or earlier if shape is changed	Replace
4	Orifice	1 month	Clean with trichloroethylene
5	Stop valve and regulating valve	3 months	Clean with trichloroethylene
6	Diaphragm	3 months	Clean with trichloroethylene
7	Manometer	3 months	Clean with water
8	Manometer	3 months	Calibrate
9	Gasket	3 months	Replace
10	Sleeves	3 months	Replace
11	Filter	3 months	Clean or replace
12	Pressure gauge	3 months	Inspect and calibrate if necessary
13	Injector	3 months	Clean with water
14	Tube	6 months	Replace
15	Nut bolt	12 months	Replace
16	Sulphuric acid	12 months	Replace
17	Rubber hose	12 months	Replace

Table 5.10: Suggested Maintenance of Chlorine Equipment and Fittings — Vacuum- type Chlorinator

S. No.	Name of Item	Period	Action Needed
1	Chlorine leakage through fittings, etc.	Daily	Inspect and take necessary action
2	Chlorine leak detector and exhaust fans	Daily	Inspect and take necessary action
3	Safety equipment and breathing apparatus	Weekly	Inspect and take necessary action

S. No.	Name of Item	Period	Action Needed
4	Chlorine neutralisation system	Weekly	Inspect and take necessary action
5	Water pump	3 months	Inspect and take necessary action
6	Chlorine gas filter	6 months	Replace filter element
7	Sedimentation trap	6 months	Clean
8	Rotameter tube and metering orifice	6 months	Clean
9	Wind cock	6 months	Replace
10	Gas header valve packing	1 year	Replace
11	Stem and seat of valves	1 year	Clean
12	Injector throat	1 year	Clean with mild HCl and then with water
13	Lifting tackle/crane	1 year	Inspect and take necessary action
14	Copper tubing between header and cylinder	1 year or screeching sound is heard on bending	Replace
15	Header system	After every 250 tonnes passing of chlorine	Clean with water and dry it
16	Springs in the valves	2 years	Replace
17	Pressure gauges and pressure switches	5 years	Replace
18	Diaphragm in spring loaded valve	5 years	Replace
19	Joints	Whenever opened	Replace gasket with new one. Wire brush the thread and use teflon tape as a lubricant
20	Evaporator vessel	250 tonnes of chlorine passage	Clean

V. Routine Maintenance

- Routine maintenance should be scheduled to assure that problems are corrected before unnecessary damage occurs to the equipment. In this way, unplanned chemical and labour costs can be reduced, treatment efficiency maintained, and many safety hazards prevented.
- Routine O&M of the chlorine feed systems includes the following.
    - Inspection of the chlorinators, evaporators, and storage tanks each day to ensure proper operation. Low gas pressure or no feed may indicate flow restrictions, empty vessels, clogged injectors, or damaged equipment.
    - Inspection of the diffusers. Diffusers may become plugged.

- Monitoring of the combined and total chlorine residual daily. Excess variations may indicate equipment malfunction.
- Monitoring of the treated water quality daily. Perform a periodic review of treated water quality. This should include analysis of daily reports.
- Draining of the contact chambers annually and repair of structures and equipment as needed.
- Testing of leak detectors and emergency equipment every six months and verifying of operator training in emergency procedures.

- On a daily basis, chlorinator should be inspected for proper operation and leaks. The items to be checked should include injector water supply pressure, injector vacuum, and chlorine supply pressure feed rate on roto-meter tube.
- The chlorine residual should be checked and recorded.
- On a weekly basis, check chlorinator feed rates through the full range of its capacity, clean any filters, and check operation of all valves.
- On a monthly basis, exercise all chlorine valves, inspect ventilation, heating, and lighting equipment for proper operation.
- Check the chlorinator vent line for obstructions such as insect nests, inspect the vacuum system for leaks, and perform other maintenance.

Inspect all safety equipment for proper operation including chlorine alarm system and the self-contained breathing apparatus or gas masks.

Some abnormal operating conditions which could occur are as follows:

- Chlorine leak – it is usually detectable by your sense of smell as soon as you arrive at the chlorination location.
- Low gas pressure – if the chlorine gas pressure drops, it is usually the result of the chlorine container being empty, clogged filters, or closed valves. To correct, replace the container, clean the filters, and check the valves.
- Injector vacuum too low – if the injector vacuum drops too low, the chlorinator should automatically shut off. The cause of the vacuum being low is a leak in the vacuum hoses, low water pressure, or clogged ejector.
- If there is a vacuum leak, repair the leak.
- If there is low water pressure, check the source, pump operation, or line strainers. If the ejector is clogged, remove and clean it.

VI. Troubleshooting

Troubleshooting Chart for Vacuum-type Chlorinator is given in **Annexure 5.3**.

Predominantly observed impurities in chlorine are ferric chloride, hexachloroethane, and hexachlorobenzene. Normally, the chlorine available for disinfection purpose is 99.8% pure (liquid chlorine as per IS 646-1986, reaffirmed 2010).

Ferric chloride is formed due to reaction of chlorine with water vapour and metal. This is deposited in the equipment during corrosion from liquid form to gaseous form. While carrying out maintenance of this equipment, warm water is used to clean the equipment. The cleaned equipment is dried thoroughly before putting into the system.

Hexachloroethane and hexachlorobenzene, being volatile impurities, are deposited from the chlorine gas in the equipment wherever pressure changes occur in the system, for example with pressure reducing valve. These impurities are removed while carrying out maintenance by means of trichloroethane or isopropyl alcohol; carbon tetra chloride (CTC) should never be used as it is carcinogenic.

Sometimes among other impurities, nitrogen trichloride may be present. This impurity is present when the brine solution from which chlorine is manufactured by electrolysis method, contains ammonia or its compound. Because of vapour pressure difference between nitrogen trichloride and chlorine in the evaporator, chlorine is evaporated first leaving more concentration of nitrogen trichloride in the evaporator. If under such condition, the evaporator temperature exceeds 94 °C, the evaporator may explode. It is, therefore, always recommended not to exceed evaporator temperature of 90 °C.

Before carrying out any maintenance of the equipment, it should be confirmed that all the chlorine present in equipment is purged out completely. Any chlorine present in the piping will prove hazardous if welding work is carried out on it. Similarly, while putting the chlorination system into use all the water vapours should be removed by means of moisture free dry air. The piping carrying chlorine of a length more than 3 m running from cylinder to the equipment should be provided with a pressure reducing valve just downstream of the cylinder. These two aspects reduce the maintenance problems to a minimum. Whenever cylinders are removed from the system, the disconnected piping should be plugged with Teflon or similar kind of material in order to avoid entry of humid air into it.

VII. Safe Handling Practices as per BIS Code “IS 10553-1” (1983, Reaffirmed 2007)

Requirements for Chlorination Equipment, Part I: General Guidelines for Chlorination Plants Including Handling, Storage, and Safety of Chlorine Cylinders and Drums may be referred to. This standard (Part I) covers recommendations for installation of chlorination plants including handling and storage of cylinders and drums.

VIII. Storing and Shipping Containers

Chlorine gas units and cylinders shall be housed in separate rooms, easily accessible, close to the point of application, and convenient for truck loading and safe container handling. The floor shall be flat and at least 150 mm above the surrounding ground and drainage shall be adequate. The height of the container room should be at least 4.0 m. Under no circumstances such units shall be housed in the basement or below the ground level since the chlorine gas is heavy and settles into depressions. Chlorine cylinders preferably should be stored upright and secured, and in such a manner as to permit ready access and removal. Tonne containers should be stored horizontally, slightly elevated from the ground or floor level, and blocked to prevent rolling; a storage rack of I-beams is convenient. Tonne containers should not be stacked or racked more than one high unless a special provision is made for easy access and removal. Full and empty cylinders and tonne containers should be segregated.

Storage areas should be clean, cool, well ventilated, and protected from corrosive vapours and continuous dampness. Cylinders and tonne containers stored indoors should be in a fire-resistant building, away from heat sources (such as radiators, steam pipes, etc.), flammable substances, and other compressed gases. Subsurface storage areas should be avoided, especially for chlorine and sulphur dioxide. If natural ventilation is inadequate, storage and use areas should be equipped with suitable mechanical ventilators. Cylinders and tonne containers stored outdoors should be shielded from direct sunlight and protected from accumulations of rain, ice, and snow.

All storage, handling, and use areas should be of such design that personnel can quickly escape in emergencies. It is generally desirable to provide at least two means of exit. Doors should open out and lead to outside galleries or platforms, fire escapes, or other unobstructed areas. The handling, safety, and storage of chlorine cylinders and drums should adhere to IS 10553 (Part 1).

IX. Emptying Containers

Chlorine cylinders deliver gas when in an upright position and liquid when in an inverted (or partially so) position. Tonne containers in a horizontal position and with the two valves in a vertical line deliver gas from the upper valves and liquid from the lower valve.

To withdraw gas from a cylinder or tonne container, the liquid chlorine must be vaporised. The flow rate is a function of the vaporisation rate, which, in turn, is dependent on the rate of heat transfer to the liquid.

The rate of withdrawal of chlorine from the container depends upon the size of the container and the surrounding temperature. For guidance, Table 5.11 may be followed.

Table 5.11: Rate of Withdrawal of Chlorine from Container

Temperature	**Kg of Chlorine Discharge per day**		
°C	Cylinders		Tonne container
	45 kg	67 kg	
4	2.72	4.08	45
10	6.35	9.50	110
15	10.75	16.10	130
20	14.50	21.54	254
Above 27	18.70	28.12	315

X. Connecting and Disconnecting Containers

The design and operation of facilities should be such as to minimise all hazards associated with connecting emptying and disconnecting chlorine containers. These operations should be performed in well-lighted places by authorised personnel equipped with gas masks or other suitable respiratory protection devices. Container valve protection goods should always be in place when the container is not in use. Valves should not be left open when operating personnel are not available to maintain proper surveillance of the operations.

Connections to valve outlets on cylinders and tonne containers can be made by either a clamp and adapter or a union connector; the former is preferred. In making connections, it should be ascertained that the outlet valve is closed before the outlet cap is removed. Gasket surfaces should be thoroughly inspected and cleaned and a new gasket of standard material should be used. Connections that do not fit should never be forced.

Cylinder and tonne container valves should be slowly opened by using a special wrench, not more than 150 mm long, for this purpose. One complete turn of the stem in a counterclockwise direction opens the valve sufficiently to permit maximum discharge. An auxiliary cylinder or tonne container valve should be installed adjacent to the container valve between it and the chlorine feeder or gas header on manifold systems. Such a valve serves as an emergency shut off if the container valve should leak. Moreover, it prevents chlorine gas from escaping from the supply line when the container is removed from service. In the interests of safety, the ventilation system should be operating whenever containers are being placed into or removed from service at all times in which an emergency exists or adjustments and repairs are being made.

Specifications and manufacturing of chlorine cylinders/containers, its transportation, handling, filling, possession, and safety shall be governed as per Gas Cylinder Rules of the Government of India.

5.4.8.4 Electrochlorinator

The electrochlorinator set basically comprises two compartments, one comprising of a brine solution tank, electrolyser, cooler, etc., and the other comprising of a compact panel board (rectifier). The schematic diagram as well as various parts of electrochlorinator are given in Figure 5.18 for a typical electrochlorinator.

Normal life of the electrochlorinator is 12 years provided reconditioning of the electrodes at regular intervals of four years is carried out. These chlorinators are available in various capacities ranging from 50 g/h to 18 kg/h of active chlorine production. The electrolyser consists of a number of electrodes as required. For a 500 g/h capacity plant, there are six numbers of electrodes comprising anodes and cathodes. The rectifier has facilities for auto tripping if there is a variation in certain set conditions.

I. Principle of Operation

Chlorine is instantly produced by electrolysing brine solution. Common salt is mixed with water to prepare brine solution. This solution is passed through an electrolyser of electrodes comprising of anodes and cathodes, which are energised by D.C. current to produce NaOCl. Sodium hypochlorite is used as disinfectant.

II. Process Details

1) Make a concentrated brine solution at 310 g of industrial grade salt with 97% purity or more salt in 1 litre of water in a brine solution tank. After pouring salt, the mixture is stirred either manually or through a motor-driven reduction gear arrangement. In order to reduce the capacity of brine solution tank, a concentrated solution is prepared.
2) Allow brine solution to flow inside the electrolyser at a controlled rate as required for a chlorinator which depends upon active chlorine production. But the quantity of water in brine solution tank is to be replenished, for which freshwater at the same rate is simultaneously sent after controlling the flow, through one of the flowmeters (flowmeter No. 2) placed in front of brine solution tank.
3) Dilute the concentrated solution with freshwater to attain a strength of 30 g of salt per litre. Accordingly, freshwater is added to electrolyser after controlling flow through flowmeter No.1 (for a 500 g/h capacity plant, the rate is about 65 L/h). It may be mentioned here that for effective functioning of flowmeters to control flow, one valve is installed in the common line and the pressure through the flowmeters is controlled at a specified pressure rating.

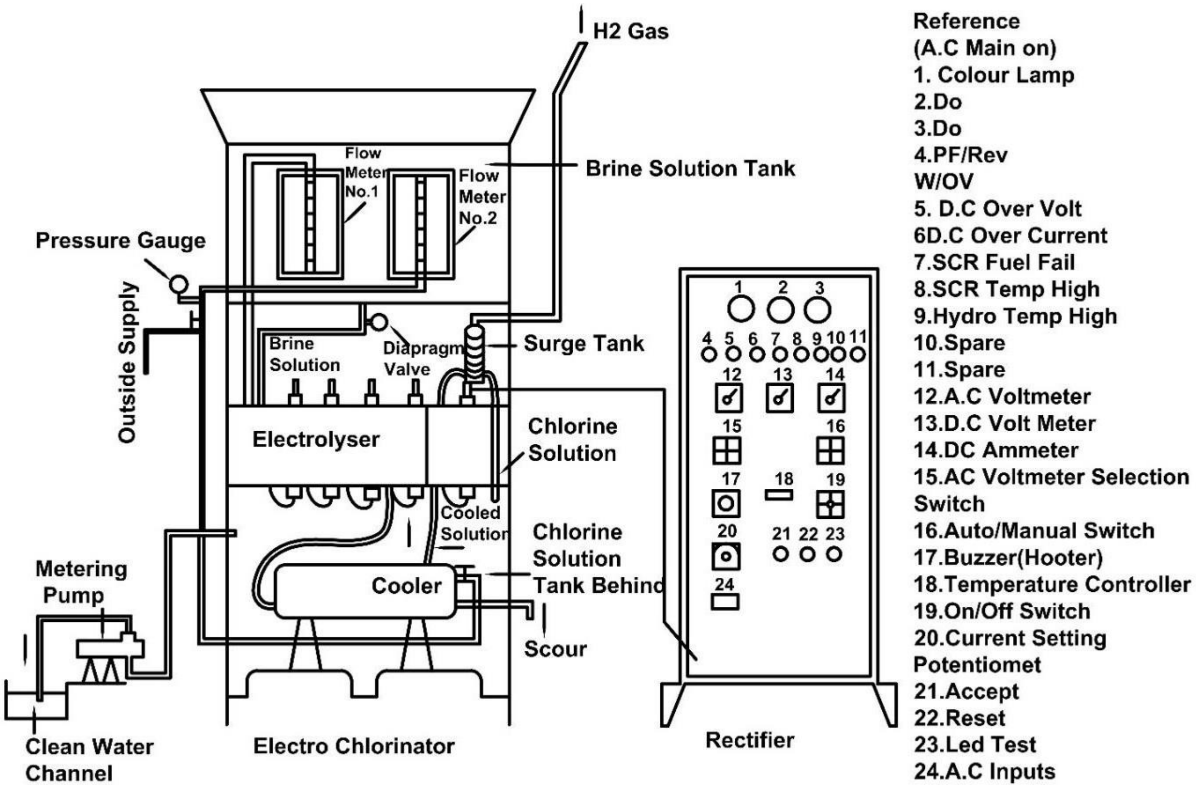


Figure 5.18: Onsite production of Hypo-Solution Common Salt

4) After filling the electrolyser with the required solution of salt and water, D.C. power supply through rectifier is put on.
5) The electrolysis process evolves heat. The maximum permissible temperature is of the order of ambient temperature + 12 °C.
6) In order to control the temperature, the aqueous solution is required to be cooled through a cooler placed below the electrolyser chamber. The solution is introduced at one end of the cooler and fresh cold water is circulated through coil pipe placed inside the cooler. The cold water used for cooling is continuously discharged to a sump connected with clear water reservoir. The electrolysed solution after cooling is continuously introduced to the 2nd chamber of the electrolyser.
7) After the complete electrolysis process, the solution of sodium hypochlorite (NaOCl), sodium chloride (NaCl), water (H2O), and hydrogen gas (H2) is now passed on to a surge tank which is placed on the rear side of electrolyser, i.e., just below the brine solution tank. The hydrogen gas is allowed to escape through a pipe fitted at the top of the surge tank. The solution is now collected through an outlet pipe placed below the surge tank into a solution tank located below.
8) The concentration of active chlorine in the form of sodium hypochlorite solution is, therefore, 7.00 g/L.
9) The solution is now taken from the chlorine solution tank and dosed to the clear water reservoir through metering pump installed by the side of the electrochlorinator at the rate at which it is required.

III. Operation

1) For starting the operation, open the brine solution diaphragm valve to allow flow to the electrolyser. Open flowmeter No.1 for freshwater so that dilution starts inside the electrolyser. The pressure of incoming freshwater should be 1 to 1.1 kg/cm^2. As soon as the outflow from surge tank starts, electrical operation through rectifier is to be started.

2) Before starting rectifier, A.C MCB is to be put in “ON” position. A.C. mains supply in 3 phases is to be checked through indicator lamps. A.C. voltage reading is checked so that requisite voltage of 355 V to 455 V comes to rectifier. By rotating potentiometer clockwise, the D.C. volt and D.C. ampere are set to 23–25 V and 95–100 A, respectively. Now, electrolysis process is started.
3) Before closing the operation, brine solution diaphragm valve is to be closed and fresh water is to be allowed inside the electrolyser for cleaning of electrodes for 15–20 minutes. Simultaneously, potentiometer is to be operated in anticlockwise direction slowly to set to “zero” position. Now A.C. main MCB is put to “OFF” position.
4) If there is any sudden power trip, potentiometer is to be set to “Zero” position to avoid any sudden shock to the whole system, if power comes back again, immediately. In that case, brine solution diaphragm valve is also to be closed and only freshwater is allowed through flowmeter No. 1 for 10–15 minutes.
5) If the temperature of hypo solution is increased (i.e., more than ambient temperature +12 °C), it is sensed through sensor and there will be auto tripping. Potentiometer is then brought zero position. Then brine solution is closed and freshwater is circulated through flowmeter No. 1 for 20 to 25 minutes before re- starting. The cooler is checked conveniently to see its effectiveness.
6) Before closing of the electrochlorination, the flowmeter No. 1 will be operated for 15 to 20 minutes for cleaning the electrodes.
   If the brine solution concentration is reduced, then the D.C. volt will rise from 23 to 25 V and there will be corresponding fall of ampere reading from 95 to 100 A. At that time, the concentration is to be restored by adding salt and water.
7) Normally, 4.5 kg of common salt (NaCl) is required to produce 1 kg of chlorine with 4.5 kWh power.

IV. Maintenance

1. If there is deposition of chemicals on the body of the electrodes, then D.C. voltmeter will indicate high voltage and concentration of hypochlorite solution will reduce, which can be detected on checking chlorine content. In such situation, electrodes are to be cleared.
2. If there is any fault, at first, all fuses, contact points, and their joints are to be checked.
3. D.C. voltage must be kept within the range of 23 V to 25 V. The rectifier shall be cleaned and checked occasionally so that all electrical connections remain intact.
4. Plumbing arrangements shall also be cleaned from time to time, if choked with salt deposition.
5. Due to the accumulation of positive and negative ions on the anodes and cathodes of the electrolyser, the efficiency of electrolyser process gets reduced and, therefore, the electrodes require cleaning every 25 to 30 days with a water jet, i.e., without touching them by hands.
6. The staff will require special training for routine maintenance and annual maintenance contract to the specialised agency could be considered for trouble free maintenance of the system.
7. The byproduct hydrogen gas (H2) shall be vented, by design, to the atmosphere. Special care shall be taken to route the piping with gradual rise. Before the start of maintenance, check if the vent line is clear to avoid danger of explosion.

5.4.8.5 Safety Aspects of Chlorine

I. General

Chlorine is potentially dangerous. It is, therefore, important that the person engaged in a chlorine plant or in any activity involving handling of chlorine should understand the hazards of chlorine and should know preventive measures needed.

a) Only trained personnel should be permitted to handle chlorine cylinders and chlorinating equipment. They should be made aware of the hazards involved, the precautions to be observed, and first aid to be rendered in emergencies. Rubber gloves, aprons, and suitable gas masks should be provided. These should be housed in an easily accessible (unlocked) cupboard placed outside the chlorinator room. It is very important that the operating personnel are trained in the proper use of gas masks. A faulty gas mask is worse than none at all. Hence, it is very important that these are tested frequently and the containers are changed at proper intervals.
b) When a chlorine leak occurs, the mechanical ventilation system should be opened immediately before any person enters the chlorine room. It must be made a point that chlorine container valves are closed first before any investigation is started.
c) Cylinders containing chlorine should be handled gently. They should not be bumped, dropped, or rolled on the ground, and no object should be allowed to strike them with force. The protective hoods over the valve should always be kept in place except when the cylinders are in use. Flames should never be applied to chlorine cylinders or their valves.
d) Cylinders should not be stored in the open or damp places. Empty cylinders should be stored away from full cylinders so that they do not get mixed up. It would be desirable to tag the empties as an additional precaution. Incidentally, this will ensure the prompt return of used cylinders.
e) In case the valve is found to be stuck, the cylinder should be immediately returned to the supplier. No attempt should be made to ease a stuck valve by hammer, as this is very dangerous.
f) Only the spanners prescribed for use should be used as it is important not to put too much leverage on the valves.
g) Cylinders, as well as the chlorinators, must be tested at the start and end of every shift period, for leaks, first by trying to detect the sharp irritating smell of chlorine, then by passing over each cylinder and around each valve and pipe connections, a rod with a small cotton wool swab tied on the end, dipped in an aqueous solution of ammonia, any leakage noticed anywhere must be attended immediately; otherwise, same is going to lead major trouble in the plant. If chlorine is present in the air, the swab will appear to “smoke” due to the formation of white clouds of ammonium chloride. If the leak appears to be heavy, all persons not directly concerned should leave the area and the operator should put on his mask and make a thorough search for the leak. In tracing a leak, always work “downstream”, i.e., start at the cylinder and work down along the line of flow until the leak is found. It will save many valuable minutes over the practice of starting in the middle of the chlorinator and searching vaguely back and forth over the whole equipment.
h) Water should never be applied to a chlorine leak to stop it as it will only release “free chlorine”. If the leak is in the chlorinator, the cylinder should be immediately shut off until the pressure has reduced. The joint or gasket should be repaired, and replaced with new packing, if necessary.
i) Solvents such as petroleum, hydrocarbons, or alcohols should not be used for cleaning parts that come in contact with chlorine. The safe solvents are chloroform and carbon tetrachloride. Grease should never be used where it can come in contact with chlorine as it forms a voluminous frothy substance on reaction with chlorine. The only special type of

cement, recommended by manufacturers, should be used.

j) No direct flame should be applied to a chlorine cylinder, when heating becomes necessary, as this is hazardous. A water bath, with a controlled temperature not to exceed 27 °C, should be used.

k) Before disconnecting the flexible lids from containers to gas headers, the cylinder valves should be closed first and then the gas under pressure should be drawn from the header and flexible lids before the header valve is closed. The exhaust system should be turned on and operated while the cylinders are being disconnected or repairs are being made.

The list of safety systems at chlorination plant are given in **Annexure 5.2**. The important facts about hazards of chlorine and their preventive measures are given in Table 5.12:

Table 5.12: Important Facts about Chlorine from Safety Point of View

S. No.	Facts	Reasons	Remedy
1	Chlorine is supplied in liquid form under pressure and it requires heat for converting it into gas	It occupies less space	Proper ventilation and proper handling
2	It is not poisonous but irritant	It forms corrosive acid with body moisture and hence inhalation can cause respiratory injury ranging from irritation to death depending upon its concentration and duration of inhalation	Use breathing apparatus
3	Dry gas is not corrosive but wet gas is highly corrosive	It forms acid with water	Do not use water on leaking container
4	It is neither flammable nor explosive but supports combustion of carbon steel at 251 °C	Containers are made up of carbon steel	Do not carry out welding work on chlorine containers or piping unless purged out
5	Gas combines with ammonia and forms white smoke	White smoke detects chlorine leak.	Use for detecting chlorine leakage through the system
6	Liquid chlorine has large coefficient of expansion	If the container is filled with filling ratio of 1:19, complete container will be occupied by liquid chlorine at 84 °C and hydrostatic rupture may take place.	Do not place the container near the fire or source of heat
7	Vapour pressure increases with temperature rise	Container may rupture due to rise in pressure	Do not place the container near the fire or source of heat

S. No.	Facts	Reasons	Remedy
8	Gas is 2.5 times heavier than air	Leaked chlorine settles at the ground level.	Install exhaust fans at ground level and inform the public to take higher level during chlorine leakages
9	It is slightly soluble in water, but it gets absorbed in caustic soda, soda ash, and hydrated lime	During reaction with caustic soda. Soda ash and hydrated lime heat is evolved	Use soda ash, caustic soda, or hydrated lime for neutralisation of chlorine. Do not use water for neutralisation purpose. Do not push container into solution.
10	Liquid leaks 15 times more than the gas	It is because of viscosity difference as well as different laws of gas and liquid	Turn the leaking container to allow the leakage in gaseous form
11	Chlorine forms hydrate with water at temperature below 9.4°C	Solid layer is formed	In case of liquid leak, if chilled water is sprayed on the top, a solid layer formation will reduce the rate of evaporation of chlorine
12	It is dangerous with ammonia gas, hydrogen, turpentine, and hydrocarbon as reactions with these are explosive; powdered metal may cause fire in chlorine.	Fire may start in storage of chlorine	Avoid storage of these materials in the chlorine storage. Do not lubricate the valves.

II. Cylinders

Cylinders are fabricated as per IS: 3196-4 (2001), reaffirmed 2012 (superseding IS: 7680, IS: 7681, and IS: 7682).

In a vertical position with the valve at the top, chlorine in gaseous form can be drawn from the cylinder. If, however, liquid chlorine is to be drawn, the cylinder can be inverted to bring the valve towards the bottom with the use of an inverting rack which holds the cylinder at 60°. The withdrawal rates of Cl_2 at 20 °C are 2 kg/h and 10 kg/h for gas and liquid chlorine respectively for 100 kg. The withdrawal rate depends upon ambient temperature and it reduces with reduction in temperature (Figure 5.19).

SPECIFICATION OF CHLORINE GAS CYLINDER

Water Capacity (Litres)		84
Gas Capacity (Kg.)		100
Maximum Working Pressure (Kg/Cm^2 at 65°C)		19.90
Hydraulic Test Pressure (Kg/Cm^2)		29.85
Nominal Dia	Inside (d)	356
Approx (mm)	Outside (D)	368
Nominal Wall Thickness (I) mm		6
Approx Height excluding		988
Valve & Cap (H) mm		
Tara Weight excluding Cap (Kg)		65
Construction		3 Piece

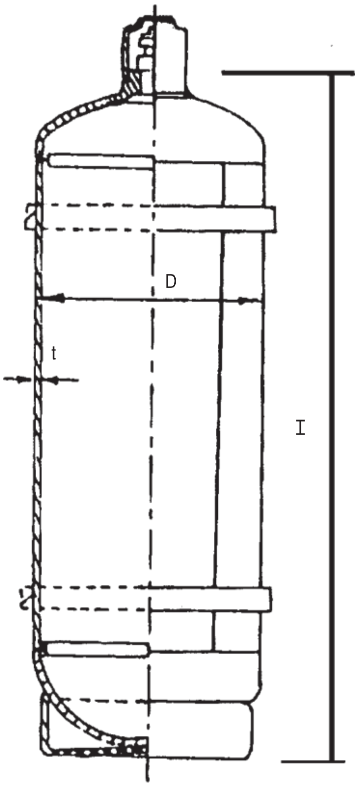


Figure 5.19: Details of Chlorine Cylinder

III. Tonners

Bigger containers are commonly known as "Tonners". Indian tonners are generally fabricated conforming to the British Standards (B.S:1500).

These are kept horizontally so as to bring the two valves in vertical plane. Each has a capacity of approximately 900 kg. It has built-in safety by way of providing concave dished ends.

Both the valves are covered by a protective hood connected to the container by means of lugs. The inside ends of the valves are connected to the eduction pipes (Figure 5.20).

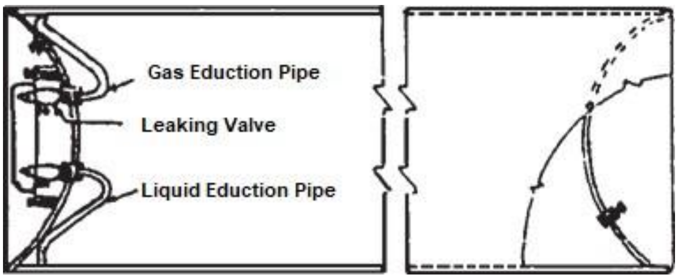


Figure 5.20: Details of Chlorine Tonner

Design Code	– ASME Section VIII Div. 1, Edition 2017
Water Capacity (approximately), kg	– 780
Chlorine Capacity (approximately)	– 928
Design Pressure, kg/cm^2	– 20.63 (g)
Hydrostatic Test Pressure, kg/cm^2	– 30
Inside Diameter (approximately), mm	– 760
Shell Thickness, mm	– 12

Dished Ends Thickness, mm	– 12 (minimum)
Overall Size (approximately), mm	– 2090 length × 784 diameter
Tare Weight (approximately), kg	– 600
Material of Construction	– SA 516 Grade 60/70

Tonners manufactured in India after 1981 do not have fusible plug as per the Gas Cylinder Rules 1981. However, in imported design where these are provided, they melt between the temperatures of 70 °C and 74 °C thereby reducing the pressure inside the container in case of fire or high temperature.

The withdrawal rates of Cl_2 at 20 °C are 7 kg/h and 180 kg/h for gas and liquid, respectively, it depends upon ambient temperature.

IV. Container Valves

Both chlorine cylinder as well as tonners must be fitted with standard valves conforming to IS: 3224 (2002), reaffirmed 2002 (Figure 5.21).

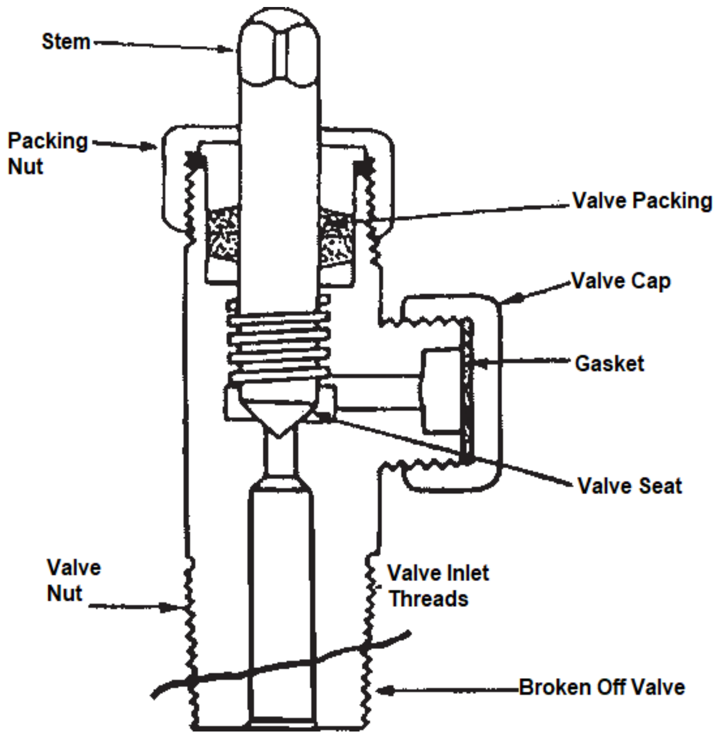


Figure 5.21: Standard Chlorine Container Valve

5.4.8.6 Storage and Handling of Chlorine Cylinders

Chlorine is stored in special grade steel containers. As per IS: 4379 (1981) (reaffirmed 2002), the colour of chlorine (Cl) container (Cl cylinder ground colour) should be “golden yellow”.

a) Storage Area

1) Obtain storage license from controller of explosives under Gas Cylinder Rules 1981 if the quantity of Cl_2 containers to be stored is more than 5 Nos.
2) Storage area should be cool, dry, well ventilated, and clean of trash and protected from external heat sources. Refer to Section 9.10.3 of Chapter 9: Disinfection, Part A for further details.

3) Ventilation must be sufficient to prevent accumulation of vapour pockets. The exhaust should be located either near the floor or duct be provided extending to the floor. All fan switches should be outside the storage area.
4) Do not store container directly under the sun.
5) Weather cock should be installed near the storage to determine wind direction.
6) The storage building should be of non-combustible construction with at least two exits opening outside.
7) Neutralisation system should be provided.
8) Continuous monitoring of chlorine leak detection equipment with alarm should be installed in the storage area.
9) The area should be free and remote from elevators, gangways, or ventilating system to avoid dangerous concentration of chlorine during leak.
10) Two portable foam type fire extinguishers should be provided in the premises.
11) Corrosive substances shall not be stored nearby which react violently with each other.
12) Unauthorised person should not be allowed to enter into the storage area.
13) The floor level of storage shed should be preferably 30 cm (at least one foot) higher from the ground level to avoid water logging.
14) Ensure that all containers are properly fitted with safety caps or hooks.

b) Cylinder and Drum Containers

1) Store chlorine cylinders upright and secure them so that they do not fall.
2) Drum containers should be stored on their sides on rails, a few inches above the floor. They should not be stacked one upon the other. They should be stored in a way that the valves are in a vertical plane.
3) Keep enough space between containers so as to have accessibility in case of emergency.
4) Store the containers in a covered shed only. Keep them away from any source of heat as excessive heat may increase the pressure in container which will result into burst.
5) Do not store explosives, acids, turpentine, ether, anhydrous ammonia, finely divided metals, or other flammable material in the vicinity of chlorine.
6) Do not store containers in wet and muddy areas.
7) Store filled and empty containers separately.
8) Protective covers for valves are secured even when the containers are empty, except during use in the system.
9) Never use containers as a roller to move other equipment.
10) Never tamper with fusible plugs of tonners.
11) Check leakages every day by means of ammonia torch. However, it should not be touched to brass components like valves of container for safety.
12) Never carry out any welding work on the chlorine system as combustion of steel takes place at 251 °C in presence of chlorine.
13) The boxes containing emergency kit, safety applications, and self-contained breathing apparatus should be kept in working order in an easily approachable area.

c) Use of Cylinders and Drum Containers in Process System

1) Use containers in the order of their receipt, as valve packing can get hardened during prolonged storage and cause gas leaks.
2) Do not use oil or lubricant on any valve of the containers.

3) Badly fitting connections should not be forced and correct tool should always be used for opening and closing valves. They should never be hammered.
4) The area should be well ventilated with frequent air changes.
5) Transport the cylinders to the process area by using crane, hoist, railings, etc.
6) The drum containers should be kept in a horizontal position in such a way that the valves are in a vertical plane. The upper valve gives out gas and the lower one gives out liquid chlorine.
7) The cylinder should be kept in upright position in order to release gas from the valve. For liquid chlorine withdrawal, it should be inverted with the help of an inverted rack.
8) Connect the containers to the system by using approved accessories.
9) Use copper flexible tube, with lead washer containing 2% to 4% antimony or bonded asbestos or Teflon washer. Use yoke clamp for connecting chlorine container.
10) Never use rubber tubes, PVC tubes, etc., for making connections.
11) Use the right spanner for operating the valve. Always keep the spanner on the valve spindle. Never use ill-fitting spanner.
12) After making the flexible connection, check for the leakage by means of ammonia torch but it should not come in contact with a valve.
13) Keep minimum distance between the container valve and header valve so that during change-over of the container, only minimum amount of gas leaks.
14) The material of construction of the adopter should be same as that of valve outlet threads.
15) The valve should not be used as a regulator for controlling the chlorine. During regulation due to high velocity of chlorine, the valve gets damaged which in turn can cause difficulty in closing.
16) The tools and other equipment used for operating the container should be clean and free of grease, dust, or grit.
17) Wear breathing apparatus while making the change-over of the container from the process header.
18) Do not heat the container to withdraw more gas at faster rate.
19) Use pressure gauge and flow measuring device to control the flow and to know the quantity of gas left in the container.
20) Use an inverted U type barometric leg or vacuum breaking arrangement for connecting the container to the process piping.
21) Withdrawal of the gas should be stopped when the gas pressure inside the container is between 0.1 to 0.5 kg/cm^2 approximately.
22) If withdrawal of the gas from the container connected to the process system has to be suspended for long intervals, it should be disconnected from the system, and the valve cap and hood replaced.
23) Gas containers should be handled by trained persons only.

d) Disconnecting Containers from Process System

1) Use breathing apparatus before disconnecting the container.
2) First, close the container valve fully. After removal of chlorine, the process valve should be closed.
3) Remove the flexible connection, plug the flexible connection in order to avoid entry of humid air. Replace the valve cap or hood on the container.
4) Put the tag on the empty container and bring it to storage area marked for empties.
5) Check for the leakage.

6) Most of chlorine leakage incidents happen during replacement of tonners. Therefore, SOPs shall be followed scrupulously. The shift in-charge shall supervise this operation in person without fail to identify hazard and to guide his staff to avert it. As far as possible, change of tonners operation shall be carried out in general shift when maintenance staff is available for additional help if needed.

e) Loading and Unloading of Containers

1) The handling of containers should be done under the supervision of trained and competent person.
2) It should be done carefully with a crane, hoist, or slanted ramp. Do not use magnet or sharp object for lifting the containers.
3) Small cylinders should not be lifted by means of valve caps as these are not designed to carry the weight.
4) The containers should not be allowed to strike against each other or against any hard object.
5) Vehicles should be braked and isolated against any movement.
6) After loading, the containers should be secured properly with the help of wooden wedges, rope, or sling wire so that they do not roll away.
7) The containers should never be dropped directly to the ground or on the tyre from the vehicle.
8) There should be no sharp projection in the vehicle.
9) Containers must have valve caps and plugs fitted properly.
10) Check containers for leakage before loading/unloading.

f) Transportation of Container

1) The name of the chemical along with diamond pictorial sign denoting the dangerous goods should be marked on the vehicle.
2) The name of the transporter, his address, and telephone number should be clearly written on the vehicle.
3) The vehicle should not be used to transport any material other than what is written on it.
4) Only trained drivers and cleaners should transport hazardous chemical.
5) The driver should not transport any leaking cylinder.
6) The cylinder should not project outside the vehicle.
7) The transporter must ensure that every vehicle driver must carry “Trem Card” (Transport Emergency Card) and “Instructions in writing booklet” and follow them.
8) Every driver must carry safety appliances with him, viz., emergency kit, breathing apparatus, etc.
9) The vehicles must be driven carefully, especially in crowded localities and on bumpy roads. Do not apply sudden brakes.
10) Check for the leakage from time to time.
11) In the case of uncontrollable leakage, the vehicle should be taken to an open area where there is less population.

g) Emergency Kit

It consists of various tools and appliances like gaskets, yokes, studs, tie rods hoods, clamps, spanners, mild steel channels, screws, pins, wooden pegs, etc., of standard sizes. Separate kits are used for cylinders and tonners. All the gadgets are designed for using in controlling or stopping the leakages from valves, fusible plug, and side walls of cylinders and containers used for handling chlorine.

1) Leakage may occur through the valve. There are basically four types of valve leaks:

   i) Valve packing
   ii) Valve seat
   iii) Defective inlet thread
   iv) Broken valve thread

   For controlling the leak, refer to Figure 5.29 and Figure 5.31 for tonner and cylinder, respectively.

2) Leakage may occur through container wall. For controlling such leakages, clamps are used for cylinders and chain and yoke arrangement is used for tonner. Sometimes wooden peg is used by driving into the leaking hole as a temporary arrangement.

3) Leakage may occur through fusible plug:

   i) If the leakage is through the threads of fusible plug, yoke, hood, and cap nut arrangement is used to control the leak.
   ii) If fusible metal itself in the plug is leaking, yoke and stud arrangement is used to control the leak.

h) Health Hazards

Wet chlorine being corrosive, it forms corrosive acid with body moisture. Inhalation can cause respiratory injury ranging from irritation to death depending upon its concentration and duration of inhalation.

1) **Acute Exposure**

   The first symptom of exposure to chlorine is irritation to the mucous membranes of eyes, nose, and throat. This increases to smarting and burning pain. Irritation spreads to chest. A reflex cough develops which may be intense and often associated with pain behind the breastbone. The cough may lead to vomiting. Cellular damage may occur with excretion of fluid in the alveoli. This may prove fatal if adequate treatment is not given immediately. Vomit frequently contains blood due to lesions of the mucous membrane caused by the gas. Other common symptoms include headache, retrosternal burning, nausea, painful breathing, sweating, eyes, nose, throat irritation, coughing, vomiting, increase in respiration and pulse rate. Massive inhalation of chlorine produces pulmonary edema, fall of blood pressure and in a few minutes, cardiac arrest.

2) **Chronic Exposures**

   Persons rapidly lose their ability to detect the odour of chlorine in small concentrations. On account of this, the concentrations beyond threshold limit value may exceed without notice. Prolonged exposure to concentrations of 5 ppm results in disease of bronchitis and predisposition to tuberculosis and concentration of 0.8–1.0 ppm can cause moderate but permanent reduction in pulmonary function. Person exposed for long period of time to low concentrations of chlorine may suffer from acne, tooth enamel damage may also occur.

i) First Aid – Trained Personnel and Equipment

In the plant, trained first aider having the knowledge in the use of aid equipment and rendering artificial respiration should be available. First-aid box with necessary contents should be available. Properly designed showers and eye fountains should be provided in convenient locations and they should be properly maintained. If oxygen is available, the same should be administered by authorised person. Such training is imparted by civil defense.

1) **General**
Remove the affected person immediately to an uncontaminated area. Remove contaminated clothing and wash contaminated parts of the body with soap and plenty of water. Lay down the affected person in cardiac position and keep him warm. Call a physician for medical assistance at the earliest.

Caution: Never attempt to neutralise chlorine with other chemicals.

2) **Skin Contact**
Remove the contaminated clothes, wash the affected skin with large quantity of water.

Caution: No ointment should be applied unless prescribed by the physician.

3) **Eye Contact**
If eyes get affected with liquid chlorine or high concentration of chlorine gas, they must be flushed immediately with running water for at least 15 minutes keeping the eyelids open by hand.

Caution: No ointment should be used unless prescribed by an eye specialist.

4) **Inhalation**
If the victim is conscious, take him to a quiet place and lay him down on his back, with head and back elevated (cardiac position). Loosen his clothes and keep him warm using blankets. Give him tea, coffee, milk, peppermint, etc., for making good effect on breathing system.

If the victim is unconscious, but breathing, lay him down in the position mentioned above and give oxygen at low pressure until the arrival of the doctor. If breathing has stopped, quickly stretch him out on the ground or a blanket if available, loosen his collar and belt and start artificial respiration without delay. Neilson arm lift back pressure method is useful. Automatic artificial respiration is preferable if available. Continue the respiration until the arrival of the doctor. Ambu bag can also be used for this purpose.

j) Fire and Explosion Hazards
Chlorine may react to cause fires or explosions upon contact with turpentine, ether, ammonia gas, hydrocarbons, hydrogen, powdered metals, sawdust, and phosphorus.

Due to fire in the vicinity, the temperature of the containers rises excessively which results in explosion. In order to avoid explosion of the containers, remove all the movable containers from the fire zone immediately by wearing full protective clothing with respiratory protection. In the case of immovable containers, use water for cooling provided there is no leak.

k) Emergency Measures
In case of leakage or spillage:

1) Take a shallow breath and keep eyes opened to a minimum.
2) Evacuate the area.
3) Investigate the leak with proper gas mask and other appropriate personal protection.
4) The investigator must be watched by a rescuer to rescue him in emergency.
5) If liquid leak occurs, turn the containers so as to leak only gas.
6) In case of major leakage, all persons including neighbours should be warned.

7) As the escaping gas is carried in the direction of the wind all persons should be moved in a direction opposite to that of the wind. Nose should be covered with wet handkerchief.
8) Under no circumstances should water or other liquid be directed towards leaking containers because water makes the leak worse due to corrosive effect.
9) The spillage should be controlled for evaporation by spraying chilled water having temperature below 9.4 °C. With this water crystalline hydrates are formed which will temporarily avoid evaporation. Then try to neutralise the spillage by caustic soda, soda ash, or hydrated lime solution carefully. If fluro-protein foam is available, use it for preventing the evaporation of liquid chlorine.
10) Use emergency kit for controlling the leak (Figures 5.22, 5.23, 5.24, and 5.25).
11) On controlling the leakage, use the container in the system or neutralise the contents in alkali solution such as caustic soda, soda ash, or hydrated lime.

Caution: Keep the supply of caustic soda, soda ash, or hydrated lime available. Do not push the leaking container in the alkali tank. Connect the container to the tank by barometric leg.

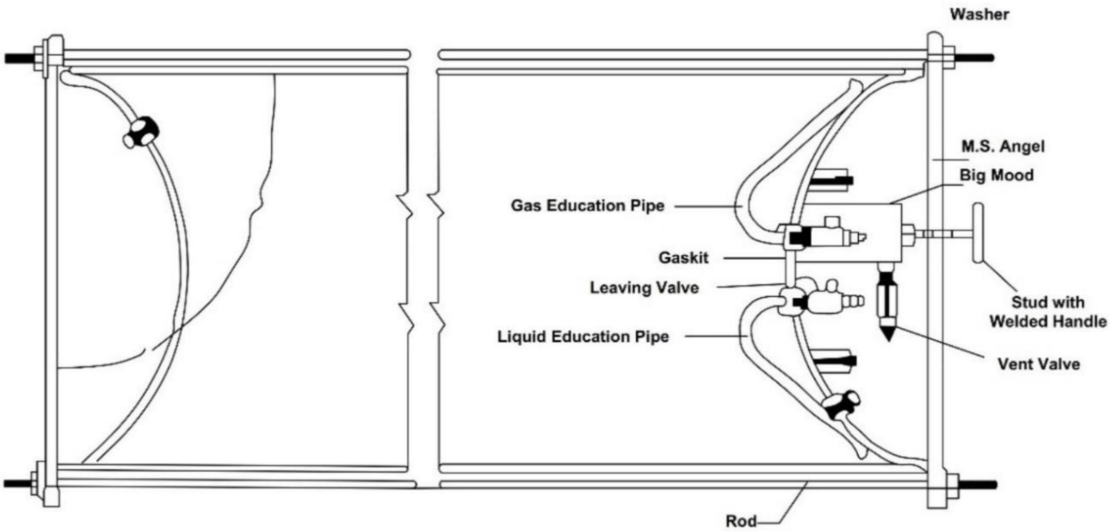
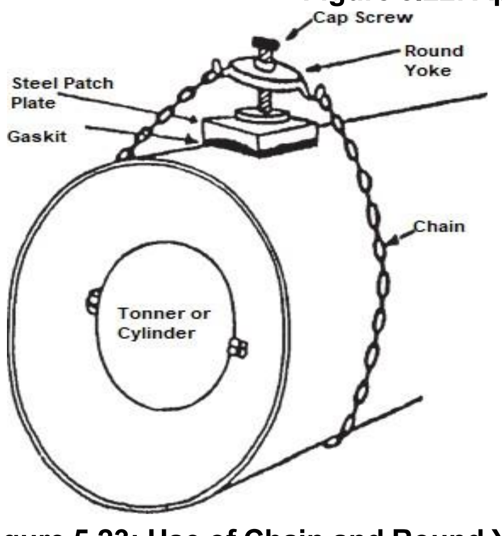


Figure 5.22: Application of Emergency Kit



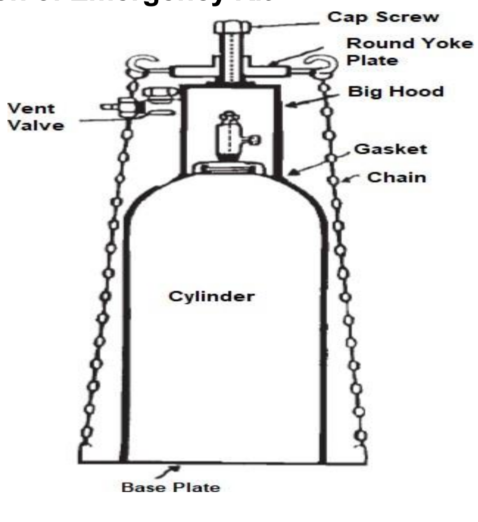


Figure 5.23: Use of Chain and Round Yoke Plate for Tonner Cylinder Wall Leak

Figure 5.24: Cylinder Valve Hood Assembly Device

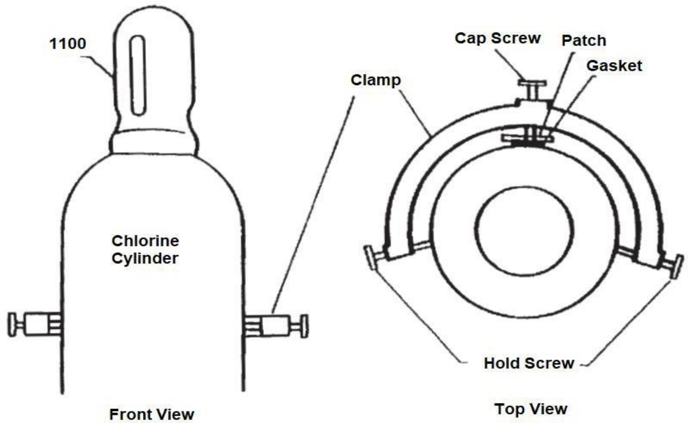


Figure 5.25: Container Wall Leak

12) If container commences leak during transport, it should be carried on to its destination or manufacturer or to remote place where it will be less harmful. Keeping the vehicle moving will prevent accumulation of high concentrations.
13) Only specially trained and equipped workers should deal with emergency arising due to major leakage.
14) If major leak takes place, alert the public nearby by sounding the siren.
15) Any minor leakage must be attended immediately or it will become worse.
16) If the leakage is in the process system, stop the valve on the container at once.

I) Personal Protective Equipment

1) **Breathing Apparatus**

Various types of respirators and their suitability are as follows:

i) **Self-contained breathing apparatus**

This apparatus is equipped with a cylinder containing compressed oxygen or air which can be strapped on to the body of the user or with a canister which produces oxygen chemically when the reaction is triggered. This type of equipment is suitable for high concentration of chlorine in an oxygen deficient atmosphere (Figure. 5.26).

ii) **Air-line respirator: Air-line length 90 m (maximum)**

It is suitable for high concentrations of chlorine provided conditions permit safe escape if air supply fails. This device is suitable in any atmosphere, regardless of the degree of contamination or oxygen deficiency, provided that clean, breathable air can be reached (Figure 5.27).

Figure 5.26: Self-contained Breathing Apparatus

Figure 5.27: Air-line Respirator

iii) Industrial Canister-type Mask: Duration: 30 minutes for 1% of Cl_2

It is suitable for moderate concentration of chlorine provided sufficient oxygen is present. The mask should be used for a relatively short exposure period only. If the actual chlorine concentration exceeds 1% by volume or oxygen is less than 16% by volume, it is not useful. The wearer in such cases must leave the place on detection of chlorine or experiencing dizziness or breathing difficulty (Figure 5.28).

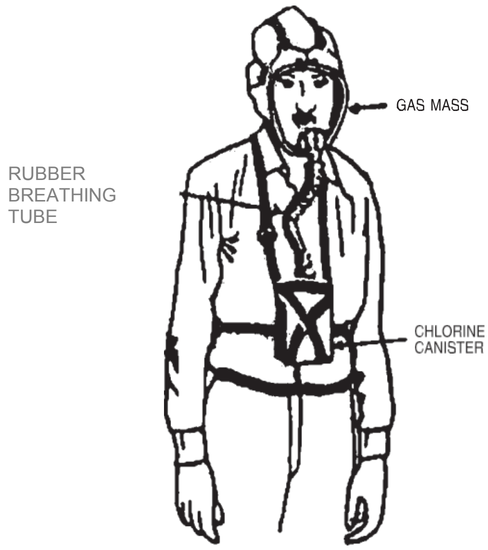


Figure 5.28: Use of Chlorine Canister Gas Mask

iv) **Protective Clothing**

Rubber or PVC clothing is useful in massive exposure which otherwise creates mild skin burns due to formation of acid on the body.

v) **Maintenance of Protective Equipment**

1) Clean with alkali after every use.
2) Keep in polythene bag at easily accessible place.
3) Check them periodically about their suitability. Many times, the seal ring of face mask gets hardened.

m) Employees Selection

Preplacement medical examination should be carried out of the persons to confirm that they are free from asthma, bronchitis, and other chronic lung conditions.

Follow-up medical examination should be carried out once in a year.

n) Employees Training

It is essential to impart training to the employees who have to face emergency. This training should include the following:

i) Instructions in the action to be taken in an emergency.
ii) Use of emergency kit.
iii) Handling of containers.
iv) First aid.
v) Use of protective equipment.
vi) Knowledge of chlorine hazards.
vii) Firefighting.
viii) Use of safety showers and eye fountains (Figure 5.29).
ix) Crash shutdown procedure for valves and switches.
x) Communication system.
xi) Study of plant layout with diagram.
xii) Mock drills.

Figure 5.29: Emergency Shower and Eye Wash Fountain

o) Neutralisation of Chlorine

A suitable provision should be available for emergency disposal of chlorine from the leaking container. Chlorine may be absorbed in solution of caustic soda, soda ash, and hydrated lime. Caustic soda is recommended as it absorbs chlorine more readily. If hydrated lime is used, the slurry must be continuously agitated and recirculated for chlorine absorption. The neutralisation can be carried out by:

- neutralisation tank holding caustic soda, hydrated lime, or sodium carbonate in solution form;
- scrubber.

i. Neutralisation tank

For the neutralisation tank, following proportion of alkali and water is recommended in order to neutralise 900 kg of Cl_2.

Chlorine, kg	Caustic soda and water		Soda ash and water		Hydrated lime and water	
	Weight (kg)	Volume (L)	Weight (kg)	Volume (L)	Weight (kg)	Volume (L)
900	1160	3680	2720	9050	1160	11350

This system can be used only after controlling the leaking container by emergency kit and connecting it to the tank by inverted U tube of 11 m height.

It is desirable to provide excess quantity of alkali solution over indicated quantities in the table in order to facilitate ready absorption. A suitable tank to hold the solution should be provided in a convenient location.

ii. Scrubber

This system consists of a blower, an alkali (NaOH) tank, an absorption tower packed with raschig rings, alkali circulation pump, piping valves, light weight FRP and PVC duct. In the event of leak which is uncontrollable with emergency kit this system would allow the person to breath easily rather than panic. In this system, the leak is confined by a hood covering the leaking container, sucking the chlorine by blower and delivering it to the absorption tower (Figure 5.30). Chlorine leak absorption capacity of the system is kept 100 kg/h and 200 kg/h for 100 kg cylinder and 900 kg tonner, respectively.

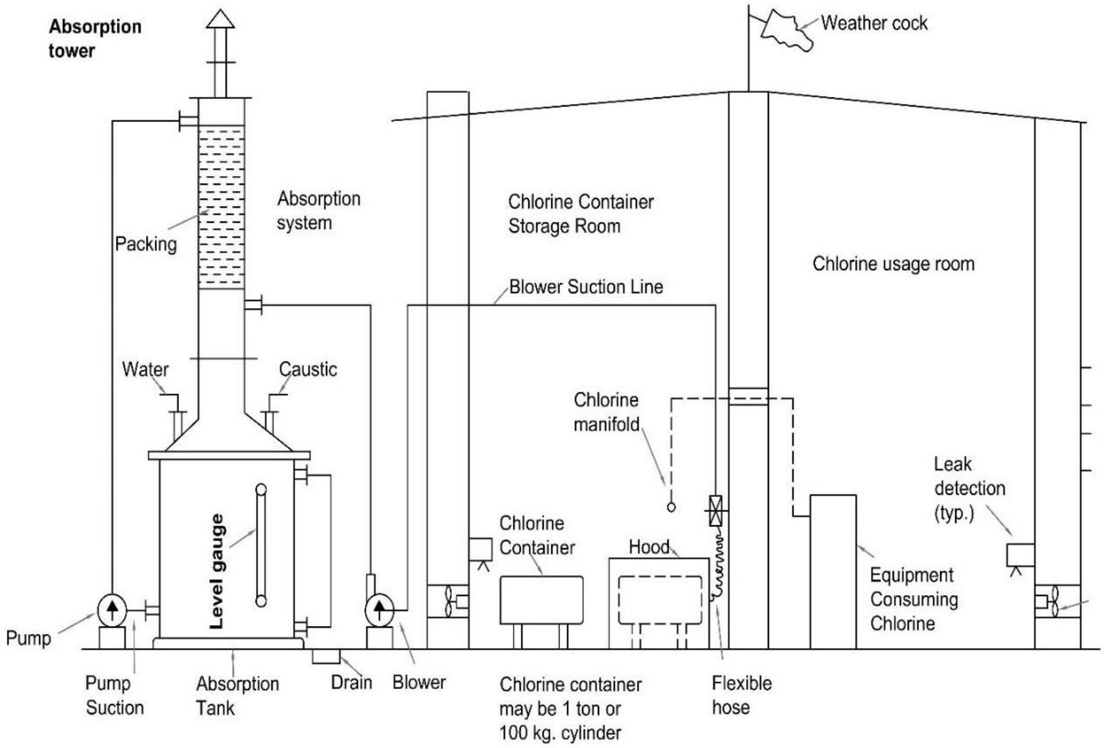


Figure 5.30: Typical Chlorine Leak Absorption System

p) Emergency Response Planning

When a large quantity of chlorine or similar toxic or flammable gases are stored, it is essential to have an emergency response planning as leakage of such gases may lead to a major accident such as emission, fire, or explosion resulting from uncontrolled developments in the course of an industrial activity, leading to serious danger to man, immediate or delayed, inside or outside the establishment and/or to the environment, and involving one or more dangerous substances. It has, therefore, become obligatory on the part of occupier to take all measures necessary to prevent accidents and to limit their consequences for man and the environment. The hazard control can be achieved by drawing an effective “onsite emergency plan” for individual organisation and, if necessary, “offsite emergency plan” by the local authority for that area.

i. Onsite Emergency Plan

As chlorine is a hazardous chemical, handling and storage of it demand adequate precautions to avoid possible hazards. Leakage of chlorine may develop into a major emergency. Therefore, the emergency procedure to cover this eventuality is essential. It is drawn in the form of on-site emergency plan.

The elements of onsite emergency plan are as follows:

a) Identification of hazard chart

In this case, the site risk is evaluated by the expert and the extent of the probable damage is calculated on the basis of stored chlorine quantity, nearby population, wind direction, type of equipment failure, etc. For this purpose, hazard analysis is conducted in which case all the hazardous properties of chlorine are considered. If evacuation is required, the range of it is calculated.

b) Appointing key persons

In order to control the incident like chlorine leakage, it is essential to appoint various persons with their well-defined responsibilities. Taking into account the various activities likely to be involved, the following key persons are appointed: (i) Site Controller, (ii) Incident Controller, (iii) Shift Executive In-charge, (iv) Communication Officer, (v) Safety Officer, (vi) Fire and Security Officer, (vii) Utilities and Services In-charge, (viii) Traffic Controller, and (ix) First Aider.

c) **Assembly points**
These points are set up where persons from the plant would assemble in case of chlorine leakage. At these points, the in-charge for counting the heads will be available.

d) **Emergency control centre**
The control centre is the focal point in case of an emergency from where the operations to handle the emergency from are directed and co- ordinated. It contains site plan, telephone lines, public address system, safety equipment, first-aid boxes, loud speaker, torches, list of essential telephone numbers, viz., fire brigade, police, hospital, civil defence, collector, factory inspector, organisational authorities, chlorine suppliers, mutual aid group, social workers, list of key persons and their addresses, copy of chemical factsheet, location plan of fire hydrant, details of dispersion model of chlorine gas, population distribution pattern, location of alarm system.

e) **Procedure to meet emergency**
The actions to be taken by the staff and authority are given below:

Emergency alarm: An audible emergency alarm system is installed throughout the plant. On hearing the alarm, the incident controller will activate the public address system to communicate with the staff about the emergency and give specific instructions for evacuations, etc. Anyone can report the occurrence of chlorine leakage to section in- charge or incident controller through telephone, intercom, or in person.

f) **Communication**
Communication officer shall establish the communication suitable to that incident.

g) **Services**
For quickness and efficient operation of emergency plan, the plant is divided into convenient number of zones and clearly marked on the plan. These are emergency services, viz., firefighting, first aid, rescue, alternative source of power supply, communication with local bodies, etc. The incident controller will hand over the charge to the site controller of all these co-ordinating activities when the site controller appears on the site. The site controller will co-ordinate all the activities of the key persons. On hearing the emergency alarm system, all the key persons will take their charge. In case of their absence, other alternatives are nominated.

The person nominated for personnel and administration purposes will be responsible for informing all statutory authorities, keeping account of all persons in the plant including contract labour, casual workers, and visitors. He will be responsible for giving information to press or any outside agencies. He is also responsible for organising canteen facilities and keeping informed the families of affected persons.

The person nominated as security officer should guide the police, firefighting, and control the vehicle entries.

The site controller or any other nominated person will announce resumption of normalcy after everything is brought under control.

The onsite emergency plan needs to be evaluated by mock drill. Any weaknesses noticed during such drills should be noted and the plan is modified to eliminate the weaknesses.

ii. Some additional safety compliances for major accident hazard (MAH)

a) Safety manual
b) SOPs
c) Safety audit
d) Safety report
e) Max credible scenario for chlorine spreading
f) Display of key plan showing emergency instructions and safe assembly areas at the gate and other strategic locations of the plant system
g) Six monthly mock drill for chlorine safety

As soon as there is an indication of a chlorine leak or other abnormal condition, corrective steps should be taken. Leaks never get better by themselves; they always get worse if not promptly and suitably repaired. Authorised trained personnel with suitable gas masks should investigate and all other persons should be kept away from the affected area. The ventilation system should be placed in operation immediately. Unconfined chlorine, being heavier than air, tends to lie close to ground levels; these characteristic must be kept in mind in designing chemical storage and usage areas, as well as when implementing appropriate natural or mechanical ventilation systems. If leaks cannot be handled promptly, the chemical supplier or nearest office or plant of the producer should be called immediately for emergency assistance.

In case of fire, containers should be removed from the fire zone immediately. Portable tanks, tank cars, trucks, and barges should be disconnected and, if possible, should be removed from the fire zone. Even if there are no visible leaks, water should never be applied to a chlorine container. Chlorine is only slightly soluble in water and the corrosive character of its reaction with water will always intensify the leak. In addition, the heat supplied by even cold water will increase the vaporisation rate. Leaking chlorine containers similarly should not be thrown into a body of water because the leak will be aggravated and the container might float when still partially full, allowing uncontrolled gas evolution at the surface.

If a leak occurs in equipment or piping, the supply should be discontinued and the material under pressure at the leak should be disposed of. Leaks around the container valve stem usually can be stopped by tightening the pack out or gland. If this action does not stop the leak, the container valve should be closed and the material under pressure in the outlet piping should be disposed of. If the valve does not shut off tight, the outlet plug or cap should be applied. In the case of a leaking valve of a tonne container, the container should be positioned so that the valves are in a vertical plane with the leaky valve at the top. Additionally, following actions can be taken if a tonner is found to be leaking:

- Position cylinders or tonne containers so that gas instead of liquid escapes. The containers may be insulated with sacks, earth, etc., to decrease the absorption of heat and the discharge rate.
- Apply appropriate emergency capping devices, if available.
- Call the supplier or nearest producer for emergency assistance.
- If practical, reduce pressure in the container by removing the gas to process or suitable disposal system. Caustic soda, soda ash, or other suitable alkali absorption system should be provided for disposing of chlorine from leaking cylinders and tonne containers.
- In some cases, it might be desirable and possible to move the container to an isolated spot where it will do the least harm.

Safety in handling hazardous materials depends to a great extent, upon the effectiveness of employee education, proper safety instructions, intelligent supervision, and the use of safe equipment. Training for both new and old employees should be conducted periodically to maintain a high degree of safety in handling procedures. Employees should be thoroughly informed of the hazards that may result from improper handling. They should be cautioned to prevent leaks and thoroughly instructed regarding proper action to take in case leaks do occur. Each employee should know what to do in an emergency and should be fully informed about first-aid measures. In addition, employee training should encompass the following:

- Instruction and periodic drills or quizzes regarding the locations, purpose, and use of emergency firefighting equipment, alarms, and emergency crash shutdown equipment such as valves and switches.
- Instruction and periodic drills or quizzes regarding the locations, purpose, and use of personnel protective equipment.
- Instruction and periodic drills or quizzes regarding the locations, purpose, and use of safety showers, eye baths, bubblier drinking fountains, and the closest source of water for use in emergencies.
- Instruction and periodic drills or quizzes of selected employees regarding the locations, purpose, and use of respiratory first-aid equipment.
- Instruction to avoid inhalation of toxic vapours and all direct contact with corrosive liquids.
- Instruction to report to the proper authority all leaks and equipment failures.

5.4.8.7 Maintenance

Every chlorinator is supplied with an instruction book that includes specific steps to follow for servicing. However, the following four areas are most often associated with maintenance requirements and causes of trouble.

I. Moisture

Moisture in chlorine is corrosive to ferrous and most non-ferrous metals. Most chlorinators use plastic materials in the sections where gas is handled under a vacuum. Metal parts or fittings, which are generally external to the chlorinator, are header valves, header lines, and flexible connections. When any connection is broken, even for a short time, the openings should be plugged immediately to exclude moisture. Corrosion is internal and not evident upon external inspection until failure occurs. A good rule to follow is to exclude moisture from any part of the equipment that is normally exposed to dry chlorine only.

Corrosion products, primarily ferric chloride, are a major cause of chlorinator malfunctioning.

II. Impurities in Chlorine

Even trace amounts of impurities can cause problems if they accumulate. Two compounds are frequently found in chlorinators after continuous use. The first one, ferric chloride, may be present in the chlorine containers or may result when careless operation allows moisture to enter the system. This compound is recognisable as a dark brown, syrupy liquid, and is soluble in water. After chlorinator parts are washed to remove impurities, they must be dried thoroughly before reassembly.

The second material, hexa-chloroethane or a similar compound, is classed as a volatile solid. It tends to deposit in gas lines at points of pressure-temperature drop. This material is not soluble in water but can be dissolved in tri-chloroethane, a common industrial solvent.

III. Flexible Connections

Flexible connection (comprising small diameter metal tubing), used to connect two cylinders or tonne containers, needs special attention. Because they are flexed every time a cylinder is changed, thereby subject to metal fatigue. These connections should be changed once a year.

Each time a connection is made either to a chlorine container or to the chlorinator, a new gasket must be used.

IV. Gaskets

Elastomeric (flexible) materials used for gasket and O-rings generally become brittle over time. If a gasketed joint is not broken, the gasket may last for years. Regular practice of replacement is desirable, but guidelines are difficult. Every recommended spare-parts list includes spare gaskets. If swelling or hardening of a gasket is noticed, it should be replaced. Distorted or hardened gaskets cannot be properly seated.

5.4.8.8 Statutory Regulations

Applicable Acts and Rules are:

1) The Gas Cylinder Rules 1981.
2) The Factories Act 1948.
3) The Manufacture, Storage and Import of Hazardous – Chemicals Rules 1989.
4) Public Liability Insurance Act & Rules 1991.
5) The National Environment Tribunal Act 1995.
6) Chemical Accident Rules 1996.
7) National Environment Appellate Authority Act & Rules 1997.
8) Standards Related to Chlorinators are given in **Annexure 5.4**.

5.4.8.9 Ozone Disinfection (Ozonation)

Ozone is one of the most potent and effective germicide and viricide for water treatment.

I. Ozonation Advantages

(i) Ozone is effective against bacteria, viruses, and protozoan cysts.

(ii) Inactivation efficiency for bacteria and viruses is not considerably affected in the 6 to 9 pH range.
(iii) Ozone disinfection efficiency increases on increasing water temperature.

Ozone can be also used to remove taste, odour, and colour caused by different substances present in water. Ozone loads of 2.5 to 2.7 mg dm^{-3} and 10 minutes of contact time with ozone residual of 0.2 mg dm^{-3} significantly reduces taste and odours.

II. Operation

The equipment may only be operated by persons authorised by the owner and/or user. It is up to the owner and/or user how many persons he authorises to operate the installation, and whether he will instruct further persons with partial functions.

The owner and/or user must ensure that the persons authorised by him have familiarised themselves with the safety measures and regulations, and that they also comply with them, in addition to having read and understood the operating instructions.

1) Operation and setting of the equipment: The preconditions for servicing include:
   - the process (installation) is ready for taking up ozone;
   - power supply switched on;
   - mains switch on;
   - cooling media is flowing;
   - gas feed open.
2) The equipment can now, locally or remote, be switched on, to the pre-set values for gas flow and electrical set point. For the setting of the equipment, the “gas flow diagram” and the setting curves provided by OEM can be used. Set and operate the ozone generator within its design parameters.
3) Ozone generation uses a significant amount of electrical power. Thus, constant attention must be given to the system to ensure that power is optimised for controlled disinfection performance.
4) The ozone generator is sensitive to moisture for this reason the feed gas must always comply with the specification and the ingress of moisture from the process side must be prevented.
5) Maintain the required flow of generator coolant (air, water, or other liquid as the case may be).
6) Monitor the ozone gas feed and distribution system to ensure that the necessary volume comes into sufficient contact with the water.
7) Maintain ambient levels of ozone below the limits of applicable safety regulations.
8) Stop production in cases of danger, such as
   - ozone leakage;
   - electrical accidents, etc.

   The main switch of the equipment must be switched off, which also functions as a production stop switch. In this way, the electrical energy supply and the feed gas flow will be immediately interrupted.
9) Alarm signals: If an alarm signal is given, the equipment will switch off. After the fault has been cleared, the alarm signal can be acknowledged and the equipment can be switched on again. If a fault repeatedly appears, the service personnel can be informed.

10) Required minimum gas flow: The actual feed gas flow should never be set to lower than 10% of the gas flowmeter's scale value in order to avoid any inaccuracies due to low flow conditions.

III. Safety Information

Ozone in gaseous form will remain hazardous for a significant amount of time thus extreme caution is needed when operating the ozone gas systems. It is important that the ozone generator, distribution, contacting, off-gas, and ozone destructor inlet piping be purged before opening the various systems or subsystems. When entering the ozone contactor, personnel must recognise the potential for oxygen deficiencies or trapped ozone gas in spite of best efforts to purge the system. The operator should be aware of all emergency operating procedures required if a problem occurs. All safety equipment should be available for operators to use in case of an emergency.

IV. Maintenance

Maintenance work may only be carried out by personnel who have been trained and authorised for this work by the owner and/or user. The owner and/or user must ensure that the maintenance personnel are familiar with the safety measures and regulations, and that they also comply with them, in addition to having read and understood the operating instructions. Maintenance activities shall include the following:

1) Regularly inspect and clean the ozonator, air supply, and dielectric assemblies, and monitor the temperature of the ozone generator.
2) Carry out periodical tightness checks on the complete installation. There must be no leaking connections in or surrounding the ozone generator. Therefore, the operator must check for leaks routinely, since a very small leak can cause unacceptable ambient ozone concentrations.
3) Lubricate the compressor or blower in accordance with the manufacturer's specifications. Ensure all compressor sealing gaskets are in good condition.
4) Condensation drain rupture disc: Periodically, open the connection at the outlet of the pressure relief line (rupture disc) to drain some possible condensation. At the same time, check the line for blockages.
5) The operator must, on a regular basis, monitor the appropriate subunits to ensure that they are not overheated.
6) Periodical check of the ambient ozone monitoring devices: The ozone monitoring equipment must be tested and calibrated as recommended by the equipment manufacturer.
7) Periodical check of the breathing apparatus: Breathing apparatus must be regularly checked in accordance with the supplier's instructions.

5.4.8.10 UV Radiation Disinfection System

Ultraviolet radiation (UV) technology is being used for disinfection in water treatment. Several types of radiations, including ultraviolet, gamma, X-rays, and microwaves, are cited in the literature for the destruction of microorganisms. This is elaborately discussed in Section 9.16.6 of Chapter 9: Disinfection, Part A of the manual.

However, proper O&M is needed to ensure the best performance. In addition, using best O&M practices extends equipment life.

Unlike chemical approaches to disinfection, UV provides inactivation of microorganisms through a physical process. When microorganisms are exposed to the specific wavelengths of UV light, they are disinfected and rendered incapable of reproducing and infecting. In WTPs if used in combination, it provides additional protection and also reduces chlorine consumption.

Ultraviolet rays are most commonly produced by a low-pressure mercury lamp constructed of quartz or special glass which is transparent and produces a narrow band of radiation energy at 2537 A° emitted by the mercury-vapour arc.

I. Operation

1) Preconditions

- Check for healthiness of electrical circuit.
- Ensure all UV lamps are in working condition.
- Check if UV lamps are well immersed in water.
- Primary considerations for effective UV disinfection are Total Suspended Solids (TSS) and UV Transmittance (UVT) shall be within permissible limits. The UV radiation of 264 nm is considered as more effective.

2) The controls that are critical to UV disinfection performance include

- flow rate monitoring;
- UVT;
- lamp on/off status;
- lamp output through the use of UV Intensity (UVI) sensors.

These parameters allow calculation of real-time UV dose and enable automatic adjustment of lamp power to deliver the required dose.

3) The operators shall be observant of changing influent and site conditions.
4) The systems equipped with automatic lamp sleeve cleaning (i.e., a dual-action cleaning system that uses mechanical wiping in conjunction with a cleaning solution), ensure that the cleaning solution is replaced at predetermined intervals. For products without automatic lamp sleeve cleaning, manual sleeve cleaning at predetermined intervals shall be followed. Inadequate cleaning is one of the most common causes of a UV system's ineffectiveness.
5) In many cases, the UV System Control Centre (SCC) will be connected to a plant SCADA system, so system status and any alarms will be available remotely. However, it is recommended that a local visual inspection shall be carried out for UV dose, lamp status, and any alarms.
6) Operators should routinely inspect for system alarms and take the necessary measures to rectify non-conforming conditions.
7) Keep the system in automatic mode for efficiency purposes.

II. Safety Information

Know and understand the safety precautions associated with working with a UV system (e.g., high voltage and the impact of UV exposure).

III. Maintenance

1) Operators should routinely inspect electrical enclosures, conduits, and wiring. When

maintained and kept dry, this equipment will have a longer life span.

2) Ensures that sufficient UV radiation is transmitted to the organisms to render them sterile. All surfaces between the UV radiation and the target organisms must be clean and the ballasts, lamps, and reactor must be functioning at peak efficiency.
3) Mechanical/electrical checks should be made on the system regularly. Core components include UV lamps and drivers or ballasts, quartz sleeves, and the sleeve cleaning system. They shall be maintained as per the O&M manual of the manufacturer.
4) Defective UV lamps and those that have outlived their useful life with deteriorated performance shall be replaced.
5) For UV equipment with cleaning systems, it’s important to visually inspect sleeves to ensure they are being evenly and effectively cleaned.
6) Ensure that no portion of the lamp arc is exposed to air.
7) Furthermore, it’s imperative that the system is maintained as per the manufacturer’s guidelines and O&M manual instructions.
8) The O&M manual will also specify consumable parts. These parts should be checked for wear on a periodic basis and replaced as needed.

5.4.9 Specific Treatment Processes

In some cases, it will be necessary to use raw water supplies containing unacceptably large concentrations of constituents that cannot be removed by conventional treatment processes. The most common of these objectionable constituents are mineral salts, such as sulphates and chlorides, and volatile organic compounds (VOCs). Special treatment processes are necessary to remove these materials, which are explicitly described in Chapter 10: “Specific Water Treatment Processes”, Part A of the manual and can be referred to.

5.4.9.1 Demineralisation

The presence of excessively high concentrations of dissolved minerals in water is indicated by high chloride (Cl^-), sulphate (SO^{4-}), and TDS levels. The recommended limits for these substances are 250 mg/L, 250 mg/L, and 500 mg/L, respectively. These limits are based on aesthetic considerations and considerably higher concentrations, while not desirable, can be tolerated.

Where demineralisation is required, processes commonly employed are electro- dialysis, reverse osmosis (RO), distillation, and ion exchange. Disposal of waste brine solutions derived from these processes often poses a serious problem and must be carefully considered at an early stage in project development. All demineralisation processes are energy intensive, and alternative water sources should be thoroughly investigated before a commitment to a demineralisation project is made. If the demineralisation process selected requires large inputs of electricity, consideration should be given to its operation principally during “off-peak” hours with storage of desalted water until needed.

I. Removal of Volatile Organic Compounds

VOCs can be either halogenated naturally occurring organic substances (trihalomethanes) or synthetic organic compounds (SOCs).

Trihalomethanes. Naturally occurring organic substances (precursors), such as humic and fulvic acids, are derived from leaf and soil extract and are not themselves volatile. When the precursors (usually found in surface waters) enter the treatment facility in the raw water they react with the free available chlorine injected for purposes of disinfection. These halogenated organic compounds are known as trihalomethanes (THMs). Other THMs can be produced by exposing precursors to other halogens, such as bromine or iodine. This grouping of total trihalomethanes (TTHMs) is generally comprised of four primary constituents: trichloromethane (chloroform), bromodichlormethane, chlorodibromomethane, and tribromomethane (bromoform). THMs are difficult to remove, hence, the need for special processes to assist in their removal.

Basic approach to control THMs

Three basic approaches to control THMs are: (a) use of a disinfectant that does not generate THMs in water (ozone, chlorine dioxide); (b) treatment to reduce the concentrations of precursor material prior to chlorination (coagulation, flocculation, filtration); and (c) treatment to reduce THM concentrations subsequent to their formation (aeration, carbon adsorption).

II. Synthetic Organic Compounds (SOCs)

SOCs are found in groundwater due to improper disposal of spent industrial-type solvents, paint thinners, cleaning agents and some household chemicals, two common SOCs are trichloroethylene (TCE) and tetrachlorethylene. Some VOCs are rather solvable and have little affinity for soil materials and, therefore, can travel great distances to an aquifer from an industrial waste lagoon, industrial, commercial on domestic septic system, landfill, accidental spill, or illegal disposal.

III. Removal Technologies for Volatile Organic Compounds (VOCs)

Three different technologies are available for the removal of VOCs: aeration, carbon adsorption, or resin absorption. All of these methods have been presented in previous sections of this technical manual, with the exception of resin absorption. Resin absorption involves the physical separation of the organic compounds from water by using a polymeric absorbent or resin filled unit. The resin is specific to the VOC it will remove, therefore great care must be taken in the selection of the resin. The resin- filled units also require frequent regeneration with a low-pressure backwash and an alcohol-wash. The waste from the backwash will contain high concentrations of VOCs and may be classified as hazardous waste.

IV. Selection of a Removal Technology

Important parameters for removing VOCs are the concentrations concerned, the type of VOC, and the cost of the removal method.

a) Higher the concentration of VOCs the more expensive removal will become. The higher concentrations of VOCs will normally require larger equipment, e.g., counter-current packed column aeration towers must increase in either volume or blower and pump horsepower for increased removal of VOCs. Low TTHM concentrations may be handled by simply changing the point of chlorination and allowing coagulation and flocculation to remove THM precursors. High TTHM concentrations may require the addition of an aeration tower or a GAC contactor and at the extreme an alternate disinfectant such as ozone.
b) The type of VOC to be removed may dictate the method of removal. Most VOCs can be reduced to meet federal maximum contaminant levels through air stripping by an aeration tower. However, some VOCs, such as bromoform, cannot be easily removed through air stripping and a more expensive method of removal, such as carbon adsorption, must be used.
c) Air stripping through counter-current packed column aeration towers appear to be a cost-effective method for reducing VOCs. Preliminary analyses suggests that it may be more

economical than GAC or resin absorption treatment. Predicted capital costs and overhead and maintenance expenditures for aeration towers are less than other treatment technologies. However, pilot testing must be performed to prove the feasibility of any solution to the removal of VOCs. Pilot testing will allow enhancement of a selected method, once that method has been proven feasible, allowing a maximum removal of VOCs for a minimum of cost.

5.4.9.2 Algal Control

Note: Only a brief description of algae removal is being given in order to help the operator to understand and take effective steps in operating and maintaining such plant processes. Sustainable algae management practices should be aimed to reduce the inflow of nutrients in water bodies. Long-term success requires changes in policies and human activities. Therefore, it can take several years to significantly improve water quality. For more details, a reference may be made to Section 10.2 of Chapter 10: Specific Water Treatment Processes, Part A of the manual.

Algae are unicellular or multicellular chlorophyll bearing plants without any true root, stem, or leaves. They may be microscopic unicellular colonial or dense mat forming filamentous forms commonly inhabiting surface waters. Their growth is influenced by a number of factors, such as mineral nutrients, availability of sunlight, temperature, and the type of reservoir. During certain climatic conditions there is an algal bloom which creates acute problems for treatment and production of potable water.

The algae encountered in water purification plants are diatoms, green algae, blue- green algae, and algal flagellates. Algae may be seen floating (plankton) in the form of blooms.

I. Problems Caused by Algae

1) Many species of algae produce objectionable taste and odour due to their characteristic oil secretions. These also impart colour ranging from yellow green to green, blue-green, red, or brown.
2) Profuse growth of algae interferes with the chemical treatment of raw water by changing water pH and its hardness.
3) Some algae act as inhibitors in the process of coagulation carried out for water purification.
4) Some algae clog filters and reduce filter performance.
5) Some algae produce toxins and their growth in drinking water reservoirs is harmful for humans and livestock.
6) Some algae provide shelter to a large number of bacteria, some of which may be pathogenic.
7) Some algae corrode metal tanks, forming pits in their walls.
8) Algae may also cause complete disintegration of concrete in contact with them.
9) Prolific growth of algae increases organic content of water, which is an important factor for the development of other organisms.

II. Remedial/ Preventive Measures

Preventive measures can be taken to a limited extent by making environmental conditions unfavourable as explained in Section 10.2.3 of Chapter 10: Specific Treatment Processes, Part A of the manual.

Control Measures

Adequate records of number, kind, and location of algae becomes handy for algal growth control. Details are given in Section 10.2.3 of Chapter 10: Specific Treatment Processes, Part A of the manual.

Algaecide dose used should be harmless to humans, have no effect on water quality, should be inexpensive and easy to apply. The most commonly used *algaecides* are copper-sulphate and chlorine.

III. Chlorine Treatment

Chlorine treatment is relatively cheap, readily available, and provides prolonged disinfecting action. Though chlorine is generally used for disinfecting potable water, it can also be used as an algaecide. Pre-chlorination has specific toxic effect and causes death and disintegration of some of the algae. It also assists in removal of algae by coagulation and sedimentation. It prevents growth of algae on basin walls and destroys slime organisms on filter sand thus prolonging filter run and facilitating filter washing.

1) **Dosage:** Lethal dose of chlorine for common types of algae is given in Table 10.1 of Chapter 10: Specific Treatment Processes in Part A. Effective chlorine dose should be such that sufficient chlorine is there to react with organic matter, ammonia, iron, manganese, and other reducing substances in water and at the same time leave sufficient chlorine to act as algaecide. Dose required for this purpose may be over 5 mg/L. With chlorine treatment essential oils present in algae are liberated which may lead to development of objectionable odour, colour, and taste. Occasionally, these oils as well as organic matter of dead algae may combine with chlorine to form intensified odour and taste. In such cases, breakpoint chlorination is required. Post filtration chlorination dose can be adjusted to obtain minimum 0.2 mg/L residual chlorine in potable water at consumer end.
2) **Application Methodology:** Chlorine is preferably applied as a strong solution of chlorine from chlorinator. A slurry of bleaching powder can also be used. For algal growth control, generally, chlorine is administered at the entry of raw water before coagulant feeder.

IV. Chlorine Treatment Versus Copper Sulphate Treatment

Chlorination is preferred over copper sulphate treatment in certain conditions, which are:

1) Copper sulphate cannot be used when the application is too close to pipeline, as copper will plate out on metal thus becoming inactive.
2) Copper sulphate cannot be used to prevent algal growth in coagulant basin, as it will be immediately thrown out of solution.
3) If adequate time (for proper precipitation of the added copper sulphate) is not available between copper sulphate treatment and supply of water, copper sulphate treatment should be avoided and chlorine treatment should be preferred.
4) Death and decay of algae imparts taste and odour to water. It also results in increase of organic matter, which supports proliferation of saprophytes (organisms growing on dead organic matter) resulting in lowering of oxygen content of water. Breakpoint pre-chlorination helps in removal of objectionable taste and odour, also assists in coagulation and controls growth of saprophytes.
5) Certain algae are resistant to copper sulphate treatment.

V. Micro-strainer

Algae can be removed from water by using micro-strainers. The infested water can be passed through stainless steel drums with cloths of mesh size ranging from 15– 45 µm. Micro-straining is a useful process for the removal of filaments and colonial algae, but it does not remove smaller species or reproductive forms which can multiply later on, creating problems. Micro-straining cannot constitute a complete treatment for effective disposal of algae, but it can be used as a part of treatment line. Moreover, this procedure requires frequent cleaning of strainers for its effectiveness.

5.4.9.3 Softening

Hard water contains excessive amounts of calcium and magnesium ions and cause problems with formation of chemical scale in hot water systems and in distribution systems. Hard water also results in excessive soap and detergent usage because it does not foam or lather readily. Many groundwater sources contain high concentrations of hardness-causing substances.

Chemical softening involves the addition of chemicals to hard water to remove calcium and magnesium ions from the water by means of precipitating them in the form of calcium carbonate (CaCO3) and magnesium hydroxide ($Mg(OH)_2$).

Softening involves similar operational actions than coagulation with lime, i.e., dosing and mixing of lime with the water and removal of the sludge that formed by sedimentation. Re-carbonation involves the addition of carbon dioxide to the water and monitoring the pH to ensure adequate addition of CO_2.

Most softener failures can be avoided with a strong preventative maintenance strategy. A comprehensive preventative maintenance plan can aid in the prevention of problems.

O&M Plan

I. **Valve wear and tear evaluation**
   The condition of **water softener's** valves will be inspected during preventative maintenance by skilled water system experts. Internal parts are removed to check for wear and tear and, if necessary, are replaced.

   The faulty valve may be replaced by an experienced professional to get commercial water softener back up and running.

II. **Study of brine**
   A brine study on your facility's water is generally performed by the water softener expert who comes to inspect to determine how much salt is being introduced into the water. A brine study can tell whether or not the softener is working properly. The technician can make adjustments to improve the brine concentration and provide effective softening if not enough salt is getting into the water.

III. **Replacement or rebuild of the solenoid**
   The **water softener's** solenoid valve doubles as a water meter and a flow restrictor. It controls the flow of water by turning it on and off in accordance to predetermined flow rates. To provide proper water flow regulation, a technician can repair or rebuild solenoids.

IV. **Pilot screens that need cleaning**
   Industrial water softeners pilot screens might become blocked with build-up or valve corrosion chips over time. The blockage of the pilot line and the multiport valve can cause problems. It's possible that the brine tank will overflow, making the cycles appear shorter.

V. Lubrication

Many moving parts, such as softening pistons and valve shafts, are included in the industrial water softener design. Lubrication on these critical components keeps them moving smoothly, allowing the softener to work at its best. It decreases friction to reduce wear and tear on these components, extending the life of the pistons or shafts and reducing the need for maintenance and replacement.

VI. Inspections by sight

A thorough visual assessment of the softener as part of routine maintenance is done by the water system specialist. The technician can assess the status of important components to spot problems and upgrade opportunities. Several evaluative aspects are commonly included in a visual inspection of a water softener:

a) **Checking for leaks in components:** The technician can repair or replace broken parts before minor leaks turn into severe problems needing extensive repairs.
b) **Checking the brine tank level:** A high water level in the brine tank usually indicates a leaking brine valve. Before the brine valve malfunctions and overfills the tank, producing extra salt dissolving and waste outflow, a technician should remedy this issue.
c) **Checking pressure gauges:** The technician should inspect the pressure gauges on the input and outflow of the industrial water softener.
d) **Evaluating the control valves:** An industrial water softener's electronic controllers provide a plethora of relevant system information. The technician should also look for signs of wear and tear on the control valves.
e) **Examining the drain:** The drain can reveal leaks and resin degradation.
f) **Testing of resin:** Hiring an expert to test your resin will help you establish how long it has left to live, as well as discover any foulants.
g) **Backwash flow controllers inspection:** Backwash flow controllers should be checked and cleaned to ensure that there is enough flow for backwash and no limits for brine.
h) **Measuring resin concentration:** Checking the resin level in the softener might help you figure out if you have enough resin.
i) **Pressure gauges for monitoring:** The pressure gauges in your industrial water softener must be checked on a regular basis as part of routine maintenance.
j) **Installing a compound gauge:** Installing a compound pressure gauge that shows both pressure and vacuum helps ensure that your commercial water softener is operating properly.
k) **The brine tank needs cleaning:** Cleaning the brine tank once a year can assist with adequate brine injection.

5.4.9.4 Removal of Iron and Manganese

Note: Only a brief description of removal of iron and manganese is being given in order to help the operator to understand and take effective steps in operating and maintaining such plant processes. For more details, a reference may be made to Section 10.7 of Chapter 10: “Specific Water Treatment Processes”, Part A of the manual.

Minerals like iron and manganese generally make their way into groundwater from shale, sandstone, and other rocks. These minerals dissolve in water containing carbon dioxide in absence of oxygen; the insoluble oxides of these elements being reduced and transformed into their soluble bicarbonates. These soluble bicarbonates when exposed to air by pumping lead to the formation of brown-coloured oxides of iron and manganese which creates unaesthetic condition giving characteristic metallic taste and colour from brownish to blackish. It also stains plumbing fixtures and laundered material.

I. Iron

Iron exists as reduced ferrous and chelated forms dissolved in groundwater or in deeper layers of some water reservoirs lacking oxygen. In surface water, iron is generally found in its precipitated ferric form. Reduced iron in water promotes the growth of autotrophic bacteria in distribution mains creating serious nuisance. The problem is further aggravated when water also contains sulphates, as reduction of iron and sulphate compounds leads to the formation of disagreeable odour and black deposits of iron sulphide.

1. Removal of Iron

Chemical analysis of water for iron content as well as its various forms is a good start to provide clue to the removal method to be adopted. But it is always advisable to perform laboratory analysis and pilot plant studies before any particular method is adopted.

The most common method for iron removal from water is oxidation followed by sedimentation and filtration. In certain types of water treatment like pH correction and chemical oxidation can be carried out in addition to above mentioned processes. The details can be referred in Section 10.7 of Chapter 10: “Specific Water Treatment Processes” in Part A of this manual.

2. Problems and Remedial Measures

a) **Problems**

Iron and manganese are two similar elements that can be a nuisance in a drinking water supply. Iron is more common than manganese, but they often occur together. They are not hazardous to health. Chlorine bleach and alkaline builders (such as sodium and carbonate) may even intensify the stains.

Iron and manganese deposits build up in pipelines, pressure tanks, water heaters, and water softening equipment. These deposits restrict the flow of water and reduce water pressure. More energy is required to pump water through clogged pipes and to heat water if heating rods are coated with mineral deposits. This raises energy and water costs.

Water contaminated with iron and manganese often contains iron or manganese bacteria. These bacteria feed on the minerals in the water. They do not cause health problems, but do form a reddish-brown (iron) or brownish- black (manganese) slime in toilet tanks and can clog water systems.

Iron and manganese in drinking water can impart a metallic taste, can cause the water to be discoloured, and can stain plumbing fixtures and laundry. Iron and manganese can affect the colour and flavour of your water. They may react with tannins in coffee and tea to produce a sludge, which affects taste and appearance. Iron and manganese can give water an unpleasant taste, odour, and colour. Iron causes reddish-brown stains on laundry, porcelain, dishes, utensils, glassware, sinks, fixtures, and concrete. Manganese causes brownish-black stains on the same materials. Detergents do not remove these stains.

b) **Remedial measures**

If the test shows that your water does contain undesirable levels of iron and/or manganese you have two options: 1) obtain a different water supply; or 2) treat the water to remove the impurities. The most appropriate method depends on factors such as the concentration of iron and manganese in the water, whether bacteria are present, and the amount of water you need to treat.

c) **Phosphate treatment**

Low levels of dissolved iron and manganese (combined concentrations up to 3 mg/L) can be remedied by injecting phosphate compounds into the water system. Phosphate prevents the minerals from oxidising and thus keeps them in solution. The phosphate compounds must be introduced into the water at a point where the iron is still dissolved in order to keep the water clear and prevent staining. Injection should occur before the pressure tank and as close to the well discharge point as possible.

Phosphate compound treatment is relatively inexpensive, but there can be disadvantages to this method. Phosphate compounds do not actually remove iron, so treated water retains a metallic taste. Adding too much phosphate can make the water feel slippery. Phosphate compounds are not stable at high temperatures, which means that if treated water is heated (in a water heater or when cooking) the iron and manganese will be released, react with oxygen and precipitate. Finally, the use of phosphate products is banned in some areas because of the environmental concerns.

d) **Ion exchange water softener**

Low to moderate levels of iron and manganese (a combined concentration of up to 5 mg/L) usually can be removed by an ion exchange water softener. Before you buy one, be sure the concentration of iron in your water does not exceed the maximum iron removal level of the equipment. Not all water softeners can remove iron from water, so selecting appropriate softener is advisable.

An ion exchange softener works by exchanging the iron in the untreated water with sodium on the ion exchange medium. Backwashing flushes iron from the softener medium, forcing sodium-rich water back through the device. This process adds sodium to the resin medium while the iron is carried away in the wastewater. There are several effective methods to choose from. These are summarised in Table 5.13 below.

Table 5.13: Treatment for Iron and Manganese in Drinking Water

Cause	Indication	Treatment
Dissolved iron or manganese	Water clear when drawn but reddish or blackish particles appear as water stands	Phosphate compounds (use for <3 mg/L iron)

	Reddish-brown or black stains on fixtures or laundry	Water softener (use for <5 mg/L combined concentrations of iron and manganese) Oxidising filter — manganese greensand or zeolite (use with <15 mg/L combined concentrations of iron and manganese) Aeration/filtration (use with <25 mg/L combined concentrations of iron and manganese) Chemical oxidation and filtration (use with >10 mg/L combined concentrations of iron and manganese)
Dissolved (colloidal) iron or manganese (organic complexes of these minerals)	Water is reddish or blackish colour from the tap and colour remains longer than 24 hours (no particles precipitate)	Chemical oxidation and filtration
Oxidised iron in the water supply	Water from the tap contains reddish-brown particles that settle out as water stands	Particle filter
Corrosion of pipes and equipment	Water from the tap contains reddish-brown particles that settle out as water stands	Raise water pH and use a particle filter
Iron or manganese bacteria	Reddish-brown or black slime in toilet tanks and sink and tub drains	Shock treatment and filtration

e) An oxidation (aeration) process is invariably required when groundwater contains more than 1 mg/L of dissolved iron or manganese. Iron and manganese can be removed by filtration although oxidation, coagulation, and sedimentation may be required for high concentrations, particularly if the metals are in dissolved form.

1) Compact-type plant
The process comprises of:

i) spray aeration through a grid of pipes to flush out CO2, H2S, and to improve pH level;
ii) trickling of aerated water through a contact catalytic media, viz., limestone of 20 mm size or a combination of manganese dioxide (MnO2) and lime; or hard coke, MnO2, and limestone;
iii) sedimentation;
iv) filtration through rapid gravity filter;
v) disinfection.

The structure consists of ordinary masonry or concrete. The aerator with contact media may be placed at the top of the sedimentation tank. Sedimentation tank may be rectangular with a length to breadth ratio of 3:1. The detention time may be around 3–5 hours. The surface loading may be around 25 m3/d/m2. Filter media shall consist of sand with effective size of 0.5–0.7 mm and a depth of 750-1000 mm over a 450–600 mm deep gravel ranging from 3 to 50 mm size.

3. Operation and Maintenance

1) The nozzles/orifices attached to the aeration pipe grid shall have their angles so adjusted as to ensure maximum aeration and to prevent loss of water. These nozzles/orifices shall require regular manual cleaning to remove incrusted iron. The residual iron deposits from inside the pipe grid shall be flushed out by opening end plugs or flanges. These operations should be repeated at least once in 2 months.
2) The limestone and other contact media require manual cleaning and washing at least once in 45–60 days.
3) The contact media bed should not remain exposed to sun for a long time to prevent hardening of bed by iron incrustation.
4) The sedimentation tank inlet baffle wall opening shall be cleaned of iron slime at least once in 45–60 days.
5) Sedimentation tank bed should be regularly scoured for removal of sludge.
6) Floc forming aid (coagulant aid) may be used for better coalescing and agglomeration.
7) The rapid gravity filter should have a water depth of about 1.2–1.5 m.
8) Since iron deposits create incrustation of filtering media, at least 100–150 mm of the top layer of sand shall be scraped and replenished with fresh sand at least once on 60 days. The whole bed may require replacement once in 2 years or so.
9) The characteristics of iron flocs are different from those of surface (river) water flocs. Due to the aeration process and contact of water with air, there may be incrustation of filter bed by residual oxidised deposits. To avoid this, common salt may be mixed with standing water and after 1–2 hours, the filter may be backwashed for better results and longevity of sand bed.

4. Package-type Iron Removal Plant (IRP)

The process incorporates the following steps:

1) Dosing of sodium aluminate solution to the raw water pumping line, to raise pH up to the optimum level and to ensure subsequent coagulation, as it is an alkaline salt.
2) Injection of compressed air for oxidation of dissolved iron.
3) Thorough mixing of raw water, sodium aluminate, and compressed air for proper dispersion in a mixing chamber of M.S. welded cylindrical shell equipped with one M.S. perforated plate fitted inside through which the mixture flows upward.
4) Passing the mixture through an oxidation chamber of M.S. shell, in which a catalytic media of manganese dioxide (MnO2) is sandwiched between two M.S. perforated circular plates (through which the mixture flows).
5) Passing the above mixture into an M.S. welded cylindrical shell type of filter in which dual media comprising of anthracite coal or high graded bituminous coal, sized 3–6 mm, is placed at the top and the finer sand with a size of 0.5–1.00 mm and 98% silica content is placed at the bottom, over a gravel- supported bed. At the bottom is the under-drainage system. Backwashing is done by air agitation

followed by backwash with water.

6) Disinfection.

Operation and Maintenance

1) Sodium aluminate should be so mixed as to raise the pH up to 8.5–9.5.
2) The quantity of compressed air should be so regulated as to achieve the optimum oxygen level.
3) The manganese dioxide (MnO2) may need replacement every 6–9 months.
4) The inside of both the mixing chamber and oxidising chamber should be coated with epoxy resin to avoid corrosion and incursion.
5) The filtration rate should be controlled within a range of 100–125 lpm/m^2.
6) The inlet pipe at the top should be fitted with a cylindrical strainer to obviate the possibility of loss of anthracite coal during washing.
7) After backwashing, rinsing of filtering media for at least 5 minutes has to be done to resettle the filtering media before normal functioning.
8) Where the iron content is very high, the whole media like manganese dioxide (MnO2), anthracite coal, sand, gravel, strainers, etc., require replacement and replenishment at least once a year for effective functioning and performance. The interior epoxy painting should also be done simultaneously.

II. Manganese

In water, manganese is usually present in soluble ionised form – manganese ion and manganese hydroxide. It can form complexes with bicarbonates, sulphates, silicates as well as with certain organic matter. It is often associated with iron and ammonium.

1. Removal of Manganese

Manganese can be removed following the same procedure as for iron removal, i.e., by oxidation, followed by sedimentation and filtration. Removal of manganese is a little difficult and complicated as compared to the iron removal. Oxidation of manganese is carried out by using following methods.

a) **By Aeration**
Oxidation by aeration needs high pH of at least 8.5–10 with lime treatment to enhance the oxidation of manganese on coke or sand beds coated with manganese oxide; however, high removal is not assured.

b) **By Catalytic Action**
Oxidation by catalytic action of pyrolusite ore is used in absence of air to change complex manganese compound to manganese hydroxide which is further oxidised to insoluble manganese hydroxide by aeration in second contact bed followed by filtration.

c) **By Chlorination**
Manganese is oxidised by free residual chlorine at pH 8.4–10. The dose of chlorine should be selected to provide about 1.25 ppm free chlorine for each ppm manganese to be oxidised. Oxidation is aided by the use of 0.2 ppm copper sulphate, the copper acting as catalytic agent.

d) **By Potassium Permanganate**
Potassium permanganate provides better oxidation than chlorine and the reaction is

independent of the pH in range above 7.0; so, manganese may be oxidised without lime treatment. The dose is about twice the content of manganese. Potassium permanganate is a point-of-entry treatment method that oxidises dissolved iron, manganese, and hydrogen sulphide into solid particles that are filtered out of the water. It can also be used to control iron bacteria growth in wells. Potassium permanganate is available as a dry, purplish solid. A device injects a solution of potassium permanganate into the water between the water pump and holding tank. Potassium permanganate oxidises iron, manganese, and hydrogen sulphide into particles. The particles are then filtered with a multimedia filter which can be either manganese-coated aluminium silicate above manganese-treated greensand or an 8-inch layer of anthracite above manganese-treated greensand. If an insufficient amount of iron, manganese, or hydrogen sulphide is oxidised prior to filtration, the manganese coating on the filter media acts as a backup oxidant to treat any remaining contaminant. If too much potassium permanganate is fed into the water prior to filtration, the excess potassium permanganate serves as a regenerant for the filter media. The water should be colourless when it leaves the filter. When treating water to remove iron bacteria, a solution of potassium permanganate is fed into the well. A concentration of 3.8 to 7.6 grams per gallon has been found to be very effective. After the solution is added in the well, continuous agitation will help loosen and disintegrate sediment and organic material produced by the bacteria, thus enhancing treatment effectiveness. Agitation can be accomplished by turning the well on and off, which brings water up through the well casing and then lets it fall back into the well. Potassium permanganate supplies must be periodically refilled as part of the maintenance routine. If using potassium permanganate in a well, periodic treatment to dissolve iron deposits and mineral scale may also be necessary. Such treatment requires the use of strong acids, so consult a water treatment specialist for guidance. Potassium permanganate injection devices and pumps are similar to those used in chlorination systems. Using potassium permanganate requires careful calibration, maintenance, and monitoring. Potassium permanganate is sensitive to temperature extremes and performs best between 50 °F and 72 °F. Well water is approximately 55 °F. Normally, potassium permanganate is purchased as dry solid crystals in bulk or in drum containers. The chemical is mixed with water and the solution is pumped directly into a raw water line. The maximum solubility of potassium permanganate is about 6.5% at 20 °C. After the dry crystals are added to the water, the solution should be mixed for at least 15 minutes with a mechanical agitator. Continuous mixing is recommended. The most common application of potassium permanganate in water treatment is as an oxidant for iron and manganese. A by- product of this oxidation step is insoluble manganese dioxide. Potassium permanganate can be used in combination with either gravity filters or pressure filters. The most popular type of pressure filter media used is manganese greensand.

CAUTION: Potassium permanganate is poisonous and irritates the skin, so handle it carefully and ensure that there is no excess potassium permanganate in the treated water. The chemical gives water a slight pink tint. Water should be colourless after treatment. The concentrated chemical must be stored in its original container, away from children and animals. Protect storage containers from physical damage.

Potassium to iron particles (not manganese dioxide particles) in water; these iron particles are of a size that can be filtered for removal. Therefore, filtration must follow oxidation to remove the insoluble iron and manganese particles.

e) **By Manganese Zeolite**
Manganese zeolite is an active contact material, which removes 1.63 kg of manganese per cubic metre of zeolite per cycle by oxidation. Regeneration of zeolite bed can be accompanied by backwashing with solution of 3.26 kg of potassium permanganate per cubic metre of zeolite. Incomplete regeneration will result in passage of manganese through contact beds.

f) **Record Keeping in Mixing**
Records of the following items should be maintained:

- Source water quality (pH, turbidity, temperature, alkalinity, chlorine demand, and colour).
- Process water quality (pH, turbidity, and alkalinity).
- Process production inventories (chemicals used, chemical feed rates, amount of water processed, and amount of chemicals in storage).
- Process equipment performance (types of equipment in operation, maintenance procedures performed, equipment calibration and adjustments).
- A plot of key process variables should be maintained. A plot of source water turbidity versus coagulant dosage should be maintained. If other process variables such as alkalinity or pH vary significantly, these should also be plotted.

5.4.9.5 De-fluoridation of Water

Fluoride occurs naturally in groundwater via weathering/leaching of rocks and soils containing fluoride. Water contamination by fluoride from industrial activities includes effluent discharge, fertilisers and pesticides, fluorosilicone and fluorocarbon polymer synthesis, coke manufacturing, glass, etc., and of groundwater by natural sources (weathering/leaching of rocks and soils containing fluoride) as well as anthropogenic sources.

The optimum fluoride level in drinking water should be below 1.5 mg/L. High doses of fluoride lead to the development of dental and skeletal fluorosis, depending on the concentration of fluoride in drinking water. Different technologies have been used for the removal of fluoride from drinking water including precipitation/coagulation, membrane-based processes, ion-exchange methods, and adsorption methods.

Treatment plant operators must use proper handling techniques to avoid overexposure to fluoride chemicals. Dusts are a particular problem when sodium fluoride and sodium fluorosilicate are used. The use of PPE should be required when any fluoride chemical is handled or when maintenance on fluoridation equipment is performed. The fluoride injection point should be as far away as possible from the injection points for chemicals that contain calcium, in order to minimise loss of fluoride by local precipitation.

5.4.9.6 Removal of Arsenic

In water, arsenic is usually present in inorganic forms of arsenite and arsenate. The exposure of arsenic can be through ingestion of arsenic-contaminated water or food and contact with arsenic-contaminated air. In groundwater levels exceeding the standards can often be linked to the contamination of groundwater by geothermal processes, mineral dissolution (e.g., pyrite oxidation), mining activities, desorption in oxidising environments, and reductive desorption and

dissolution. In regions where contaminated drinking water is not the main source of arsenic for inhabitants, intake of food grown in areas with elevated arsenic concentrations in soils and irrigation water represents the primary cause of arsenic toxicity.
The drinking arsenic-contaminated water is one of the major concerns for the health of mankind. Therefore, removal of arsenic is important and is done by the following processes:

1. **Oxidation Techniques**
   Oxidation involves the conversion of soluble arsenite to arsenate. This alone does not remove arsenic from the solution, thus, a removal technique, such as adsorption, coagulation, or ion exchange, must follow.

2. **Membrane Technologies**
   Generally, there are two categories of pressure-driven membrane filtrations: (i) low- pressure membrane processes, such as microfiltration (MF) and ultrafiltration (UF); and (ii) high-pressure membrane processes, such as RO and nano filtration (NF).

   Using membranes with pore sizes between 0.1 and 10 μm, MF alone cannot be used to remove dissolved arsenic species from arsenic-contaminated water. Thus, the particle size of arsenic-bearing species must be increased prior to MF; the most popular processes for this being coagulation and flocculation.

   In the same way as MF, UF alone is not an effective technique for the treatment of arsenic-contaminated water due to large membrane pores.

   Both NF and RO are suitable for the reduction of the dissolved arsenic level in water given that the feed is free from suspended solids and that arsenic is preferably present as arsenate.

3. **Arsenic Sludge Disposal**
   All the arsenic treatment technologies ultimately concentrate arsenic in sorption media, sludge or liquid media, and indiscriminate disposal of these may lead to environmental pollution. Hence, environmentally safe disposal of sludge, saturated media and liquid wastes rich in arsenic is of high concern. Experiments were conducted to assess transformation of arsenic from aqueous solutions in the presence of cow dung. Some studies suggested that bio-chemical (e.g., bio-methylation) process in the presence of fresh cow-dung may led to significant reduction of arsenic from arsenic rich treatment wastes (ALI, et al., 2001). Another option would be to blend the arsenic contaminated material into stable waste or engineering materials such as glass, bricks, concrete, or cement blocks. However, there is also possibility of air pollution or water pollution downstream of kilns burning bricks containing arsenic contaminated sludge due to volatilisation of arsenic during burning at high temperature.

5.4.9.7 Removal of Nitrate

Nitrate pollution of water is due to several potential sources such as animal wastes, septic tanks, municipal wastewater treatment systems, and decaying plant debris. However, nitrogen enriched fertilisers for farming are considered as the main source of nitrate pollution.

Numerous methods have been developed to reduce the nitrate concentration in water like RO, ion exchange, electrodialysis, biological denitrification, chemical denitrification, and adsorption.

However, the major limitation of these methods is the disposal concentrated waste stream to environment and risk of nitrite formation (potential incomplete denitrification). Adsorption methods absorb pollutant therefore are free from some limitations.

5.4.9.8 Removal of Uranium

Uranium is used for some severe medical treatments, therefore, due to their improper disposal it is a radioactive element that is commonly found in groundwater. It is detrimental to human health and can have extremely dangerous health effects resulting in diseases like cancer, birth defects, and kidney damage.

Water treatment systems are designed to remove uranium from raw water sources to ensure these effects do not take place. The recommended solutions to this issue are Reverse Osmosis (RO) System and Ion Exchange System.

The RO system process consists of pressurising water through a membrane that does not allow uranium to pass through. RO effectively removes 99% of contaminants.

The process of ion exchange occurs by replacing uranium with other harmless compounds through a resin bed. Like most contaminants removed with ion exchange, uranium will be absorbed by the resin bed and exchanged with a safer compound.

5.4.9.9 Removal of Ammonia

The removal of ammonia from water is required, due to its toxicity.

The most widely used methods for removing ammonia from water are: a) Catalytic Oxidation Filter, b) Breakpoint Chlorination and Oxidation, and c) Biological Filters.

O&M Schedule for Special Treatments

A routine O&M schedule should be developed and implemented for any of the special treatment system includes the following activities:

- Following the manufacturer's O&M recommendations.
- Testing and calibrating equipment.
- Maintaining pumps and blowers.
- Inspecting periodically for fouling.
- Maintain proper air and water flows.
- Proper pH adjustment with safe handling of chemicals.
- Clarifying the raw water received after pre-sedimentation.

5.4.9.10 Membrane Technology

A wide range of membrane configurations and types to allow each and every system of UF, MF, NF, and RO according to their specific separation application are available in Indian market.

I. Reverse Osmosis (RO)

The RO removes contaminants by forcing pressurised water through a semi- permeable membrane covered in microscopic pores. These pores act like a sieve. It also removes turbidity, including microbes and virtually all dissolved substances. However, while RO removes many harmful minerals, such as salt, nitrate, and lead, it also removes some healthy minerals, such as calcium and magnesium. This is why water that is treated by RO benefits by going through a magnesium and calcium mineral bed. This adds calcium and magnesium to the water, while also increasing the pH and decreasing the corrosive potential of the water. Corrosive water may leach lead and copper from distribution systems and household water pipes.

II. Ultrafiltration (UF)

The UF is a water treatment process that mechanically filter water containing very small particulate and an effective means of reducing the silt density index of water and is frequently used to pretreat surface water, seawater, and biologically treated municipal water upstream of the RO unit.

When strategically combined with other purification technologies in a complete water system, UF is ideal for the removal of colloids, proteins, bacteria, pyrogens, proteins, and macromolecules larger than the membrane pore size from water. UF removes bacteria, protozoa, and some viruses from the water.

A. Ultrafiltration Membrane System

The function of Membrane Filtration System is to provide a physical barrier for removing various bacteria, turbidity, and suspended solids. The Membrane Filtration System in this case consists of three numbers of UF skids. Water from filter feed buffer tank is pumped to the membrane filters through basket strainers with the help of filter feed pumps. The filtered water from the membrane filters is conveyed to Ultraviolet System for disinfection.

The inlet of each membrane skid is provided with a magnetic-type flowmeter/transmitter with a totaliser for measuring the water flow to each filter. The flow to each filter skid is regulated with the help of a flow control valve.

The operation of UF comprises of the following processes:

a) service;
b) backwash;
c) forward flush; and
d) chemically enhanced backwash.

B. Operation and Maintenance

Daily records of feed and permeate flow, feed pressure and temperature, and pressure drop across the system should be kept. Membranes should be cleaned when the system permeate rate drops by 10% or more. Feed flow is critical to the operation of UF systems. A drop in feed flow may be due to a problem in the pre- filter (if any), with the flow control valve, or with the pump itself. When the system is shut down for more than two days, a bactericide should be circulated through the membranes. At restart, permeate should be diverted to drain until all the bactericide is removed.

III. Microfiltration (MF)

The MF is also a pressure-driven separation process, which is widely used in concentrating, purifying or separating macromolecules, colloids and suspended particles from solution. MF processing is widely used in the food industry, for wastewater treatment and plasma separation from blood, and as pretreatment filter prior to UF, NF, and RO membrane-based processes.

IV. Nanofiltration (NF)

The NF removes these microbes, as well as most natural organic matter and some natural minerals, especially divalent ions which cause hard water. NF, however, does not remove dissolved compounds.

V. Operation

Membrane plants may be controlled manually or automatically, depending on the plant design and operating conditions. In automatically controlled plants, the operating conditions such as flows and pressures are monitored and recorded continuously. Should any of these go outside the preset limits for the specific parameter, the plant normally shuts down automatically to prevent damage to the membranes or other parts of the plant such as the pumps.

A relatively high level of operating expertise is required for manual operation of RO plants. The pretreatment and membrane cleaning processes involve the use of different chemicals and operators must therefore receive special training in the handling, make-up, and accurate dosing of different pretreatment and membrane cleaning chemicals. In addition, operators must monitor pressure differentials across membranes, water fluxes, and take the necessary action to prevent membranes damage if operating conditions go out of specification.

O&M and Handling of Membrane Elements Pre-operation stage

Prior to fitting membrane elements and directing water to UF, MF, and RO system, make sure all fittings are tight (in particular, joints and pressure vessel's end closures), all instruments and components are operating properly, and feed water matches requirements for membrane elements to be installed.

Before installing the elements and pumping pre-treated water to pressure vessels, verify all dust, grease, oil, metal residues, etc., have been removed from pipe installation. If necessary, clean and flush piping and pressure vessels before installation of elements.

Operation stage

After element installation, purge air from the piping system, including headers and UF/MF/RO vessels for a minimum of one hour with pre-treated feed water at low feed pressure, with brine valve fully opened. Pay attention not to exceed allowed ranges for flow and differential pressure in accordance with the operating manual of the manufacturer(s). After bleeding air from the system, an initial trial run can commence according to design operating parameters.

Prior to the final evaluation of the trial run, operate for a minimum of two hours under design operating conditions.

Regular start-up checks in daily operation

1) Check feed water quality to meet recommendations for applied membrane elements.
2) Flush UF/MF/RO system with pre-treated feed water at low feed pressure prior to start of high-pressure pump (HPP).
3) Regulating valve between HPP discharge and membranes should be nearly closed at HPP start-up to avoid water hammer.
4) Gradually increase feed pressure and feed flow rate to membrane elements while throttling brine flow rate. Avoid excessive flow rates and differential pressures across the system during start up.
5) HPP start-up procedures, to be sorted by type of HPP, should be followed in accordance with the operating manual of the manufacturer(s).

Shutdown considerations

1) Flush brine at system shutdown with product water or feed water of sufficient quality at low pressure to completely displace brine from pressure vessels.
2) Ensure membrane elements are kept wet and properly sterilised and/or frost protected at all times during shutdowns.
3) Ensure guidelines for temperature and pH of the preservation water are observed during shutdowns.
4) Take care that product back pressure never exceeds prescribed pressure after shutdowns.

Operations monitoring

Monitoring of performance is a fundamental prerequisite to ensure reliable, high- availability performance. Regular records will provide a solid basis for troubleshooting and handling of complaints.

1) Monitoring

   - Operating data to be logged and logging periods are listed in tables, as prescribed by manufacturer(s).
   - Summarise typical water analysis items for periodical check-up.
   - Summarise items for scheduled or situation-related maintenance.

2) Regular monitoring and check points

   When feed water quality and operating parameters, i.e., pressure, temperature, and recovery, are constant, permeate flow rate and permeate quality should be within ±5% of their values intended, without substantial fluctuations or trends to change performance.

   If the parameters are subject to change, perform regular “normalisation” in order to enable a comparison of nominal and actual values.

   Frequency of normalisations will depend on extent and frequency of variations in feed quality and operating conditions.

   This will also apply prior to any maintenance works affecting general operating parameters. If necessary, correct operating conditions.

3) Logbook

   Log all operation relevant events with time and date, especially where the following “key factors” are involved or could change.

4) Precautions and useful information for monitoring operating data

   Daily monitoring of operating parameters provides a solid basis for evaluation of system performance. Recognise deviant performance trends for salt passage, permeate flow rate, or pressure drop. This enables timely selection of appropriate countermeasures, avoiding irreversible damage to membrane elements, or other system components.

   Preservation procedures for membrane elements during system shutdown periods.

   Store elements under clean conditions to maintain performance and to prevent bacteria growth.

Considerations for preservation

1) After shutdown, displace brine with treated RO feed water, softened water, or permeate. If potential for scaling and fouling necessitates, membranes must be flushed according to manufacturer’s manual with treated system feed water, softened water, or permeate.
2) To maintain performance, elements must be wet at all times.
3) To prevent propagation of bacteria in the pressure vessel, sterilisation in accordance with manufacturer’s recommendations.
4) If elements are contaminated and extended shutdown is scheduled, perform chemical cleaning prior to conservation. This removes foulant from membranes and minimises bacterial growth.
5) Allowable temperature and pH range of preservation water in the pressure vessel will be:
    a) temperature range: 5 °C–35 °C
    b) pH range: 3–7.
6) Make-up water for preservation solution must be free from residual chlorine or other oxidising agents. For preservation, use sodium bisulphite solution.

General instructions and conditions for system cleaning

The surface of a used membrane is subject to fouling by suspended solids, colloids, and precipitation. Pretreatment of feed water prior to the process is designed to avoid contamination of membrane surface as much as possible. Best operating conditions (permeate flow rate, pressure, recovery, and pH value) will contribute considerably to less fouling of membranes. In case of high “Fouling Index” value of pre-treated feed water (even in allowable range), membrane fouling can cause performance decline in long-term operation. It can also be a consequence of large variations in raw water quality or of errors in system operation mode.

Fouling of the membrane surface will result in a performance decline, i.e., lower permeate flow rate, higher solute passage, and/or increased pressure drop between feed and brine. The detailed instructions for cleaning, preservation, and storage of membranes, should be strictly followed as per the respective manufacturer's manual.

References to troubleshooting

Potential problems in a system can be recognised early by monitoring the changes of permeate flow rate, salt passage (salt rejection), and pressure drop of the membrane modules.

It is, therefore, recommended for the system operator to record and review daily operation data and to take prompt and appropriate countermeasures or to correct any concerns or problems to prevent future complications.

Normalisation of the values of permeate flow rate and salt passage is required in order to properly understand the operational data. The procedures for normalisation, as described in the manufacturer’s operation manual, should be followed.

The steps for troubleshooting are briefly summarised below:

Check: Calibration of instruments, pressure, temperature, conductivity, pH, flow rate, meters, etc.
Review: Record of daily operation data, normalisation, plant history, and plant specification.

Investigate: Reason for performance changes and possible causes.
Troubleshoot: Corrective measures performed in time. Chemical cleaning, sterilisation, replacement of necessary parts, change of operating conditions, etc.

5.4.9.11 Packaged Treatment Plants

Package treatment technology offers an alternative to in-ground conventional treatment systems. Package processes are not altogether different from other treatment processes, although several package plant models contain innovative treatment elements, for instance, adsorptive clarifiers. However, the primary distinction between package plants and custom-designed plants is that package plants are treatment units assembled in a factory, skid mounted, and then transported to the site.

These units are most widely used to treat surface water supplies for removal of turbidity, colour, and coliform organisms with filtration processes. However, many other treatment technologies are available to small systems as package plants. These technologies or a combination of them can be incorporated into a package plant to provide comprehensive water treatment, including:

- disinfection (chlorination, ozonation, ultraviolet radiation);
- filtration (bag and cartridge filters, membrane filtration including RO or UF, slow sand filtration, pressure filtration, diatomaceous earth filtration);
- aeration;
- ion exchange;
- adsorption (using powdered activated carbon or granular activated carbon);
- softening.

Package plants can differ widely with regard to design criteria and operating and maintenance considerations.

Advantage
Package plants arrive on site virtually ready to operate and are built to minimise the day-to-day attention required to operate the equipment. Other major advantages are their compact size, cost effectiveness, relative ease of operation, and design for unattended operation. The main advantages of a packaged factory-finished system are savings in engineering, design and installation costs, and O&M. These features make package plants attractive to communities that must operate on a tight budget.

These plants can effectively remove turbidity and bacteria from surface water of fairly consistent quality, provided that they are run by competent operators and are properly maintained. Package plants also can be designed to remove dissolved substances from the raw water, including colour-causing substances and trihalomethane precursors (which are organic materials often found in source water that can react with chlorine to form what are called disinfection by-products (DBPs)).

Package Plant Limitations
Highly variable influent water quality requires a high level of operational skill and attention, and that tends to negate the package plant advantages of low cost and automation.

Packaged WTPs in India are generally used for removal of specific contaminants, e.g., iron, manganese, fluoride, arsenic, etc., mostly available in groundwater. There are packaged WTP available in the country for removal of several other contaminants like nitrate, hardness, etc., used as standalone unit or in combination of conventional WTPs.

Specific plant O&M manuals are generally provided by packaged plant manufacturers, which should be strictly followed by operators and the plant management unit. However, common but important issues to adhere to are summarised below:

Pre-operation stage

Plant survey – Before the packaged plant put under operation, plant survey should be conducted by the plant in-charge by way of quick inspection through sight (vandalism, high flow in earlier operation, foaming tanks, etc.), sound (water flow, motor/pump/valves, etc., immediately after switching on plant equipment), smell (abnormal odour, unpleasant smell, etc.), and touch (heated bearings, etc.) to understand if everything appears to be in order or not.

In case of identification of problem, if any, the plant in-charge should decide whether outside help is required or not and act accordingly. The goal is to take all necessary measures to put the plant in operation early. The SOPs prescribed in pre-operation stage in the O&M manual of the manufacturer should be followed for necessary troubleshooting in this stage.

Observations – Walking around the plant will allow the operator to visualise the raw water entering the plant, if there is any abnormal odour, colour, turbidity, etc., and thereby would be able to decide for raw water quality analyses and take necessary corrective measures accordingly. By observing the influent flow rate, the operator shall be able to adjust the plant operating capacity.

Similarly, all the plant components should be inspected in accordance with the prescribed SOP of the O&M manual of the manufacturer.

Water quality analyses and interpretations – Water samples shall be collected from the prescribed sampling locations as indicated in the manufacturer's O&M manual and routinely tested in the plant/prescribed laboratory. The test reports, along with observations/views from the laboratory personnel, shall be interpreted by the plant in- charge and take necessary corrective measures for efficient plant operation. Reporting to the regulatory agency, if any, should be made routinely so as to abide with the enforced Water Act (Prevention and Control of Pollution), 1974.

Operation procedures – Each and every component (i.e., aerator, flocculator, clarifier, filter, etc.) of a packaged treatment plant is generally provided with an SOP by the manufacturer, which shall be strictly followed for efficient operation of the packaged plant.

Final plant survey – Before leaving the plant for the day, a final inspection of the plant should be carried out. The following questionnaire may be helpful to ensure that the operation has left the plant in good condition and will operate well when it is attended to next time:

- Are there any equipment running poorly and may trouble during next time operation?
- Are the flowmeters working properly and cleaned (if so required)?
- Are valves clean and operating?

- If some processes are time clock controlled, are time clock set/re-set?
- If a remote alarm system is installed for any equipment, are these set to turn on?
- Is equipment (if so required) stored and secured to avoid vandalism?
- Is the plant secured (sufficiently illuminated, locked, etc.) to avoid vandalism?

Plant checklist – A comprehensive checklist for troubleshooting in all the above stages should be obtained from the plant manufacturer while procuring and commissioning the plant. The plant in-charge shall be responsible to train all the operating personnel with the help of the manufacturer during the period of operation by the firm prior to handling over the plant to the client. It would be wise to go for procurement of packaged plants under BOT/BOOT/BOO model to ensure efficient and trouble-free O&M of packaged WTPs.

5.4.10 Sludge Management

All WTPs produce waste/residue known as Water Treatment Sludge (WTS) during the purification of raw water. WTS are typically alum sludge, with solid concentrations varying from 0.25% to 10%, when removed from a basin. In gravity flow sludge removal systems, the solid concentration should be limited to about 3%. If the sludge is to be pumped, solids concentrations as high as 10% can be readily transported.

In horizontal flow sedimentation basins preceded by coagulation and flocculation, over 50% of the floc will settle out in the first third of the basin length. Operationally, this must be considered when establishing the frequency of the operation of sludge removal equipment.

The sludge produced from a typical WTP in India is investigated for physical and chemical characteristics. It consists of about 60% fine sand in grain size range 75 – 150μ. Silica, alumina, ferric oxide, and lime constitute the major percentage of chemical components present in the sludge. Some heavy metals are also found in the sludge.

Discharging WTS into rivers, streams, ponds, lakes, drains, etc., or landfilling the dewatered WTS is not an environmentally friendly disposal option. Based on the characteristics, sustainable and profitable disposal through recycling and reuse have been reviewed.

Sludge produced during coagulation-flocculation process is passed through the dewatering facility and the dehydrated sludge is subjected to landfilling. Therefore, representative samples of dehydrated sludge are brought to the laboratory for physical and chemical analysis.

5.4.10.1 Sludge Generation

The sludge removed from sedimentation tanks is the major waste produced at a WTP. The sludge consists of the suspended and colloidal material removed from the water together with the precipitate formed by the coagulant and flocculant. The nature of the sludge is largely determined by the coagulant used, for example, the nature of lime sludge differs largely from the nature of sludge produced from ferric chloride as coagulant.

The sludge is withdrawn from the sedimentation tank and may then be thickened before disposal or may be disposed of directly. The concentration of sludge produced determines the actual volume to be disposed of. Alum sludge normally has a low solids concentration of less than 1% m/v while lime sludge can have a solids concentration of up to 4% or 5% m/v.

Sludge can be thickened to reduce the volume to be disposed of. This is normally done in circular thickening tanks that produce thickened alum sludge of about 3% m/v solids concentration and lime sludge of 20%–22% m/v solids in the under flow.

Sludge is normally disposed of in sludge lagoons at smaller treatment works. A sludge lagoon is simply a large hole with sufficient capacity to store sludge for a predetermined period of time. The floor of the lagoon must be impermeable to prevent pollution of groundwater. Provision must be made for a second lagoon to remove sludge when the capacity of the first lagoon has been reached. The sludge can then be disposed of in a landfill site.

Dewatered sludge may also be disposed of on landfill sites. Dewatering is accomplished on sludge drying beds (SDBs) or by means of dewatering devices such as belt presses.

5.4.10.2 Sludge Removal Systems

Sludge which accumulates on the bottom of the sedimentation basins must be removed periodically in quick successions for the following reasons:

- To prevent interference with the settling process (such as resuspension of solids due to scouring).
- To prevent the sludge from becoming septic or providing an environment for the growth of microorganisms that create adverse taste and odour problems.
- To prevent excessive reduction in the cross-sectional area of the basin (reduction of detention time).

In large-scale plants, sludge is normally removed on an intermittent basis with the aid of mechanical sludge removal equipment. However, in smaller plants with low solid loading, mechanical sludge removal may be referred to.

High levels of sludge reduce the detention time and floc is carried over to the filters. The basin is then dewatered (drained), most of the sludge is removed by stationary or portable pumps, and the remaining sludge is removed with squeegees and hoses. Basin floors are usually sloped towards a drain to help sludge removal. The frequency of shutdown for cleaning will vary depending on source water quality (amount of suspended matter in the water).

A variety of mechanical devices can be used to remove sludge including:

- mechanical rakes;
- drag-chain and flights;
- travelling bridge.

Circular or square basins are usually equipped with rotating sludge rakes. Basin floors are sloped towards the centre and the sludge rakes progressively push the sludge toward a central outlet. In rectangular basins, the simplest sludge removal mechanism is the chain and flight system.

5.4.10.3 Sludge Dewatering, Thickening, and Safe Disposal

Sludge stabilisation process reduce odours, pathogens, and biodegradable toxins, as well as bind heavy metals to inert solids, such as lime that will not leach into the groundwater. The resulting bio-solids can be used or disposed safely. The use or disposal method for residuals depends on how much treatment they have received.

A. Sludge Thickening

The role of sludge thickening is to thicken the sludge of low concentration generated in clarifier and backwash water, and to make subsequent processes such as sludge dewatering more effective. When the water content of sludge is more, separation and thickening should be considered.

I. Gravity Thickening

Thickening is the process by which bio-solids are condensed to produce a concentrated solids product and a relatively solids-free supernatant. Thickening wastewater solids reduces the volume of residuals, improves operation, and reduces costs for subsequent storage, processing, transfer, end use, or disposal. For example, thickening liquid-solids (slurry) from 3% to 6% will reduce the volume by 50%. There are several different methods for thickening bio-solids, including dissolved air floatation (DAF), centrifugal thickening, gravity belt thickening, and gravity thickening. Gravity thickening uses the natural tendency of higher density solids to settle out of liquid to concentrate the solids.

Gravity thickeners consist of a circular tank (usually with a conical bottom) that is fitted with collectors or scrapers at the bottom. Primary and/or secondary solids are fed into the tank through a centre well, which releases the solids at a low velocity near the surface of the tank. The solids settle to the bottom of the tank by gravity, and the scrapers slowly move the settled, thickened solids to a discharge pipe at the bottom of the tank. A v-notch weir located at the top of the tank allows the supernatant to return to a clarifier. In addition, many systems also use a skimmer to collect and remove any floatable and grease that have accumulated at the top of the tank.

The bio-solids concentration and thickening that occurs in the tank is achieved through three different settling processes, which include gravity settling, hindered settling, and compaction settling. Gravity settling occurs when solid particles travel downward due to their weight. Settlement continues as solids begin to concentrate near the bottom of the tank, but the settlement rate decreases as the solids concentrations increase. This is known as “hindered settling”. Compaction settlingoccurs when bottom solids are further concentrated due to the pressure of solids on top of them.

Gravity thickening reduces the downstream requirements for further sludge processing and thus, it is often used prior to anaerobic digestion or lime stabilisation. Historically, thickening was not employed prior to aerobic digestion because it was difficult to supply enough oxygen to the digestion process when the total solids content was greater than 2%. Recent improvements in aeration equipment have allowed some plants to aerobically digest 3%–4% TS. Thickening prior to storage or transportation offsite is also common.

Advantages

- Gravity thickening equipment is simple to operate and maintain.
- Gravity thickening has lower operating costs than other thickening methods such as DAF, gravity belt, or centrifuge thickening. For example, a well-run gravity thickening operation will save costs incurred in downstream solids handling steps.

- Facilities that have to transfer/transport sludge to the landfill disposal site can benefit from thickening in several ways, as follows:
  - truck traffic at the plant and the farm site can be reduced;
  - trucking costs can be reduced;
  - existing storage facilities can hold more days of bio-solids production;
  - smaller storage facilities can be used;
  - less time will be required to transfer solids.

Disadvantages

- Scum build-up can cause odours. This build-up, which can occur because of long retention times, can also increase the torquerequired in the thickener. Finally, scum build-up is unsightly.
- Grease may build up in the lines and cause a blockage. This can be prevented by quickdisposal or a back flush.
- Septic conditions will generate sulphur-based odours. This can be mitigated by minimising detention times in the collection system and at the plant or by using oxidising agents.
- Supernatant does not have solids concentrations as low as those produced by a DAF or centrifuge thickener. Belt thickeners may produce supernatant with lower solids concentrations depending on the equipment and solids characteristics.
- More land area is needed for gravity thickener equipment than for a DAF, gravity belt, or centrifuge thickener.
- Solids concentrations in the thickened solids are usually lower than for a DAF, gravity belt, or centrifuge thickener.

Operation

Gravity thickener operation responds to changes in process temperatures; therefore, loading rates should be reduced to values at the lower end of the range when temperatures exceed 15 °C to 20 °C, depending on the ratio of primary to secondary sludge. Higher temperatures will require additional dilution. The following should be checked before and during operation:

- Avoid starting a thickener that contains accumulated sludge. To avoid overload, the sludge should be disposed of before starting the mechanism.
- Check and adjust the skimming mechanism to increase the amount of scum drawn into the scum box and to reduce the amount of supernatant carried with the skimming.

Maintenance

- Visually examine the skimmer to ensure that it properly comes into contact with the scum baffle and scum box.
- Install kick plates on the gravity thickener bridge to prevent objects from falling into the tank.
- An object lodged in the underflow discharge pipe or under the mechanism will quickly halt operation of the thickener. If an object falls into the tank, immediately halt thickener operation to prevent torque overload.
- During plant rounds, regularly observe and record the drive torque indicator, which

is the best indicator of mechanical overload.

- Regularly check the underflow pump capacity because pumps wear rapidly in a thickened sludge operation.
- Follow the manufacturer's recommended lubrication schedule and use recommended lubricant types.

II. Centrifugal Thickening

Thickening by centrifugation is chosen only when space is limited or sludge characteristics will not permit the adoption of other methods. This method involves high maintenance and power costs.

Operation and Maintenance

All process devices benefit from a constant feed quality and centrifuges are no exception.

The manufacturer generally sets the bowl speed. Assuming the present speed was the correct speed several years ago is not proof that it is the best speed now. The plant engineer should adjust the speed periodically, to confirm that it is correct and to remind operators that it is a variable. It is a good policy to consult the manufacturer before changing the bowl speed.

Start-up

Most modern centrifuges have a one-button start. Manual systems take a few minutes, but are not difficult. The start-up sequence is as follows:

- Turn on the feed and polymer to about one-third of the normal rate.
- Reduce the differential revolutions per minute and/or pond to minimum.
- When the cake thickness reaches the normal value, begin increasing the differential and the polymer feed rate. Some plants can go directly to the normal operating condition as soon as the cake is sealed, while others have to ramp up more slowly.

Shutdown

Again, modern centrifuges have a one-button stop. The shutdown sequence is as follows:

- Shut off the feed and polymer and turn the flushing water on.
- When clear water exits both ends of the centrifuge, push the centrifuge stop button.
- At some point, as the centrifuge slows down, flush water will come around the feed tube or around the casing seals. Note how long it took between pressing the stop button and the water gushing out. Next time, shut the water off a minute or two sooner.
- With the flush water off, the centrifuge can usually come to a stop without operator intervention.

Sampling and Testing

Sampling and testing should include TSS, ammonia, and/or phosphorus (under some conditions) for centrate.

B. Sludge Dewatering

Most of the sludge can be compacted to a water content of about 90% in the digester itself by gravity but mechanical dewatering with or without coagulant aids or prolonged drying on open SDBs may be required to reduce the water content further. The dewatering of digested sludge is usually accomplished on SDBs, which can reduce the moisture content to below 70%.

I. Chemical Dosing Equipment Operation

Many metering pump systems handle chemicals that coat or build a layer of residue or slurries that can settle out solids during operation. Strainers are helpful in removing large particulates, and the operator must keep these cleaned. Periodic flushing to remove residues and deposits is often required. Piping and valve arrangements should allow the system to be isolated so that a clear liquid, such as water, can be used to pressurise the system for flushing the residue or solid build up. These can be operated manually or automatically by solenoid valves with a timer control.

The systems where the metering pumps and piping are required to be periodically shut down will require flushing connections to remove solids.

Most feeders, regardless of type, discharge their material to a small dissolving tank equipped with a nozzle system or mechanical agitator, depending on the solubility of the chemical being fed. The surface of each particle needs to be completely wet before it enters the feed tank to ensure thorough dispersal and avoid clumping, settling, or floating. When feeding some chemicals, such as polymers, into dissolvers, care must be taken to keep moisture inside the dissolver backing up into the feeder.

Maintenance

Systems where the metering pumps and piping are periodically shut down will require flushing connections to remove solids. In addition, an allowance for T-and-Y cleanouts should be included for the piping system where longer horizontal piping runs cannot be adequately flushed. A metering pump will lose capacity and become erratic when the suction or discharge valves become worn or when poor hydraulic conditions exist. These conditions will be indicated by the cylinder test. Also, debris in the chemicals being fed may obstruct or block the check valves, thus impeding their operation and decreasing the pump's performance.

- Check dust filters periodically.
- Periodically clean and calibrate level measurement and indication instrumentation in liquid and dry storage tanks.
- Check the level and condition of the oil in the gear reducer.
- Check the condition of all painted surfaces.
- Clean dirt, dust, or oil from equipment surfaces.
- Check all electrical connections.
- Stop and start equipment, checking for voltage and amp draw and any movement restrictions because of failed bearings, improper lubrication, or other causes.
- Check the drive motor for any unusual heat, noise, or vibration.
- Check the packing for leakage and wear.

II. Sludge Feed Pump Operation

Positive-displacement pumps need a drive system that can operate the pump at the speed needed to perform adequately under all operating conditions. Sometimes, this involves manually and automatically timed starts and stops, as well as variable pump discharge rates. This variable-speed arrangement can be provided via mechanical variable-drives; variable pitch pulleys; direct-current, variable-speed drives; alternating-current, variable-frequency drives; eddy-current magnetic clutches; or hydraulic speed-adjustment systems. Each has various advantages and disadvantages with respect to cost, amount and ease of maintenance required, efficiency, turndown ratio and accuracy. Because positive-displacement pumps are constant torque machines, operators should ensure that the output torque of variable- speed drive exceeds the pump's torque requirement at all operating points. Although variable-speed drives are often either a necessity or an enhancement to proper plant operation, the challenge is providing the continued maintenance and servicing required. Operators should check the following items:

- Inlet and outlet flow rate
- Noise or vibration
- Bearing housing temperature
- Running amperage
- Pump speed
- Pressure

Maintenance

Following is the maintenance checklist for sludge pumps:

- Check the level and condition of the oil in the gear reducer.
- Check the shaft alignment.
- Check the condition of all painted surfaces.
- Visually inspect mounting fasteners for tightness.
- Clean dirt, dust, or oil from equipment surfaces.
- Check all electrical connections.
- Stop and start equipment, checking for voltage and amp draw and any movement restrictions because of failed bearings, improper lubrication, or other causes.
- Check the drive motor for any unusual heat, noise, or vibration.
- Check mechanical seals and packing for leakage or wear.

III. Mechanical Dewatering Operation

A centrifuge can thicken or dewater the sludge with only a minor change in the weir setting (also called pond setting). Likewise, it can dewater sludge to a moderate consistency at low polymer dose or produce very dry solids using higher polymer dosages.

- Sludge Type and Quality
- Polymer Activity and Mixing with the Sludge
- Polymer Type and Dosage
- Torque Control
- Process Control

Maintenance

During operation, the operator should check for the following:

- The oil level and the flow of oil to the bearings in circulating oil systems.
- Flow of cooling water and oil temperature to ensure it is operating in the proper range.
- Machine vibration.

- Ammeter reading on the bowl motor.
- Bearing temperatures by touching them.
- System for leaks.
- Centrate quality.
- Scroll drive torque.
- Because the centrifuge will shut itself down in the event of a fault, the operator typically only looks at the mechanical parameters once per shift.

IV. Sludge Drying Beds (SDB)

These are age-old practices in India and are still preferred in arid parts where land is available and affords employment opportunities to unskilled labour. Other areas, where rainfall is frequent, are not suited for drying beds.

Operation and Maintenance

Sludge that is drawn to the beds contains 4% to 10% solids depending upon the type of sludge. Wet sludge should be applied to the beds to a depth of 20 to 30 cm. After each layer of dried sludge has been removed, the bed should be raked and levelled. Sludge should never be discharged on a bed containing dried or partially dried sludge. It is preferable to apply the sludge at least a day or two after the sludge cakes are removed.

Removal of dried sludge from bed surfaces should be done with shovel, taking care to remove as little sand as possible. When the sand layer is reduced to as low as 10 to 15 cm, it should be examined for clogging by organic matter and if found, the entire sand should be removed and the bed may be re-sanded to the original depth of 20 to 30 cm.

Records of operation of SDBs should show the time and quantity of sludge drawn to each bed, the depth of loading, depth of sludge after drying time, and the quantity of dried sludge removed. The solids content of wet digested sludge, its volatile portion and pH should be determined and recorded. Likewise, the moisture content and fertiliser value in terms of NPK of dried sludge should also be analysed and recorded. An operation sheet of SDB is in Table 5.14.

Table 5.14: Typical Operation Sheet of Sludge Drying Beds (SDB)

Date and time	Checklist
	Cleaning of weeds
	Quantity of sludge to respective SDB
	Depth of wet sludge
	Depth of dried sludge
	Quantity of sludge removed
	Cleaning and scrubbing of splash plate, pipes, etc.
	Volume of sand added
	Clean-up washing scrubbing of filtrate sump

Source: JICA, 2011

5.5 Maintenance Schedules – Checklists

Preventive maintenance schedules shall be prepared for each section like pretreatment, filters, chlorination, etc., and maintenance works shall be carried out on a periodic basis (monthly, quarterly, semi-annually, and yearly) by following the specific schedules of checking, overhauling, and replacement of critical parts as and when required as per manufacturer's guidelines and based on previous experience for all equipment. Checklists shall be prepared based on recommendations of the Original Equipment Manufacturer (OEM). Checklists shall be used while carrying out maintenance activities. Treatment plant web-based SCADA solutions can be employed for online monitoring, which uses certain plant data inputs and automatically send alerts via text, voicemail, or e-mail. In addition to receiving alarms, it can also provide live plant data remotely rather than having to travel to the plant to see what is going on in your system.

5.5.1 Yearly Preventive Maintenance of Clarifier

Table 5.15: Checklist Preventive Maintenance for Clarifier

S. No.	Details to be Checked	Work Done	Level of Supervision
A	Hydraulic isolation – Functioning of inlet and drain valves – Check civil structure for leakages from adjacent clarifiers	No hydraulic isolation problem	A.E./J.E./Foreman/Electrician /Fitt er, as necessary
B	Drive head		
a)	Motor		
i	Check functioning of motor	smooth/vibrations observed	
i	Noise level	Noise level ________	
ii	Direction of rotation	Clockwise/anticlockwise	
iii	Motor insulation megger value	_____MΩ	
iv	Current measurement R, Y, B, N/L	R – ____Amp. Y – ____Amp. B – __Amp.	
b)	Geared unit		
i	Check for tightness of foundation	Ok/found loose tightened	
ii	Alignment with reference to worm gear shaft	Alignment proper/corrected	
iii	Noise	No noise/Noise level ——	
iv	Oil level and condition of oil	Checked oil level and condition found not Ok. Filled fresh E. P. 140/required number oil	
v	Condition of oil seal	Oil seal condition is good, no oil leakage/replaced	
vi	Roller chain lubrication	Lubricated with oil	
vii	All electrical connection	Checked and found Ok	
C	Overload alarm switch		
	Operation Annunciation		

S. No.	Details to be Checked	Work Done	Level of Supervision
	– 2.5 mark Tripping – 3 mark	Proper Yes	
D	Worm and worm wheel (reduction gear box)		
i	Oil condition	Good / deteriorated – replaced	
ii	Oil level	Proper/topped up	
iii	Any condensate accumulated	Yes / No	
iv	Cover plate sealing	Properly sealed with sealing compound	
v	Air vent	Cleaned thoroughly	
vi	Any abnormal noise	No / Yes – corrective action	
vii	Any oil leakage	No / Yes – corrective action	
E	Turntable		
i	Turntable alignment	Proper/rectified	
ii	Weather seal plate	Good/replaced by new	
iii	Check for any leakage	No/attended	
iv	Water seal condition	Good/replaced by new	
F	Underwater rotating structure		
a)	Centre cage and rake arm with extension arm	Ok/Corroded hence painted	
i	Condition of centre cage	Ok/Corroded hence painted	
ii	Condition of rake arm	Ok/Corroded hence painted	
iii	Rubber squeegees	Replaced worn out squeegees Quantity – _____(nos.)	
iv	Condition of extension arm	Ok/Corroded hence painted	
v	Dead weight Pulley arrangement operation	Proper/replaced	
vi	Condition of wire ropes	Replaced wire rope	
vii	Rubber lined wheel	Ok/replaced	
viii	Steel pin/bushes	Ok/replaced	
ix	PVC uptake pipe	Ok/leakage attended	
x	Pentagonal box and overflow control devices	Ok/repainted	
xi	Dry run test (by rotating rake arms) for functional check and adjusting ground clearance to a minimum of 6 mm	Rotate rake, take note of the clearance between the ground and rubber squeegees. Adjust as necessary every 30 degrees.	

S. No.	Details to be Checked	Work Done	Level of Supervision
G	Trusses and walkway		
i	Check for sagging	No/if yes, corrective action	
ii	Check for overall condition	Ok/corroded hence pained	
iii	Foundation	Proper/adjusted	
iv	Cable tray	Ok/replaced	
v	Walkway railing / plates	Ok/replaced/repainted	
H	Flocculation well and "V" notches		
i	Condition of baffle plates	Ok/corroded-painted	
ii	Condition of "V" notches	Ok/corroded-painted	
iii	Condition of stiffener ring	Ok/corroded-painted	
iv	Condition of support beam	Ok/corroded-painted	
I	Tank flooring and side walls		
i	Condition of expansion joints	Ok/filled with new jointing material	
ii	Check for wall leakage	No leakage/attended	
iii	Floor surface	Very rough needs resurfacing/attended	
iv	Uplift release pressure valve	Proper/hinges broken-attended	
J	Sluice gates		
i	Condition	Ok	
ii	Check for lubrication	lubricated	
iii	Operation of gate/alignment	Proper/getting stuck up hence aligned	
K	Sludge chamber valves		
a)	De-sludge valve (butterfly type)		
i	Condition	Ok/cleaned	
ii	Lubrication	Greasing carried out	
iii	Operation	Proper/attended	
iv	Leakage/passing	No leakage/attended passing	
v	Operation	Proper	
vi	Indication on panel remote / local	Proper	
b)	Telescopic valve (butterfly type)		
i	Condition	Ok	
ii	Lubrication	Done	
iii	Operation	Proper/rectified	
iv	Indication on panel	Proper/attended	

S. No.	Details to be Checked	Work Done	Level of Supervision
	remote / local		
c)	Solenoid valve		
i	Check for air leakage	Ok/attended	
ii	Functioning	Proper	
iii	Air lubricator	Proper/adjusted	
iv	Check moisture content	Ok	
L	Any other specific remarks		
i	Clarifier tank isolated on	Date: ____	
ii	Work completed on	Date: ____	
iii	Clarifier tank handed over for operation on date	Date: ____	
iv	Manpower utilised	Superior – hours Labour – hours	
v	Material cost	Rs ____	
vi	Inspection report of ground clearance (attach a separate ground clearance report)	Attach a separate ground clearance report	

5.5.2 Yearly Preventive Maintenance of Sludge Recirculation Pumps of Clarifier

In general, major overhauling shall be planned after 10,000 running hours of pump.

Table 5.16: Preventive Maintenance Checklist for Sludge Recirculation Pump

S. No.	Details to be Checked	Work Done	Level of Supervision
1	Pressure gauge Testing of pressure gauge and calibrate, if necessary	Checked functioning properly / calibrated / replaced	A.E. / J.E./ Foreman / Electrician/Fitter as necessary
2	Flow switch Testing for satisfactorily working Clean the unit internally and externally	a) Checked. Ok b) Cleaned with clear water	
3	Terminal box Note the phase sequence Clean the carbon deposition Condition of lugs	a) Cleaned with C.T.C. b) Ok/replaced	
4	Coupling Gap between coupling Check the coupling ratchet	a) Found Ok/adjusted to 6 mm b) Ok c) Ok/replaced	

S. No.	Details to be Checked	Work Done	Level of Supervision
	pins Condition of coupling bushes Key for coupling	d) Ok	
5	Thrust bearing Check thrust collar and bearing housing Check thrust bearing	a) found Ok/replace b) found Ok/replace	
6	Split gland Check split gland and gland packing	Replaced gland packing	
7	Discharge head Foundation bolts condition Clean the discharge head internally	a) Ok/replace b) Cleaned and painted	
8	Distance pipes taper column Pipe bell mouth Clean the pipes internally and externally with kerosene	Cleaned and painted	
9	Shaft Head shaft, line shaft, impeller shaft Clean thoroughly with diesel Threads of the shafts and couplings to be cleaned with kerosene using wire brush Test the shafts for straightness	a) Cleaned b) Cleaned c) found Ok/corrected trueness	
10	Shaft protection pipes (head shaft enclosing tube, line shaft enclosure tube, impeller shaft enclosure tube) – Clean the shaft protection pipe internally and externally with a long rod.	Cleaned and painted	
11	Transmission bearing Machined surface should be cleaned with the help of thinner Rubber bearing clean with cold water Note: Rubber bearing should not come in contact with oil, grease, or paint.	a) Cleaned b) Ok/replaced worn out rubber bearing of line shaft and impeller shaft by new	
12	Impeller assembly	Found Ok/replaced due to	

S. No.	Details to be Checked	Work Done	Level of Supervision
	– Check the impeller shaft sleeve and its key	the excessive clearance	
13	Sealing ring – Check the sealing ring with bush	Ok/damaged so replaced	
14	Rubber ring – Check the rubber between the joints of tubes and replace if necessary	Ok/worn out hence replaced	
15	Observations/work done on other parts of the pump if any		
16	Any other technical data – Motor meggering before overhauling after overhauling	Motor winding RE = __MΩ YE = _MΩ BE = ___MΩ	
17	Noise	No abnormal noise	
18	Vibration	Vibration levels _____	
19	Alignment	Alignment carried out as per manufacturer's recommendation	
20	Maintain 5 mm gap between two coupling or as recommended by the pump manufacturer	5 mm gap maintained	
21	Check for axial play (maintained 2 mm)	Adjusted axial play to 2 mm	
22	Pump isolated on	Date: ________	
23	Work completed on date	Date: ________	
24	Manpower utilised	Superior – hours Labour – hours	

5.5.3 Preventive Maintenance Schedule for Clariflocculator

Table 5.17: Preventive Maintenance Schedule for Clariflocculator

S. No.	Name of Equipment	Nature of Work	Preventive Maintenance Schedule
1	Turntable drive head	Drive head lubrication, repairs	Monthly, Yearly
2	Vertical slip ring motor	Dust blowing, checking of carbon brushes, bearing, etc.	Quarterly, Yearly
3	Reduction gear box	Checking and topping oil level, checking of helical or spur gear condition	Quarterly, Yearly
4	Turntable mechanism	Checking and topping oil level	Quarterly, Yearly
5	Rail track and carriage drive	Lubricating/greasing, checking of wear and tear, alignment and its positioning	Quarterly, Yearly

6	Flocculator paddles and its drive	Electrical connections, lubricating, alignment	Quarterly, Yearly
7	De-sludge valves, pipes, fittings	Cleaning, lubricating, repairs	Monthly, Yearly
8	M.S. scrapers	Tightening of nuts and bolts, replacement of broken parts, repairs, replacement of rubber squeegees	Yearly
9	Entire M.S. structure	Repairs, painting	Yearly
10	Civil structure	Cleaning of sludge, attending leakages through structure	Yearly

5.5.4 Preventive Maintenance Schedule for Filter Plant Equipment

Table 5.18: Preventive Maintenance Schedule for Filter Plant Equipment

S. No.	Name of the Equipment	Preventive Maintenance Schedule
1	Air scour valve	Weekly, Monthly, Quarterly, Yearly
2	Air compressor set with dryer	Weekly, Monthly, Quarterly, Yearly
3	Filter outlet main + wash water main + air scour main	Monthly
4	Air receiver tank and pneumatic line	Monthly, Yearly
5	Solenoid valves	Monthly
6	Wash Water Control Panels (WWCP)	Monthly, Yearly
7	Consoles (automatic panels)	Monthly
8	Wash water valve with actuator	Quarterly, Yearly
9	Guard valve with actuator	Yearly
10	Settled Water Inlet (SWI) valve and actuator	Yearly
11	Wash Water Outlet (WWO) valve and actuator	Yearly
12	Wash Water Inlet (WWI) valve and actuator	Yearly
13	Filtered Water Outlet (FWO) valve and actuator	Yearly
14	Air Scour Inlet (ASI) valve and actuator	Yearly
15	Bed drain sluice valve 200 mm	Yearly
16	Head loss measurement tubes	Monthly
17	1250 KVA transformers	Weekly, Monthly, Yearly
18	3.3 KV HT panel	Weekly, Monthly, Yearly
19	3.3 KV VCB	Quarterly, Yearly
20	415 V LT Panel	Weekly, Monthly, Yearly
21	ACB 415 V, 2000 A	Quarterly, Yearly
22	48 V DCDB panel	Weekly, Monthly, Yearly
23	48 V battery chargers	Weekly, Monthly, Yearly
24	48 V battery bank	Weekly, Monthly, Yearly
25	PLC UPS system	Weekly, Monthly, Yearly
26	Main PLC panel	Weekly, Monthly, Yearly
27	SCADA filter operation	Monthly, Yearly

S. No.	Name of the Equipment	Preventive Maintenance Schedule
28	Submersible dewatering pump	Monthly, Yearly
29	CCT sampling submersible pump	Monthly, Yearly
30	Raw water sampling pump	Monthly, Yearly
31	Clarifier water sampling pumps	Monthly, Yearly
32	Filtered water sampling pumps	Monthly, Yearly
33	Ultrasonic flow transmitters	Monthly, Yearly
34	Electric power panels	Monthly, Yearly
35	Lighting distribution boards	Monthly, Yearly
36	Tube lights and fire cylinders	Monthly, Yearly
37	Ventilation system	Monthly, Yearly
38	Chain pulley block	Monthly, Yearly
39	Post top lanterns	Monthly
40	Flood lights for filter bed	Monthly

5.5.5 Monthly Preventive Maintenance Checklist for Washwater Control System with Panels

Table 5.19: Checklist for Washwater Control System with Panels

S. No.	Details to be Checked	Work Done	Level of Supervision
1	Clean the panel with duster and air blower		A.E. /J.E. / Foreman / Electrician / Fitter as necessary
2	Check all the electrical connections for tightness		
3	Check all the indicating lamps		
4	Check all the fuses for tightness		
5	Check the heater connections and supply		
6	Clean the D.P. Transmitter, remove the air from transmitter if required		
7	Clean the water pipes provided for the Transmitter from inside and clean the venturi with water		
8	Clean the Guard valve and wash- water valve lines		
9	Check the limit switch of guard valve and set if required		
10	Check and clean air filter and air regulator of air line		
11	Clean the air filter of wash-water valve		
12	Check the manual operations of wash-water valve		
13	Check wash-water flow readings and set if required		
14	Check valve positioner		

5.5.6 Quarterly preventive maintenance checklist for Washwater control system

Table 5.20: Checklist for Washwater Control System

S. No.	Details to be Checked	Work Done	Level of Supervision
1	Overhauling of position controller		A.E. / J.E. / Foreman / Electrician / Fitter as necessary
2	Check all the limit switches		
3	Test the IP convertor and calibration		
4	Test the DP transmitter and calibration		
5	Overhauling of station box		
6	Check and calibration of indicator		
7	Check and tight all the connections in the wash-water panel		

5.6 Early Warning System

A sudden deterioration in water quality occurs completely unpredictably, so it is necessary to build an early warning system in treatment plants, which would quickly and especially reliably detect changes in the quality of raw water to a high degree of sensitivity.

To ensure the safety of production, it is necessary to have real-time information on the quality of raw water flowing into the treatment plant and the water discharged from the treatment plant into the water supply network. Because the treatment of drinking water is a continuous process, continuous monitoring is necessary. The needs of the early warning system are therefore best met by continuous biological monitoring, where selected monitoring organisms are continuously exposed to the monitored waters and the assessment of biological properties of these waters is based on evaluating the response of these organisms to the overall composition of these waters. It must work as an automated system that allows remote control. Online monitoring of water quality at WTPs is a must for all water treatment plant and, in case there is no such arrangements, manual monitoring must be done, and data thus collected are analysed for daily plant performance status asserted. It must detect a wide range of different contaminants that have been or are being managed at the plant and at the same time maintain sufficient sensitivity and must provide a rapid response.

5.7 Record Keeping

Records need to be maintained from operations as well as statutory point of view. The SCADA, Digital Twin, CMMS records will have to be maintained in real time covering the following aspects:

- Source water quality (pH, turbidity, temperature, alkalinity, chlorine demand, and colour).
- Process water quality (pH, turbidity, and alkalinity).
- Process production inventories (chemicals used, chemical feed rates, amount of water processed, and amount of chemicals in storage).
- Process equipment performance (types of equipment in operation, maintenance procedures performed, equipment calibration and adjustments).
- A plot of key process variables should be maintained. A plot of source water turbidity

versus coagulant dosage should be maintained. If other process variables, such as alkalinity or pH, vary significantly, these should also be plotted.

The following measurements should be taken and recorded:

Table 5.21: Records of Different Measurements

S. No.	Aspect	Parameters
A	Flow measurements	1) Raw 2) Settled 3) Filtered 4) Chlorination
B	Flowmeters	1) Calibration and accuracy of equipment 2) Charts and pen recorder 3) Servicing of equipment 4) Cleaning of sump, water channel, etc.
C	Chemical feeding	1) Dosing at a point of maximum turbulence 2) Jar test apparatus – ascertaining coagulant dosing 3) Cleaning V-notches, weirs, and floor 4) Mixer painting 5) Painting alum tank with food grade anti- corrosive paint 6) Spares for rapid mix
D	Flocculator	1) Observing floc formation 2) Checking speeds of paddles 3) Checking short circuiting 4) Sludge collection, if any, and to take remedial measures to stop it 5) Lubrication of mechanical devices 6) Dosing lines 7) Valves and pipes
E	Settling basins	1) Examination of floc: Observing floc formation efficiency, floc distribution, and clarity of settled water 2) Checking short circuiting 3) Scrapers and squeegees 4) Outlet weir adjustment, biological growth 5) Sludge lines and telescopic sludge devices if any 6) Density of sludge 7) Accumulation of sludge 8) Bleeding of sludge disposal 9) Measuring turbidity at the end 10) Watching efficiency of various components 11) Overhauling all equipment 12) Painting 13) Rail tracks 14) Reduction gear box

S. No.	Aspect	Parameters
F	Filters	1) Checking turbidity at start and end 2) Adequate depth of water 3) Rate of filtration 4) Head loss at different important stages 5) Negative head 6) Filter run 7) Filter media surface cracks 8) Mud balls slime growth intermixing of media 9) Uplifting of underdrain nozzles 10) Filter media carry over 11) Backwashing time and quantity of water used in backwashing 12) Uniform washing of filter media 13) Thickness of filter media before and after washing 14) Water quantity received, wasted, consumed for backwashing, produced 15) Operation of valves 16) Performance of blowers 17) Status of functioning of instruments 18) Corrosion of underwater equipment

Formats for daily and monthly reporting of operation and maintenance of WTP are given in **Annexure 5.5**.

CHAPTER 6 : RAW WATER AND CLEAR WATER RESERVOIRS

6.1 General

The main function of raw water reservoirs and Clear Water Reservoirs (CWRs) in a water supply system is to cater daily demands and especially peak demands of water in the service area. Operators/managers must be concerned with the amount of water available in the raw water reservoirs and CWRs, and the corresponding water levels at particular times of the day. Procedures for operating the reservoirs will depend upon the design of their storage capacity and on the water demand pattern at a particular time/day. The reservoirs are classified into two types viz. raw water reservoirs/tanks and clear water/balancing reservoirs, as per the functionality.

a) **Raw water reservoirs/tanks** are designed to address seasonal variations and store water for a longer duration from the canal system. These are open and can be earthen, semi-lined, or brick/concrete lined tanks that receive and store water supplied from rivers, canals, water catchment, etc.

b) **Clear/treated water reservoir**

   i. **Ground level reservoir**
   These are constructed using concrete/masonry to hold treated/clear water with a designed storage capacity of a maximum of a day's demand. These are covered with proper roofing, ventilation, and entry points.

   ii. **Elevated/overhead reservoir**
   These are overhead or above the ground level tanks which may store treated water for the supply of water as per the designed capacity and zone.

Apart from the above, the raw water storage is also created by constructing a dam/weir on the stream/river, which acts as a source. The details for Operation and Maintenance (O&M) of sources and intakes can be referred to in Chapter 3: Sources of Water Supply in Part B of this manual.

6.2 Operation of Reservoirs

The basic purpose of creating a reservoir is to store water and supply it to water treatment plant (WTP) for treatment or supply in distribution network in case of a clear water reservoir after a WTP.

6.2.1 Operation of Raw Water Reservoirs

A storage reservoir serves to contain raw water, and rainwater in a reservoir with gate/valve-controlled outlets (Figure 6.1), wherein the surface water is retained for a period of time and released for use when the stream's normal flow is insufficient to satisfy the requirements. Raw water reservoirs have to be operated according to the design/raw water requirements, considering the availability of raw water in rivers or canals. Usually, the raw water reservoirs are constructed to supply water based on daily demand, and hence these are filled up to the top to store water during periods of raw water unavailability. These tanks usually need periodic desilting.

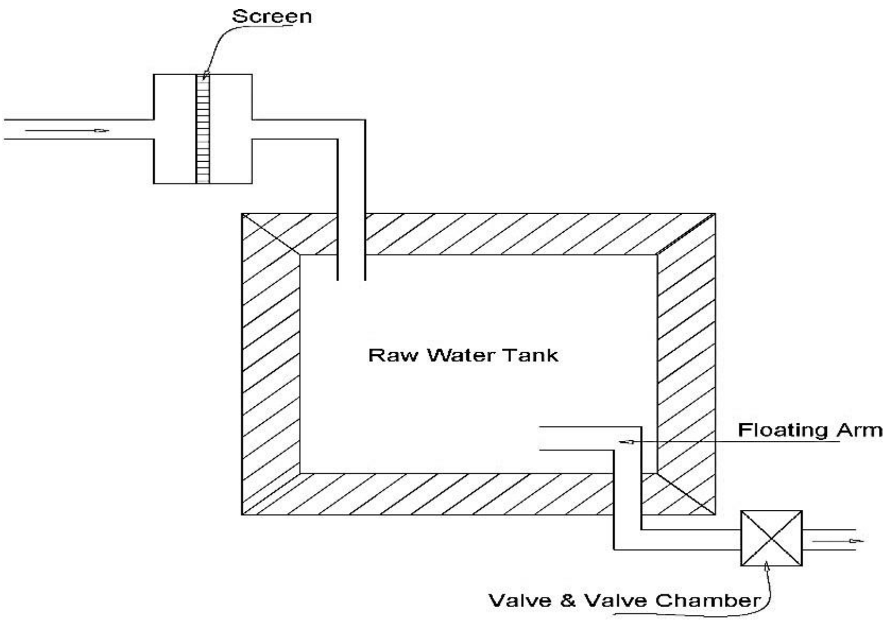


Figure 6.1: Typical Piping Arrangement in Raw Water Reservoir

Operation of Raw Water Reservoirs during Abnormal Conditions

Changes in precipitation patterns, increases in frequency and intensity of floods and droughts are some of the documented hydrologic changes which brings the abnormal conditions in the raw water reservoir/tanks.

During flooding, the operator must close or adjust the valves at strategic points to avoid ingress of silt into the intake. Also, a proper dredging arrangement should be made to avoid blockage of intake channels, intake wells, and strainers.

During droughts, the water levels generally drop very much below the required levels to supply the demands. The available water may drop down to a distance which is far from the intake arrangement, hence, temporary channels will have to be dug out with temporary pumping arrangement, if needed.

6.2.2 Operation of Clear Water Reservoirs

CWRs store treated water in order to reduce supply interruptions caused by mains, pumps, or other plant equipment failures; help maintain uniform pressure; provide a water reserve for firefighting and other emergencies; act as a relief valve on a mains- supplied pumping system; allow for a smaller distribution main size than what would have been necessary if direct pumping were used; and allow pumping at average instead of peak flow rate.

CWRs have to be operated according to the design requirements. Usually, the CWRs are constructed to supply water during periods of high-water demand; hence, the CWRs are filled during periods of low-water demand.

In some systems, reservoirs are allowed to float at the end of the distribution system when pumps are used to pump directly into the distribution system, and excess water flows into the CWR. In such systems, multiple pumps are used to cater to the varying demands and pressures in the system.

Small changes in the distribution system, such as pipeline extensions or a few more connections, will not require additional storage requirements. However, major system changes such as the addition of larger main pipelines and an increase in a large number of connections may require additional storage. Typical piping arrangement in clear water reservoir is shown in Figure 6.2.

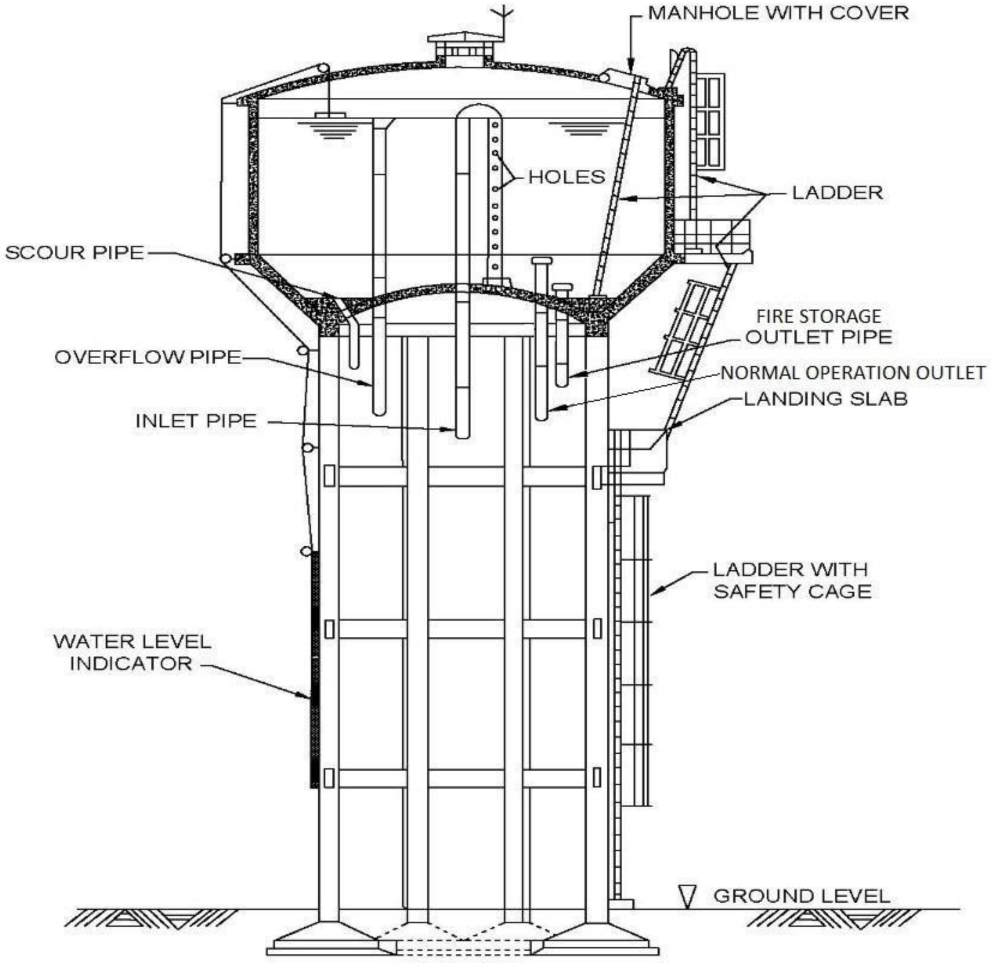


Figure 6.2: Typical Piping Arrangement in Elevated Service Reservoir

The outlet of the tank that supplies water for normal operation should be kept just above the fire storage so that the capacity provided for mitigating fire is always available. There should be another outlet at the bottom of the tank which can be opened when instance of fire occurs.

6.2.2.1 Operation of Clear Water Reservoirs during Abnormal Conditions

Abnormal operating conditions arise:

- Whenever demand for water goes up suddenly due to fire demand or due to excessive demand on one command area/zone of a system;
- Due to failure or breakdown of the water supply of another zone of the distribution system;
- During out-of-service pumps or pipelines, power breakdowns, or when service reservoirs (SRs) are out of service;
- In the event of natural calamities and disasters, such as earthquake, etc.

The operator/manager must have a thorough knowledge of the entire distribution system emanating from the service reservoirs (SRs). Closure or adjustment of valves at strategic points in the distribution system can focus or divert the flow of water towards the affected areas. Emergency plans must be developed in advance to cope- up with such situations.

6.2.3 Storage Levels

Most distribution systems establish a pattern of levels for assuring the required supplies at the required pressures. A water usage curve/table over a 24-hour period, ideally with a half-hour interval, should be prepared for each reservoir. This pattern varies not only during the different times of the day but also during different days of the week, especially on weekends, holidays, and festivals. Demand pattern also changes during different times of the year depending on the weather conditions, such as summer, winter, etc. The operator can anticipate better and be ready for expected high consumption periods from the usage curve. The maximum water levels to be maintained in the reservoir should be known to ensure that the system's daily demands are met.

In the case of intermittent supply, timings for the supply of water in the areas are fixed in advance. In large command areas, the water can be supplied to sub-zones during particular fixed hours by operation of the necessary valves. The operator should work out a programme for compliance.

6.2.3.1 Storage Level Control

A simple system used to read and control the levels in the reservoir is a gauge/water level indicator. The operator informs the pump house to stop pumping whenever the reservoir reaches the maximum water level. Mobile phones or dedicated wireless devices can be used in place of traditional telephones. Electrodes, ultrasonic signals, or solid-state electronic sensors are also used to sense the rise and fall in water levels and send signals to the pumps to be stopped or started through cables or wireless or radio frequencies.

It is also desirable to have a level indicator of the reservoir in the pump house. Automation of level controls at the reservoir is to be attempted with caution, and it is desirable that only simple level control instruments are chosen, keeping in view the availability of skilled personnel. Only trained and qualified operators are permitted to repair the instruments. However, for effective and efficient operation of the reservoirs, PLC and SCADA-based automation, with an annual maintenance contract, may be employed with the reservoir to minimise the wastage of water and power and to monitor water quality parameters. Typical layout for ESR automation is shown in Figure 6.3.

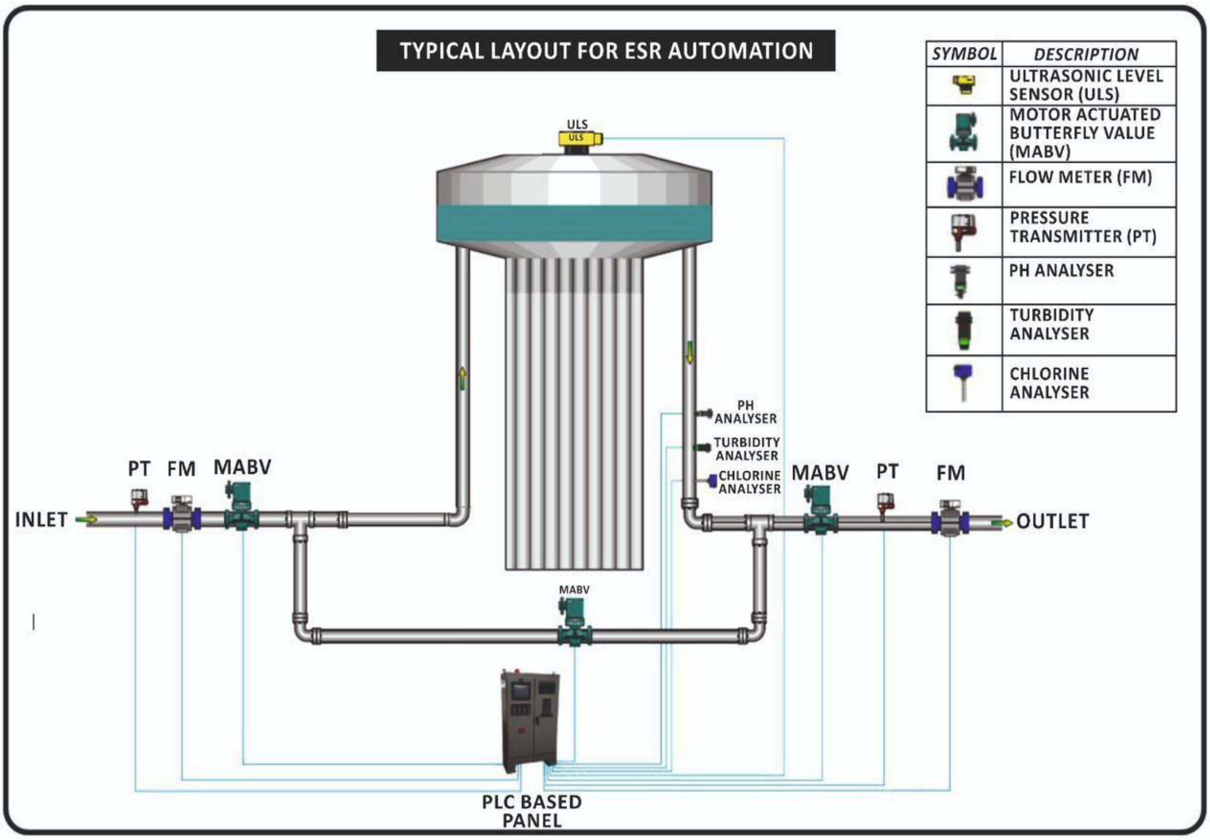


Figure 6.3*:* Typical Layout for ESR Automation

6.2.3.2 Sampling of Water Quality

Water from all reservoirs should be regularly sampled and tested for physical, chemical, and microbiological parameters, especially once before and after the monsoon, to determine the quality of water that enters and leaves the reservoirs. Sampling data can help in setting up periodic *cleaning* of reservoirs. Indicators that help to decide when the tank is due for cleaning are turbidity, excessive colour, taste, and odour.

Water quality problems may be of the microbiological type which could be caused by loss of residual chlorine due to bacterial contamination. Chemical water quality problems may also occur due to leaching from reservoir lining and coating for RCC and masonry tanks, as well as from corrosion in steel tanks. The common cause of physical water quality problems includes the collection of sediment, rust, and chemical precipitates. Water quality in a reservoir may also deteriorate due to excessively prolonged periods of stagnant conditions. Sometimes, poor design and improperly applied or cured coatings and linings may also cause water quality degradation. Proper investigation is required to identify the reasons for water quality degradation, determine the source of the problem, and address the same. Wherever seasonal demands fall, and the residual chlorine levels get depleted, it may be necessary to add additional chlorination facilities.

6.3 Maintenance Plan

The plan for O&M of the reservoirs shall contain operational procedures, maintenance procedures, and the manufacturer’s information in respect to the instruments/gauges. Display of reservoir drawings with dimensions and levels, valves and instruments, and daily operations log in the operator’s office should be available.

6.3.1 Procedures of Operations

Reservoir shall be operated keeping in view design criteria of capacity, size, and depth; piping of inlet, outlet, scour, and overflow; control valves of the inlet, outlet, and scour; source of feeding the reservoir; hours of pumping or gravity feeding into the reservoir; rate of flow into the reservoir; hours of supply from the reservoir and quantity to be supplied from the reservoir; areas to be served/supplied; highest and lowest elevations (critical control points) to be commanded from the reservoir and the water levels to be maintained in the reservoir for command of the entire area.

- Structural drawing of the reservoir and the layout drawing showing the alignment of pipe connections, bypass lines, interconnections and location of valves, flowmeters, pressure gauges, and alignment of outfall drain to lead off the scour and overflow water from the reservoir.
- Suppliers' names, addresses, and telephone numbers of the equipment installed in the reservoir, such as valves, flowmeters, level indicators, etc.
- A spot map showing the location of the piping and valves. The map shall also indicate the open or closed positions of the valves to be operated. This map shall be preserved with a glass cover or laminated to prevent unauthorised meddling.
- Step-by-step operating instructions indicating how to operate and control various valves located at the inlets and outlets, so as to ensure the required quantity of water is supplied to the command areas at the desired pressures during the period required to be supplied.
- A record sheet for each valve showing direction for turning, number of turns, inspections, repairs, and whether open or closed. The direction of operation of valves shall be clearly marked as "open" or "close".
- The name of the valve and piping, such as washout, inlet, outlet, bypass, overflow, etc., shall be painted clearly and repainted regularly.
- In the case of mechanised operation of valves, the steps include starting, running, and stopping the operations.
- Instruction for situations when valves cannot be operated due to some problems regarding authority to be informed and receive further instructions.

6.3.2 Regular Checks

Inspection of the reservoirs at different levels is very important for effective and efficient planning and implementation of O&M procedures. The major inspection of each reservoir shall be conducted at least once a year by an engineer/expert looking into various aspects, such as structural integrity of the reservoirs (cracks/holes/deterioration of external/internal structure/structural stability, etc.), the status of various equipment and appurtenances fitted with reservoirs, up-keeping of reservoir campus including vegetation growing, waterlogging, unauthorised construction, security aspects, source of contamination, if any, and operational problems, etc. To reduce or avoid any leakage or consequent contamination in the reservoir, the reservoir should be tested for water tightness, drained, cleaned, washed down, and visually inspected. The most reliable method for measuring leakage from the CWR is to fill it to full level, isolate it from the supply, and measure the change in the level over a suitable time period, preferably for 24 hours. A log should be maintained to record the date of major inspection, report, and any actions taken on the report for future reference and action.

6.4 Reservoir Maintenance

The maintenance procedures shall include a step-by-step procedure for every equipment in reservoirs, such as pipes inside the tank (chambers, screens, inlets, outlets, washouts, overflows), valves, specials, and flowmeters, following the procedures as per the manufacturers' catalogues.

6.4.1 Raw Water Reservoirs

Raw water reservoirs are often open at the top and hence require regular maintenance to remove silt/sedimentation, floating matter, and any other matter that grow inside due to favourable conditions.

Desilting chambers, screens, and outlets:

- Silting chamber needs to be cleaned regularly, especially during the running period of the river/canal.
- The screen shall be periodically painted and cleaned.
- The floating matter should be removed regularly during the operation and availability of raw water.
- Weeding of the structures may be carried out as per requirement.
- It is advisable to draw a top layer of raw water from these tanks; accordingly, the outlet system may be fitted with a floating arm or shaft with gates that should be regularly inspected and repaired as per requirement.

6.4.2 Clear Water Reservoirs

- CWRs have to be inspected regularly as per the schedule.
- Leakage from the structure, pipes and valves have to be attended to on priority. It is advisable to resort to pressure grouting to arrest leaks from structures, and sometimes an additional coating of cement mortar plastering is also done using a waterproof compound to arrest leaks from the structure.
- Maintenance is mainly concerned with protection against corrosion both externally and internally. Corrosion of roof slab of RCC reservoirs due to the effect of chlorine is also common. Internal corrosion is prevented by cleaning and painting at regular intervals. Only food-grade paints are to be used for painting the interior surface of CWRs. Anti-corrosive painting (epoxy) is also done to the interiors when corrosion due to chlorine is expected.
- External protective coating (painting, epoxy, etc.) of overhead steel tanks as and when required with waterproof cement paint for exteriors of RCC tanks once in 5 years is usually done. The inside of the painted CWR shall be disinfected before being used for a sufficient period to give chlorine residuals of at least 0.2 mg/L. Manhole covers and vent pipes shall always be properly placed and maintained.
- The air vent helps in the easy circulation of air in the tank. Ventilation windows should be provided with wire mesh so that entry of rodents, reptiles, etc., inside the tank can be stopped, and also periodic check has to be done.
- Water level indicators, level gauges/flowmeters be inspected regularly and repairs are carried out.
- Inspection of RCC ceiling, columns, etc., can only be accomplished by performing in situ tests on the structures in addition to visual inspection. The rebound hammer test, ultrasonic pulse velocity (UPV) test, pull-out and pull-off tests, core sampling and testing, carbonation test, and cover survey are all commonly used to evaluate existing concrete structures. Necessary steps should be adopted for strengthening of the RCC structure, if

found dilapidated. All the pipe fittings should be leak-proof, any leakage nearby reservoir may affect the safety of the reservoir.

- The overflow pipe should be connected with the distribution system after the sluice valve is installed on the delivery pipeline to avoid the wastage of overflow water.
- A concrete platform as protection work shall be provided around the CWR, if not provided, so as to safeguard the reservoir foundation from any leakages/overflow of water. All valves should be inspected and regulated regularly at a specified frequency of inspection.
- Valves spindles that develop leaks should be repacked.
- Rust and sediment in the valve are removed with proper caution.
- Valve chambers of the SR also require maintenance to ensure that the interiors of chambers are not silted up and also ensure that the covers are in good condition and properly positioned.
- The sluice valve chamber shall not be waterlogged by ensuring proper drainage and disposal of water from the chamber.
- Lubricate the packing gland and soften the packing.
- The valve supports should also be checked for any structural cracks, exposure of reinforcement, etc., and repaired.

6.5 Cleaning of Clear Water Reservoirs

Routine inspection is the best way to determine when a tank requires maintenance and cleaning. A visual inspection can be made from the roof manhole with the water level lowered to about half or less. Alternatively, a detailed inspection can be made after draining the tank and then cleaning or washing. The best time of the year to take up cleaning of the reservoir is during the period of lowest water consumption.

The following activities are normally involved in the cleaning of a tank:

i. Make alternate arrangements for water supply to consumers served by the reservoir.
ii. Close the inlet line before commencing cleaning of the reservoir.
iii. Draw the water from the reservoir till 200–300 mm water depth is left in the reservoir.
iv. Close the outlet valve so that no water will be used while the tank is being cleaned.
v. Collect a sample of water and silt/mud accumulated in the tank and get the biological analysis for the presence of snails and worms. If snails and worms are found, find the source and eliminate it.
vi. Drain and dispose of the remaining water and silt.
vii. Wash the interior of tank walls and floor with a water hose and brushes.
viii. The floor should be cleaned off into the scour sump and all solids should be removed by wet vacuum and disposed of appropriately.
ix. Inspect the floor, inlets, and outlets for any depression, pits, vegetation, etc., and seal such pits with rich concrete after removing loose material and vegetation and consolidating the floor below the pit.
x. The frequency of cleaning of SR depends on the extent of silting, development of biofilms, and results from water quality monitoring.
xi. Care should be taken in avoiding contamination of drinking water reservoirs in an area where there is faecal contamination from farmland.
xii. In order to facilitate smooth and safe working during the cleaning process, arrangements

for proper lighting, personal protective gears, air blower, oxygen cylinder, first aid, alarm, or hooter system should be made available to avoid health hazard.

xiii. Proper office procedure or standard operating procedure should be followed.

Best Practice: Use of Underwater Robotic System for Reservoir Cleaning

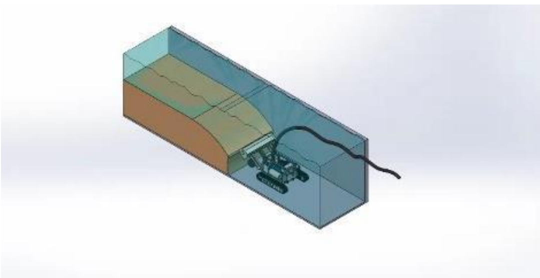
Globally, in many countries like US, European countries, Australia, Brazil, etc., the robotic underwater reservoir cleaning process is widely and rapidly used for cleaning reservoirs. In India, many of the major municipal bodies like Bombay Municipal Corporation, Pune Municipal Corporation, Nagpur Municipal Corporation, Delhi Jal Board, etc., have been using this technology.

The robotic underwater cleaning system is designed in such a way that it could clean effectively and efficiently without having to put offline or shutdown the reservoirs and without labour to go inside the reservoirs. It is remote-controlled with rotary brushes fitted with robots and an adequate pump that pumps out directly the loosen sediment without increasing turbidity in the water.

MCGM, Mumbai, was involved in robot underwater reservoir cleaning for about 5 years, from 2010 to 2015, for cleaning various reservoirs like Malabar, Bhandarwade, Worli, Goanji, etc. Reservoirs were heavily silted even with more than a metre deep silt, and with this unique technology, all their reservoirs were cleaned very effectively and efficiently without disruption of the water supply system, risk and inconvenience to the consumers as well as personnel employed for cleaning.

Use of Underwater Robotic System for Reservoir Cleaning

The classical method of manual inspection and cleaning of the UGRs by taking shutdown causes disruption in supplies and needs to public inconvenience. The following methods can be used for inspection and cleaning of UGRs without requirement of shutdown and pumping out of precious water.



6.5.1 Disinfection of Clear Water Reservoirs

After cleaning, reservoir should be disinfected before taking in the service for which qualified operator(s) wearing the appropriate personal protective gears should be allowed to perform disinfection of the reservoir. The following are some of the different methods of reservoir disinfection:

- Sodium hypochlorite/chlorine should be injected into water to give a free residual chlorine in the range of 25 to 35 mg/L to spray the internal surfaces of the reservoir. The residual chlorine should not be below 6 mg/L after a period of 24 hours.
- All outlets should be closed off during the procedure to prevent highly disinfected water

entering in the distribution network.

- Disinfected water should be kept for at least 24 hours in the reservoirs. The water should then be drained completely and the reservoir refilled with drinking water.
- Entire reservoir should be filled with chlorinated water (10 mg/L) for a specified period (6 to 24 hours) and then emptied completely (AWWA, Standard C652, Disinfection of Storage Tanks).
- Fill 5% of the reservoir with chlorinated water (50 mg/L) for 6 hours minimum, and then fill the reservoir with treated water (i.e., with normal levels of chlorine) to overflow level for 24 hours and then use this water (AWWA, Standard C652, Disinfection of Storage Tanks).
- Reservoir water should be put back into service only when the water analysis results are in compliance with the drinking water standards.
  Reference: EPA: Drinking Water Advice Note No. 10 (Service reservoir inspection, cleaning, and maintenance), 2011.

6.6 Common Concerns

- Unauthorised access.
- Protection of ground below and around reservoirs from erosion due to rain, scour, and overflow water.
- Vandalism is committed by livestock owners in order to gain access to water (normally from the scour valve).
- Water contamination from rain, animals, or humans entering the reservoir.
- Ingress of foreign particles such as dust, tree leaf, etc.

6.7 Personnel

Recommended minimum O&M staff for the reservoir is mentioned in Section 3.1.5 of Chapter 3: Institutional Strengthening and Capacity Building of Part C of this manual. The required personnel have to be trained in the O&M of the valves, flowmeters, water level indicators, etc.; training to include fault location, dismantling, and assembling after repairs and replacement of the parts of the valves, flowmeters, water level indicators, and SCADA system.

The supervisory personnel (managerial staff) also need to be trained in the supervision of the O&M.

6.8 Spares and Tools

For upkeep of drinking water supply system, it is very important to keep a proper identified stock of material for repairs especially for pipelines, gauges, and set of tools to carry out the repairs.

6.8.1 Spares

The maintenance procedures shall contain a list of spares that are likely to be damaged due to wear and tear, and have to be replaced in a reservoir. This list will also indicate the minimum quantity at which replenishment should be made. This information is to be included in the Computerised Maintenance Management System (CMMS) and Management Information System (MIS). The list of probable spares to be kept in stock may include the following:

- spare check nuts and spindle rods and assorted bolts, nuts, and washers for the flanges;
- gaskets for flanged joints for all sizes of sluice valves installed in the SR;

- spare pulleys;
- threads, floats, and indicators for water level indicators;
- spare manhole covers, spare fly-proof mesh for ventilators;
- consumables like gland, rope, grease, and cotton waste; and
- pipes, jointing materials.

6.8.2 Tools

The necessary tools to repair and correct the routine problems and facilitate repairs and replacements in a reservoir have to be identified and provided to the maintenance staff.

Some of the tools required for maintenance work in a reservoir are:

- key rods for the operation of all sluice valves;
- hooks for lifting manhole covers;
- appropriate size of pipe wrench;
- DE spanner set, ring spanner set;
- screw drivers, pliers;
- hammers, chisels;
- excavation tools such as crowbars, spades, iron baskets;
- housekeeping accessories such as long brooms and coir brushes;
- portable lighting facilities like head worn lights, emergency lights, anti-skid boots, etc.;
- dewatering pump with accessories.

6.8.3 Available Inventory

A list of consumables with available stock, such as gland rope, spindle rods or stems, check nuts or wedge nuts, and suggested tools available at each reservoir site shall be prepared and displayed in the premises of each reservoir.

6.9 Manufacturer's Information

For each SR, a compilation shall be made which contains the information about the equipment used in the SR, such as sluice valves, butterfly valves, air valves, water level indicators, pressure gauges, flowmeters, etc. The information for the equipment shall include the manufacturer's name, address, telephone number, mobile number, email, etc., and also the technical information furnished by the manufacturers. The test certificates, inspection reports, and warranty certificates of these equipment shall also be kept along with the manufacturer's information.

6.10 Records and Reports

6.10.1 Record System

A record system that should be realistic and apply to the operating problems involved at the particular reservoir site has to be developed. The most efficient way to keep records is to plan what data is essential and then prepare the formats followed by the persons to fill the data, frequency, and to whom the record is to be sent for review and report. For guidance, sample records to be maintained at a reservoir site are given below. The record should be maintained in digital format which are available as when required.

6.10.2 Records to be kept on the Operations

Note the following:

- Water levels in the reservoirs (for all compartments) at hourly intervals.
- Time and relevant operation of control valves with the time of opening and closure or throttling position of the valves.
- Hourly flowmeter readings both on the inlets and outlets.
- Hourly residual chlorine readings of inflow water and outflow water.
- The man-hours spent on routine operations at the reservoir in the previous year and the cost thereof.

6.10.3 Maintenance Records

The agency concerned should maintain the record of all items available at the site, including software and hardware components, routine activities, line repairing and painting works, and expenditures incurred for manpower, consumables, etc., so as to plan the budget accordingly. Maintain records for each of the following maintenance/repair works along with the cost of materials and labour.

- When the gland ropes of the valves at the SR were changed.
- When the spares of the valves were changed.
- When the manhole covers were changed/replaced.
- When the water level indicator was repaired or replaced.
- When the SCADA system was installed/repaired.
- When the reservoir was last cleaned.
- When the out-fall drain for scour and overflow was last cleaned.
- When the ladder was changed.
- When the structure of the reservoir was last repaired to attend to structural defects or arrest leakage.
- When the reservoir was last painted.
- When the leakage in the pipe (inlet/outlet/overflow/washout pipe) was repaired.
- When the piping at the reservoir was last painted.

Record the total cost of repairs and replacements at the SR in the previous year along with breakup cost of material and labour with amount spent on outside agencies for repairs and replacements.

The maintenance records can be maintained in the CMMS and MIS. CMMS will generate the work orders as well as keep records of all the maintenance work arrived out with resources, manpower, material, and costs incurred.

6.10.4 Reports

The major inspection report with a recommendation by the competent engineer/expert will form a basis for preparing an assessment report for evaluating the O&M of the facility. The assessment report can identify the deficiencies in the reservoirs and their appurtenances, and then plan future repairs to the structure or valves and other equipment, or for replacement of defective valves or other equipment, or additions to the storage capacity where the existing capacity is inadequate.

6.11 Checks to be Carried Out at Reservoirs

A programme has to be prepared for each reservoir which shall contain procedures for routine tasks, checks, and inspections at intervals, viz., daily, weekly, quarterly, semi-annually, or annually. This plan shall fix responsibility, the timing for action, ways, and means of completing the action as to when and who should take the action and mention the need to take this action. Simple checklists for use by the managerial staff can be prepared to ensure that the O&M staff have completed the tasks assigned to them.

6.11.1 Checklists for Clear Water Sump and Reservoir

S. No.	Checks Required/Undertaken	Status	Frequency of Reporting (to be decided by concerned authorities)
1.	Proper closure of washout valves; any abrupt stoppage during operation.		
2.	Proper operation of inlet valves; any abrupt stoppage during operation.		
3.	Proper operation of outlet valves; any abrupt stoppage during operation.		
4.	Proper operation of bypass valves; any abrupt stoppage during operation.		
5.	Does any valve pass water even after closure?		
6.	Leaks through valves, glands, bolts, and nuts.		
7.	Leaks through pipes and joints at the reservoir.		
8.	Status of valve chambers and their covers.		
9.	Status of SCADA system and its operation; and defects found and replacement required.		
10.	Status of finial ventilators; fly-proof mesh intact or is to be replaced.		
11.	Status of manholes covers; are they corroded/missing?		
12.	Functioning of water level indicators.		
13.	Functioning of flowmeters.		
14.	Status of ladders and railing; are they corroded?		
15.	Check whether the quality of the water in the reservoir is OK.		
16.	Possibility of reservoir water getting polluted.		
17.	Check for the need for cleaning and		

S. No.	Checks Required/Undertaken	Status	Frequency of Reporting (to be decided by concerned authorities)
	disinfecting the reservoir.		
18.	Check for the presence of residual chlorine in the water stored in a reservoir.		
19.	Check for the signs of corrosion of the interior of the roof due to chlorine.		
20.	Check for structural damages to the reservoir.		
21.	Check for leaks through the structure of the reservoir.		
22.	Status of interconnecting pipe work? Is it corroded?		
23.	Status of lightning arrestor.		
24.	Status of out-fall drains of scour and overflow at the reservoir.		
25.	Status of upkeep of reservoir campus like the presence of unwanted vegetation, waterlogging, unauthorised construction, security, and approach issues.		
26.	Source of water contamination, if any.		
27.	Availability of:		
	Spares		
	Consumables		
	Tools		
28.	Check for the need of painting.		
29.	Check for availability of drawings and designs of the reservoir.		
30.	Check the availability of the O&M logbook, inspection reports, and assessment reports.		

6.11.2 Recommended O&M Schedule

Daily or Weekly

- Check storage tank for signs of security breaches – damaged fences, open gates, graffiti, vandalism, etc.
- Check water level indicator – functioning, adequate amount of stored water, excessive water use.
- Check the overflow line, vents, ladder access locks, roof access hatches, and controls that are readily visible from the ground for damage, vandalism, or other conditions.
- Check storage tank and site after any adverse weather conditions – high winds, heavy snow, ice, rains, etc.

Monthly

- Verify all openings are protected from surface runoff, windblown contaminants, insects, birds, and animals.
- Check tank overflow lines for signs of damage, such as screens, flapper valves, check valves, splash plates, etc.
- Check the area for excessive vegetation or dangerous conditions – uncut grass, brush, dead trees, fire hazard, etc.
- Check control valves for proper positions, open or closed, damage or leaks.

Quarterly

- Inspect the tank's exterior and roof for signs of damage, corrosion, degradation, leakage, or structural problems, focusing on all openings into the reservoir (reservoir roof and sidewall vents, access hatch, overflow outlet, and so on).
- Check for leakage of water due to non-functioning of appurtenances or structural failure.
- Check tank-supporting structure for signs of damage, corrosion, degradation, or structural or seismic inadequacy.
- Check tank foundation for signs of damage, corrosion, degradation, and structural inadequacy.
- Check that there are no signs of damage near tank ladders, including corrosion, degradation, structural issues, or vandalism.
- Check the tank area for water ponding, poor drainage, excessive vegetation, unhealthy trees, fire hazards, etc.
- Check that the tank area is free from combustible storage, trash, debris, brush, or other material that could present a fire hazard.
- No accumulation of material on or near parts possibly resulting in accelerated corrosion or rot.
- Tank and support free of ice build-up.
- Check earth embankments for erosion, burrowing animals, improper drainage, and leakage.

Annually or Seasonally

- Check storage tank structural, seismic, and sanitary integrity – leaks, corrosion, cracks, supports, warping, etc.
- Inspect storage tank interior for pitting, concrete spalling, rot, corrosion, rust, water level sensors, biofilm build-up, etc.
- Exercise valves and make repairs as needed.
- Document inspection and maintenance activity as part of an O&M programme.
- Inventory and evaluate storage facilities capacity, condition, replacement costs, and plan for improvements.
- Evaluate stored water for clarity, sediments, floating materials or films, unusual odours, insects, birds, or animals.
- Plan for storage facility improvements and budget for the associated cost.

CHAPTER 7 : DISTRIBUTION SYSTEM

7.1 Introduction

The distribution system is the most crucial and important part of the water supply, delivering 24×7 Pressurised Water Supply Systems with “Drink from Tap”. The network has to be managed efficiently; otherwise, the very purpose of reaching equitable potable water to the consumers with adequate pressure at the ferrule (21 m head of water for Class I and Class II cities/towns and 15 m head of water for other towns) will be defeated, and the target consumers that are directly dependent on the system will have negative opinion, which will result in poor support from consumers and people at large for any further improvement in the water service delivery system.

The water distribution network (WDN) is the forefront to the consumers and people. The water is supplied through a well-articulated network of pipelines with various appurtenances including valves, collectively called as the water distribution system (WDS), which involves operation of network spread over a large area. Since the WDS operation and maintenance (O&M) task is human resource intensive and too many variables are involved in its successful operation, the well-trained O&M staff are the key to the overall success of the WDS operations and the water supply system as a whole, which are created with, generally, huge investments.

The distribution system is designed for a long horizon and have many factors that may influence the longevity of the WDS. Hence, there is a requirement of proactive measures following the best O&M practices of these assets.

7.2 Objectives

The overall objective of the “Drink from Tap” 24×7 pressurised water supply systems is to deliver wholesome water to every consumer 24 hours a day, every day of the year at adequate residual pressure in sufficient quantity at the farthest/convenient points and achieve continuity and maximum coverage at affordable cost. The “Drink from Tap” 24×7 pressurised water supply systems consists of a well-designed WDS that is continuously full and under positive pressure throughout all its pipelines and networks. To attain this objective, the water supply organisation has to evolve operating procedures to ensure that the overall system can be operated satisfactorily, function efficiently, effectively, and continuously, and as far as possible at lowest cost. Routine and emergency operating procedures should be in written form and understandable by all operators of the authority to act in emergencies. Further, specific operational procedures are required for inspecting, monitoring, testing, repairing, and disinfecting the system as well as for locating the buried pipes and valves. System records and maps should be updated and have sufficient details of the system facilities, their condition, routine maintenance that is needed and done, problems found, and corrective actions taken. Analysis of the records will enable the organisation to evaluate how well the installations are functioning and how effective its services are and, hence, assess their adequacy to meet the needs of the consumers.

7.3 Normal Operations

Extract of the relevant paras of BIS Code “IS 17482 (2020) – Drinking water supply management system – Requirements for piped drinking water supply service”.

8.5.2 District Metering Area (DMA)

District Metering Area (DMA) concept may be adopted for continuous supply of piped drinking water (see Annex C for details on the size and design of DMA).

8.5.6 Storage, Transportation, and Distribution

The distribution system shall have storage reservoirs located at key points to take advantage of natural physical topography, or for reasons of balancing supply and demand, or for emergency situations. In the absence of an advantageous natural topography, critical points shall be selected in a given distribution system for monitoring of pressures by installation of pressure recorders and gauges. These pressures are either measured manually and transmitted to the control station or automatically measured and transmitted by telemetry to control station. Pumping stations or booster, if necessary, shall be provided to maintain adequate pressure throughout the distribution system. Valves and meters and other appurtenances shall be installed throughout the distribution system as control devices and for water audit. Water supplier/utility shall maintain a documented procedure for the same.

NOTES:

1. Water supplier/utility shall ensure cleaning of storage and service reservoir as per the procedure laid down in the manual published by Central Public Health and Environmental Engineering Organisation (CPHEEO), Ministry of Housing and Urban Affairs, Government of India.
2. Emphasis may be given to operate the systems on automation mode with SCADA application.

The water supplier/utility shall ensure that water supplied to the people, after the necessary treatment, shall conform to the acceptable limits specified in IS 10500 and documented information shall be retained.

8.5.7 Water Audit

Water audit shall be conducted annually and documented. The report shall be submitted to the top management for review and further necessary action.

All components of the water balance shall be quantified over the same designated period and expressed in KLD or MLD. A guideline for conducting the water audit has been given at Annex B.

8.5.8 Metering

The water supplier/utility shall provide bulk water meters in the water distribution system to ensure water audit. Provision may also be made to have a functional/automatic/smart meter at household level, which shall support in water audit. Automatic/smart meters shall be preferred over conventional meters for DMA.

Extract of the relevant paras of BIS Code "IS 17482 (2020) – Drinking water supply management system – Requirements for piped drinking water supply service".

8.6 Release of Piped Drinking Water and Sampling

8.6.1 The water utility/services shall plan and implement control and monitoring systems, at appropriate stages, to ensure that the drinking water shall conform to the acceptable limits of IS 10500 at customer point of distribution.

8.6.2 The water supplier/utility shall prepare and implement the schedule for frequency and monitoring of water quality systems, at appropriate stages, including at production site, at distribution system, and at the customer point to ensure that the drinking water being supplied conforms to the acceptable limits of IS 10500 at customer end. Wherever contamination of water is suspected, random sampling shall be done by water supplier/utility or on demand by the customer. The details of control being exercised by water utility/services shall be documented. The advisory/guidelines issued by the Government of India from time to time shall be followed by the water supplier/utility.

9.1.2 Customer Satisfaction

The water supplier/utility shall monitor customers' perceptions of the degree to which their needs and expectations have been fulfilled. The water supplier/utility shall conduct surveys, obtain feedback on the services provided, meetings with customer to monitor customers' perceptions of the degree to which their needs and expectations have been fulfilled. The water supplier/utility shall determine the procedure for obtaining, monitoring, and reviewing this information.

9.1.3 Analysis and Evaluation

The water supplier/utility shall analyse and evaluate appropriate data and information arising from monitoring, measurement, and evaluation.

The water supplier/utility shall document performance indicators to assess and improve the services.

NOTE: Service Level Benchmark as Performance Indicator published by the Ministry of Housing and Urban Affairs, Government of India, or any relevant guidelines issued by the State/UT government may also be referred.

10.3 Continual Improvement

The water supplier/utility shall continuously make efforts to improve the suitability, adequacy, and effectiveness of the piped drinking water supply service management system.

The water supplier/utility shall consider the results of analysis and evaluation, and the outputs from management review, to determine the needs or opportunities that shall be addressed as part of continual improvement of the services, workforce, equipment, and machineries.

The water supply projects, though designed for 24×7 pressurised water supply, are operated intermittently. Factors such as intermittent hours of supply, high non- revenue water (NRW), low metering, obsolete and faulty pipeline networks, partial O&M cost recovery for water services, and poor financial health of the Urban Local Bodies (ULBs) build a strong case for the need of 24×7 Pressurised Water Supply with "Drink from Tap". Based on past experiences, it is evident that 24×7 pressurised water supply is achievable and affordable. Going forward, a city needs to formulate plans for 24×7 “Drink from Tap” water supply system so as to cover and serve the entire city, gradually transforming the existing intermittent services into a 24×7 pressurised water supply. The 24×7 operations are intended to maintain the required supply and pressure throughout the distribution system. Critical points are selected in a given distribution system for monitoring of pressures, flow, and quality by installation of pressure recorders, meters, gauges, and sampling monitoring systems. These parameters are either measured manually and the data records are then transmitted to the control station or automatically measured and transmitted by telemetry or Supervisory Control and Data Acquisition (SCADA) systems to the control station. The Digital Twin Technology is used for analysing the data and taking decisions. Details can be referred from Section 14.23 of Chapter 14 Automation of Water Supply Systems in Part A of this manual.

In direct pumping systems, whenever water pressures in the distribution system or water levels in the elevated service reservoir (ESR)/groundwater reservoir (GSR) drop below the minimum required levels, pumps would be manually or automatically started. In an intermittent water supply system, pumps and valves are operated during fixed hours. These pumps will run till the maximum levels in ESR/GSR and maximum pressures in the distribution system are reached.

Operators are required to ensure the accuracy of the measuring instruments for pressures and levels so that the pumps operate or stop at the proper levels. Sometimes, online booster pumps are introduced to work online to start whenever the desired pressures fall below the required pressures. Both upstream and downstream pressures are sensed and transmitted to the booster pumping station for automatic starting or stopping of the pumps when the actual pressures are below or above the desired pressures. The key performance indicators as described in Section 12.20 of Chapter 12: Service Reservoirs and Distribution System, Part A of this manual shall be referred to.

7.4 Common Issues in Water Distribution System (WDS)

Most common issues in WDS are:

i. **Technical issues:**
   Technical issues include intermittent system operation, design, construction and operational errors, leakages, ageing pipelines, inappropriate technology, inadequately skilled workforce, and water quality degradation, among others.

   (a) **Intermittent system operation:** A major cause of many issues such as inequitable pressure, inequitable water supply, water quantity deterioration due to contaminants ingress in pipeline, uncertainties of supply timings, discarding/wasting collected treated water by households, inadequate source of supply, watermain breaks, leaks in distribution system.

   (b) **Design, construction and operational errors:** WDS design is prone to errors coming mainly from wrong assumptions, inadequate statistics, computing input errors, inappropriate field changes during construction works and operational mistakes. Consequently, areas of low- and high- pressure regimes become unavoidable during operations. These often lead to frequent pipe bursts, loss of treated water, high repair and maintenance costs, traffic hold ups or diversions and reinstatement of roads before, during, and after pipeline repairs. Another side effect is the back siphonage of dirty and contaminated water that impact negatively on the water qualities delivered to consumers. There is always the tendency to rehabilitate or expand existing waterworks/headworks based on the assumption that any increase in production translates to corresponding increase in the number of people served. As such, little consideration is given to re-sizing the existing pipelines and trunk mains to convey the treated water.

(c) **Leakages and burst pipelines:** A major challenge is leakages. Fluctuations in pipe pressure within a WDS are the main cause of breaks and leakages. There is no WDS without some leakages and burst pipelines. Some of these leakages often come from buried joints, valves, flowmeters, aged and weak pipelines, and are physically non-detectible until water starts to boil or sinkholes created. The bursting of pipes and pipe joints cause significant supply disruptions and contaminants ingress.

(d) **Ageing pipeline:** The structural and hydraulic integrities of Water Distribution (WD) pipeline networks degrade with age. As corrosion progresses in steel and galvanised iron pipelines, they become weak and readily burst while still in service. Similarly, encrustation in cast iron pipelines not only reduces their internal diameters leading to reduction in discharge but increases head loss and brings higher hoop stresses culminating in more frequent pipe bursts especially where booster pumps are involved.

(e) Cross connections cause significant health hazards.

(f) Absence of residual head management plan for maintaining residual head at ferrules (17 - 21 m for Class I and Class II cities/towns and 12-15 m for other towns).

(g) Pipe/joints corrosion of WDSs leading to the failure of the pipes and the contamination of water in WDS as soil contaminants are transported/ingressed into the distribution system – a significant cause of supply disruption and contamination.

(h) Leaking household sumps due to poor or no maintenance leading to contamination ingress into the sump and contamination backflow to the system are a significant cause of health hazard.

(i) Public standposts causes significant water loss.

(j) Absence of regular water quality management protocol for managing water quality conforming to IS 10500 (2012).

(k) Failure of power supply resulting in overall disruption of water supply.

(l) Non-availability of as-built plan/drawings of the project implemented causes lack of knowledge of the existing infrastructure, and devoid of any proactive maintenance plan.

(m) **Inadequately skilled workforce**: Most operators do not know that transient pressure (water hammer) is induced with rapid closure of valves at reservoirs located on high grounds. Developing a team of skilled workforce is a problem as it takes time to assemble and train them. By the time they have gained sufficient technical knowhow and capabilities, some of them may be old and less agile, close to their retirement age, or have been redeployed to other districts/zones. Some may even retire or join new employments thus creating a vacuum within the water agency.

(n) **Water quality degradation:** Water quality degrades in WDS in many ways: back siphonage of dirty and contaminated water when pressures are low, dissolved corroded pipeline materials (iron, copper, etc.), contamination during repairs, reduction in disinfectant residual due to oxidation and the formation of carcinogenic organic by-products, excessively long contact times and flows from sediments-laden service reservoirs (SRs), among others. The problem becomes worse with the stringent imposition of chemical limitations (quantity and time) beyond which disinfection not only violates national BIS and WHO standards but impacts negatively on the health of consumers.

(o) **Topography:** Generally, SRs are located on high grounds to be able to feed the adjoining WDS. The steeper the slope, the greater is the flow to lowland areas in WDS and the worse the supply regime to consumers closer to the SRs on higher grounds. Operatives often have to divert flows to get consumers on higher grounds served.

ii. Environmental issues

The environmental issues include how to minimise wastages, restore or divert water supply, and minimise damages to properties during flood and how to cope with drought, rainfall variability, bushfires particularly in arid and semi-arid regions, etc.

(a) **Flood:** Flooding of urban communities can cause damages (disconnection, breakages, flotation, back siphonages, silting of chambers, etc.) to various connecting pipelines. The affected networks may have to be partly or totally shut off, repaired, flushed, disinfected, and reconnected as quickly as possible. In unpaved areas, gradual erosion of earth cover over pipelines laid on hilly slopes is common.

(b) **Drought:** With drought comes water rationing (diversions) to serve various segments of the communities affected thereby creating a good condition for back siphonage of unwholesome and dirty waters from the surrounding terrain in the areas not served or having low pressures. During this time, engineers, managers, and operators have to figure out solutions and implementing the needed diversions to reduce people’s sufferings. During this time, bushfires can also touch and damage uPVC, PVC, and HDPE pipelines that are not fully buried underground.

(c) **Cold:** In the temperate regions, taps are run to waste when temperatures drop close to or below freezing point so as to prevent blockage to ensure continuous flow.

(d) **Water Availability:** Another challenge caused by the environment is that natural availability in some localities is gradually decreasing due to climate change as compared to the water demand thus creating shortage, forcing the planners/engineers to find out climate resilient solutions including identifying additional water source.

iii. Economic issues

(a) **Inadequate networks:** The existing networks are becoming inadequate to meet up with increasing demand for drinking water due to growing urbanisation and population increase – a significant cause of overstressed system resulting in inequitable pressure and quantity fluctuations.

(b) **Cost of investment:** WD network is known to be capital intensive. The pipes, valves, fittings, SRs, booster stations, meters, etc., involve a considerably major project cost. All these huge costs of capital translate to so many challenges to determine which aged pipeline to rehabilitate or replace, how to get the unit price of water right to recover investments and operations costs, how to provide a buffer to take care of emergencies and future growth, how to gather and manage adequate demand and supply data, and how to adapt to new technologies.

(c) **Absence of cost optimisation:** To minimise capital cost, sizes of pipeline mains (rising, trunk, and distribution mains), reservoirs, valves, etc., have to be limited. Consequently, the flow carrying capacities of the trunk mains are readily exceeded by the exponentially growing water demand of the population. Unfortunately, when flow is increased in any WD pipeline network, the total head loss is increased thereby denying distant consumers of potable water supply.

(d) **Absence of common needs:** The needs are centred primarily on extension to communities not yet served, tariff determinations, revenue collection and ownership structure (i.e., whether it should remain public, private, or public-private), household taps and community standposts (“Drink from Tap”), etc.

iv. Social issues

(a) **Poor communication:** WD is taken as a social responsibility of water agencies and governments to provide. Viewed in this perspective, pipe bursts, and water wastages are not accepted as the responsibilities of the consumers. Thus, pipe bursts before flowmeters located within consumers’ premises may not be reported.

(b) **Illegal connections:** Based on the government social responsibility compulsion thus far, there exist many illegal connections to WD pipeline networks that are unreported, some of whom even install centrifugal pumps to draw water from distribution mains into their household sumps (underground or overhead reservoirs) and resell to thepublic.

(c) **Urbanisation:** Expansion of pipeline networks to new settlements moves at a lower progression whereas the urbanisation and water demand both moves at different pace and high progressions. This creates a big gap. This gap appears to continue to go wider and deeper. In addition, damages to WD pipelines, chambers, marker posts (pipelines identification posts), etc., during road expansion programmes are becoming worrisome with displaced marker posts making line tracing a herculean task. Also, some of the undamaged pipelines often lie entirely under roads and make monitoring operations very difficult.

v. Administrative issues

(a) Main administrative issues facing WD include the determination and implementation of adequate wages and allowances structures to motivate engineers, managers, and operators; their training and re-training; provision of adequate tools and equipment; better suited work schedules, etc. Others include ability to gather and manage large scale volumes of data on consumers, supply and demand, tariffs, revenue, repairs and maintenance, water quality, volume, pressure, pipeline materials, age, etc.

(b) Management structure: In the past, WD has been under the government/ULBs ownership. It continues to be so in many cities/towns, and not many are moving towards outsourcing for the public-private partnership (PPP) or public-private sector participation, which faces basic management challenges of transfer of workforces, accounts and funds, etc., along with deploying expertise in the operation and management of WD network.

Some critical issues have been deliberated in detail in the subsequent sections.

7.4.1 Intermittent System Operation

The distribution system is usually designed as a continuous system but mostly operated as an intermittent system. Intermittent supply creates doubts in the minds of the consumers about the reliability of the water supply quantity and quality. This leads to limited use of the water supplied, which does not promote personal hygiene at times. During the supply period, the water is stored in all sorts of vessels for use during non- supply hours, which might contaminate the water. Often, when the supply is resumed, the stored water is wasted and the fresh water is stored again. During non-supply hours, polluted water may enter the supply mains through leaking joints and pollute the supplies. Further, this practice prompts the consumers to always keep open the taps of both public standposts and house connections leading to wastage of water whenever the supply is resumed. Intermittent systems and systems requiring frequent valve operations are likely to affect the equitable distribution of water mostly due to operator negligence. When the system is designed for continuous but operated intermittently, the system is stressed to handle the higher flow within a short duration of supply with frequent on and off will deteriorate the system faster than expected.

7.4.2 Household Sumps

Household sumps are commonly used for water storage in areas where the water supply is intermittent. There are several considerations that need to be taken into account to ensure they are safe and properly maintained.

- **Monitoring:** Sumps should be regularly inspected to ensure they are not leaking and that the water is safe for use. It is recommended that households should have a protocol in place for regular inspection and cleaning of sumps.
- **Construction:** The sump should be constructed at a safe distance from any septic tank, drain, or sewage system using durable and non-toxic materials that are resistant to corrosion and contamination. Commonly used materials include concrete, plastic, and fibreglass.
- **Waterproofing:** Proper waterproofing is essential to prevent leaks and contamination of the stored water. Waterproofing materials such as bitumen or polyurethane coatings can be used to seal the sump.
- **Cleaning and maintenance:** The sump should be regularly cleaned and maintained to prevent the growth of algae, bacteria, or other harmful organisms. The water in the sump should be periodically tested to ensure it is safe for use.
- **Elimination:** If possible, it is recommended to eliminate the use of sumps gradually and instead rely on a reliable and safe water supply. This can be achieved by improving the local water supply infrastructure or implementing “Drink from Tap” with 24×7 continuous water supply.

ULBs should frame and implement bye-laws covering above points, clear plan for elimination of existing household sump in a phased manner and not allowing any new sumps to be constructed once 24×7 Pressurised Water Supply with “Drink from Tap” is implemented.

7.4.3 Water Quality Management

Water quality management is of prime importance to test the performance of O&M of the distribution system in order to provide “Drink from Tap” and its ability to deliver water of acceptable/permissible quality to its consumers conforming to IS 10500 (2012). The most important potential consequences of an improper and ill-managed distribution system are health problems caused by presence of substances more than acceptable limit in the water. In order to ensure potable water supply for drinking purposes, it is essential to monitor water quality at various locations in the distribution system as well as at consumer ends at regular interval/frequency for various physical, chemical, and bacteriological parameters for which services of in-house or NABL- accredited outsourced laboratories can be availed. Table 7.1 shows the minimum routine monitoring frequency of water quality parameters in WDS at the critical points at the consumer ends (ferrule point).

Table 7.1: Minimum routine monitoring frequency of water quality parameters in water distribution system (Introduction to O&M of water distribution system: JE Val Zyl-Water Research Commission)

S. No.	Parameters	Test Frequency
1	pH	Fortnightly
2	Turbidity	Fortnightly
3	Electric conductivity	Fortnightly
4	Residual chlorine	Fortnightly
5	E. coli (faecal coliform)	Fortnightly

The water supply authority needs to ensure proper water quality management in distribution system. The detailed water quality monitoring and surveillance issues are discussed in Chapter 8: Drinking Water Quality Monitoring and Surveillance, Part B of this manual.

7.4.4 Non-availability of Required Quantity of Water

Failure of power supply may cause reduced supplies. Normally, the distribution reservoirs are designed for filling in about 8 hours of pumping and whenever the power supply is affected, the pumping hours are reduced and, hence, the distribution reservoirs are not filled up leading to reduced supply hours and, hence, reduced quantity of water. In remote areas, frequent power supply cuts can affect the adequate supply of water to consumers.

7.4.5 Low Pressure Problem

Normally, peak factor on demand side is considered ranging from 2 to 3 while designing the network, whereas the water supply is given only for a limited duration of few hours, leading to large peak factors on supply side and hence causing substantial drop in the pressures in the distribution system. This is a common phenomenon with most intermittent water supply systems.

7.4.6 Leakage of Water Through Valves and Pipelines

Large quantity of water is wasted through leaking pipes, joints, valves, and fittings of the distribution systems either due to bad quality of materials used, poor workmanship, corrosion, age of the installations, or through vandalism. This leads to reduced supply, loss of pressure, and deterioration in water quality. The main culprit for most of the system's real loss is poorly connected service connections.

7.4.7 Unauthorised Connections

Illegally connected users will contribute to the reduction in service level to authorised users/consumers and deterioration of quality of water. Sometimes, even legally connected users draw water by sucking through motors causing reduction in pressures. These illegal connections add to water loss thereby loss of revenue to water boards.

7.4.8 Extension of Area

Due to extension of service area without corresponding extension of distribution mains, the length of house connections will be too long leading to reduction in pressures. Also, in some of the places, an extension of distribution mains is not possible but a number of service connections are tapped at one location and extended for long distances which adds up misery to the supply system.

7.4.9 Age of Pipeline

With age, there is considerable reduction in carrying capacity of the pipelines due to incrustation, particularly unlined CI, MS, and GI pipes. In most of the places, the consumer pipes get corroded and leaks occur resulting in loss of water and reduced pressure and pollution of supplies.

7.4.10 Mapping and Condition Assessment of the Pipeline

An accurate estimation of the location, size, depth, and material of the pipelines laid down are critical for the O&M of any pipeline network. If the existing data is unavailable, the maps must be prepared, updated by field survey, and plotting the map based on consultation with fitters working in the field to maintain the pipeline. Various technologies may also be employed such as Ground Penetrating Radar (GPR), crawler-based inspection and extrapolation, etc.

Condition assessment shall also be carried out which can be defined as the collection of data and information, through direct and/or indirect methods, followed by the analysis of the data and information to make a determination of the current and/or future structural, water quality, and hydraulic status of the assets. The section has been discussed in detail in Section 2.7.1 of Chapter 2: Planning, Design and Investigation, Part A of this manual.

Apart from these, in-line detection techniques can be employed to inspect conditions and detect issues, which are discussed in Section 4.2.5. Methodology for determination of "C" value of existing pipeline can be referred from Chapter 6: Transmission of Water in Part A of this manual.

Condition assessment can also be carried out using crawler-based motorised and remotely controlled robotic (Figure 7.1) should be used for checking the pipeline for defects.

Figure 7.1: Robotic Water Pipeline Conditional Assessment

7.4.11 Lack of Records

Lack of data, system maps, designs of the network and reservoirs, and historic records of the equipment installed in the distribution system are often not available, as such does not permit to take a cohesive decision, while some minimum information is required to operate and maintain the system efficiently.

7.4.12 Inequitable Distribution

This is one of the major problems in WDS. The consumers nearer to the ESRs receive more water with high pressure while it reduces as the distance from the ESR increases. If an area to which the SR is serving is uneven, the water will tend to flow towards downward gradient developing high pressure thereby consumer collects more water, on the other hand, the areas with higher elevation receives less water. This causes dissatisfaction in the consumers and, hence, to cater water to these consumers, the system has to be run for more time thus imparting more energy and cost consumption.

7.4.13 Deficient Operational Integration of Service Reservoirs (SRs)

Deficiency in integration of SRs, in a town or city, lead many SRs to function at low water levels or water in SRs remain unutilised. This raises serious concerns about inequitable water distribution in different parts of the city. This difficulty arises because some SRs deliver water to smaller zones than their capacity, while others supply water to zones that have demand more than their capacity. Such problem may be resolved by dividing the entire town or city into operational zones (OZs)/DMAs and distributing the size of each OZ based on the elevation and demand of the region in question. This is accomplished by increasing the spread of OZ for SRs with excessive capacity and decreasing the spread of OZ for SRs with low water levels.

7.4.14 Reasons for Pipeline Failure

Various factors can cause pipe or its joints performance to deteriorate or lead to failures. The main reasons for failures are as follows:

- Transport, storage, and handling of pipe and its fittings, valves, and specials
- Poor or faulty construction methods which may be due to insufficient bedding, blanket support, sharp stones or other materials pushing against the pipes, mishandling of pipes, improper jointing, etc.
- Loads on a pipe exceeding its strength; this may be caused from traffic and other surface loads, water hammer, construction activities or laying of other utilities, cutting of roads, soil movement, natural disaster, etc.
- Deterioration of pipe strength, increase of velocity due to incrustation over time
- Corrosion of pipes which removes materials from metal pipes and reducing pipe wall thickness which result leaks and failure of pipes
- Direct sunlight deteriorates PVC pipes during storage and pipes laid exposed to sun
- Exposed to chemicals

Factors causing pipe failures are dependent on the type and characteristics of the pipes. Due to the impact from various factors and uncertainty in the nature of these factors, failure mechanisms are complex. The failure may not be easily attributed to a single or combination of factors.

7.4.15 Typical Failure Modes

Typical failures modes are described as below:

I. Faulty Laying

a) Deviation from proper laying procedures.

b) Improper bedding.
c) Loss of support of bedding after laying.
d) Slipping of trench sides.
e) Sinking of soil after laying.
f) Poor quality of backfill material.
g) Improper compaction of trench backfill and its subsequent settling.
h) Excessive overburden on piping trenches, not taken care of during the design of pipeline.
i) Point loads coming on the pipe through the backfill.
j) Excessive vibrations due to traffic during the laying of pipeline.

II. Faulty Joints

a) Defective jointing material.
b) Direct strike on the body of the pipe with any sharp edge, while jointing.
c) Slipping of jointing material like rubber ring or lead, etc.

III. Undetected Hair Cracks at the Time of Construction

a) Pipe material affected by temperature stresses.
b) The surrounding soil, its wetting and drying also imparts stress on the pipe surface causing cracks.
c) Sudden jerk or vibration on the pipe while loading and unloading due to mishandling.
d) Impact on pipe due to hard surface while laying.

IV. Corrosion in Distribution System

Corrosion is chemical factor of pipeline failure which causes degradation of material by chemical reaction with its environment. Normally, three types of corrosion, i.e., galvanic, electrolytic, and microbiological corrosion are predominant in WDS. Corrosive water, soil with low pH and low soil oxygen level, anaerobic microbiological activity cause internal corrosion occurring inside distribution system and external corrosion occurring outside of the pipeline. The internal and external corrosion can lead to failure of components by creating a hole in the material or weakening it to fail due to internal and external loads. Other reasons of corrosion are as follows:

a) Corrosive water could leach trace metals from the piping system that are in direct contract with the water.
b) High flow rate within the piping can cause physical corrosion.
c) The presence of suspended solids, such as sand, sediment, corrosion by- products, and rust can aid in physical corrosion damage and facilitate chemical and biochemical corrosion.
d) Corrosion in pipeline can lead to leakages in the distribution system.

V. Pipe Laid under Corrosive Nature of Soil

a) Sulphates, chlorides, and other acidic contents are present in soil.
b) Soils with clay content retain moisture thus affecting the pipe material.

VI. Solutions for Laying of Pipeline under Corrosive Nature of Soils

Characteristics of soils are major factor of external corrosion of pipeline to be laid under the soils. Soils having low pH (acidic soils), low soil oxygen levels creating the potential for anaerobic microbiological activities, stray electrical currents in the soils that may take shortcuts through the metal pipes cause external corrosion of the pipelines and other components of the distribution system. Based on types of pipes to be used/selected, different factors are considered to access the problems and the solutions to be adopted. For metal pipelines, factors to be included are soil resistivity, pH, redox potential, presence of sulphide, and site drainage conditions. For concrete pipes, soil chloride content and resistivity should be considered. Based on soil characteristics, the solutions to control external corrosion include selection of appropriate pipe materials, applying protective coatings and linings, installing and maintaining cathodic protection, suggesting and mitigating stray currents.

VII. Extreme Changes in Temperature

a) Expansion: severe compression, end crushing.
b) Contraction: pull out or separation of joint.
c) Freezing: pipe blockages and splits.

VIII. Overload on the Buried Pipes

a) The pipelines are almost exclusively buried in the ground, therefore, their interaction with the surrounding soils is very important in pipe deformations.
b) Susceptible to failure when the overburden is higher than the internal pressure of the pipe.
c) Breaking can occur in case of no flow condition in pipe.
d) Live load can damage the pipe if proper cover has not been provided or the pipe is not encased.

IX. High Internal Water Pressure

a) Sudden closure or operation of valve will create high internal pressure on the walls of the pipe thus leading to bursting.
b) Extended high fluctuations of internal water pressure can lead to pipe failure.

X. Other Common Failures

A common failure is rupture of the pipe wall due to excessive stress. This failure mode is common in freeze failures and results in a characteristic “fish mouth” appearance, named for the split and deformation of the pipe wall which resembles a fish mouth. Another common event is “water hammer”. Water hammer events in piping systems occur when a rapid deceleration of flowing water results in a pressure wave within the pipe. This is a common happening in long straight runs of the pipe where there is a chance of increased velocity. In case of intermittent water supply, regular on and off induces the water hammer, thereby system deteriorates faster than in continuous system. Quite number of the joints opened up due to this on and off process during supply and non-supply period.

XI. Failure of Pipe Barrel

Modes of failure of pipe barrels may be as below:

a) **Brittle Type Fractures**
These may be found in rigid and semi-rigid materials such as cast iron and PVC. These are characterised by relatively clean, sharp-edged splits, or cracks. These may occur as circumferential breaks or longitudinal cracks which may run straight but more often irregularly curved along the pipe barrel.

b) **Ductile Type Failures**
These occur in polyethylene and ductile iron. These are usually found as relatively short splits or tears with irregular edges which are often associated with some local swelling around the break.

c) **Blow Outs**
These are localised failures which only occasionally occur and are usually associated with high pressure, e.g., pumping surges in weakened brittle materials.

d) **Pinholes**
These may be caused by an impurity or inclusion in the pipe wall or, more often, by localised chemically or electrically induced corrosion which thins and weakens the pipe wall until a small plug is blown out by internal pressure.

Pinholes often enlarge quite quickly due to erosion around the edges of the hole. Pinholes are frequently found within the metallic group of pipes.

e) **Generalised Deterioration**
More generalised deterioration of pipe barrel may be due to a manufacturing defect but is usually the result of some form of chemical attack. The overall effect is reduction in wall strength depending on the material group. Some of the examples are the graphitisation of iron mains, sulphate attacks on concrete, lime leaching from cement lining by soft waters, and solvent attacks on the polymeric group of materials leading to softening or delamination of composites such as GRP.

XII. Failure of Pipe Joints

Modes of failure of pipe joints may be as below:

a) **Flanged Connections**
Stress cracking of the flange can occur due to unequally tightened bolts. Such a situation arises during ground movement or the forceful activation of a valve or hydrant.

b) **Crushing of Pipe Ends**
Cracking may occur due to crushing of pipe ends when they touch or bind and are then subjected to high compressional or bending forces.

c) **Lead Joints**
Hardening of lead in association with joint movement may lead to “weeping” which gradually develops into a more serious leak.

d) **Sealing Rings and Gaskets**
Many mechanical joint designs rely upon the compression of sealing rings or gaskets which have varying compositions and different resiliencies. The physical breakdown

(e.g., biodegradation) or change of resilience with time can lead to leaking joints. The loss of compression combined with corrosion of pressure rings or collars, or the bolts, may aggravate the breakdown.

7.4.16 Cross-connections

Within distribution systems there exist points called cross-connections where non- potable water can be connected to potable sources. These cross-connections can provide a pathway for backflow of non-potable water into potable sources. Backflow can occur either because of reduced pressure in the distribution system (termed back-siphonage) or the presence of increased pressure from a non-potable source (termed backpressure). Back-siphonage may be caused by a variety of circumstances, such as mainbreaks, flushing, pump failure, or emergency firefighting water drawdown. Backpressure may occur when heating/cooling, waste disposal, or industrial manufacturing systems are connected to potable supplies and the pressure in the external system exceeds the pressure in the distribution system. Both situations act to change the direction of water, which normally flows from the distribution system to the customer, so that non-potable and potentially contaminated water from industrial, commercial or residential sites flows back into the distribution system through a cross-connection. During incidents of backflow, these chemical and biological contaminants have caused illness and deaths, with contamination affecting a number of service connections. The risk posed by backflow can be mitigated through preventive and corrective measures. For example, preventative measures include the installation of backflow prevention devices and assemblies.

Contaminated water through cross-connections of water supply lines with sewers and drains is also a problem prevailing widely. Intermittent supply further aggravates the problem since, during non-supply hours polluted water may reach the supply mains through leaking joints, thus polluting the supplies. In certain instances, when there are extremely high water demands, the pressures in the supply mains are likely to fall below atmospheric pressure, particularly when consumers start use of pumps with direct suction from supply mains.

Regular survey has to be undertaken to identify potential areas likely to be affected by cross-connections and backflow. All field personnel should be constantly alert for situations where cross-connections are likely to exist. After identifying the cross- connections, remedial measures are taken up which include providing horizontal and vertical separation between the water main and the sewer/drain, providing a sleeve pipe to the consumer pipes crossing a drain, modifying the piping including changing corroded piping with non-corrodible piping, providing double check/non-return valves at the consumer end, etc.

7.4.17 Chlorine Residual

A minimum chlorine residual of about 0.2 mg/L at the selected monitoring point mainly at farthest point is often maintained to ensure that even a little contamination in the distribution system is destroyed by the chlorine. Hence, absence of residual chlorine could indicate potential presence of heavy contamination. If routine checks at a monitoring point are carried out, required chlorine residuals and any sudden absence of residual chlorine should alert the operating staff to take up prompt investigation. Immediate steps to be taken are:

- Re-testing for residual chlorine
- Checking chlorination dosage

- Identifying the source of contamination, which has caused the increased chlorine demand
- The immediate stoppage of supplies from the contaminated pipelines

7.4.18 Ozone Residual

Disinfection by ozone (dosing): Ozone (O3) provides multiple benefits for industrial water treatment including the removal of organic compounds, certain inorganic compounds (Fe, Mn, H_2S), colour, odour and taste. It also acts as a micro flocculent, which aids in removal of suspended solids.

Additionally, ozone is an excellent disinfecting agent capable of killing a wide spectrum of microorganisms. As a result, it is increasingly considered for a wide variety of industrial water treatment applications since removing organic/inorganic compounds and disinfection are the two most common applications for ozone treatment.

The ozone dose required will vary according to water quality, but a typical ozone dose is 1.0 to 2.0 mg/L, which is sufficient to kill most bacteria and control tastes and odours.

Ozone is added to make the metals insoluble and they are subsequently filtered out of the water as a solid. The ozone dosage required is 0.44 mg/mg of Fe and 0.88 mg/mg of Mn. Application of ozone for iron and manganese removal depends on a variety of factors, so a pilot testing will define the exact amount of ozone required and the type of ozone generator equipment required.

Hydrogen sulphide is easily oxidised by ozone, ultimately to form sulphate. The theoretical dose to oxidise ozone to sulphate is 3:1, but in practice the ratio is 4:1. This will leave a small ozone residual in the water, 0.2-0.3 ppm. This residual can be used to ensure that the hydrogen sulphide is fully removed. In the case of variable hydrogen sulphide concentration, following the residual will allow for adjustment in the ozone dosage rate to maintain complete removal of the ozone.

In order to inactivate microorganisms, it is necessary to expose them to ozone for a certain period of time.

In order to build a concentration of ozone in water, the demand for ozone in solution must first be satisfied. This means that the organic and inorganic compounds that can be oxidised by ozone must be first removed before the concentration can build up to establish a Ct value.

In removing contaminants from the water using ozone, it is important to understand that ozone acts by the chemical process of oxidation.

Ozone use is not indicated in all situations. If more than 100 micrograms of Br ion are present, the formation of bromate might be possible. With water temperature above 105 °F, ozone will decompose prematurely.

Pilot testing will define the exact amount of ozone required and the type of ozone generator equipment required.

Ozone can corrode some pipes and fixtures, so all surfaces coming in contact with ozone should be made of ozone-resistant materials, such as stainless steel.

Like chlorine, ozone is a toxic gas and ozone generators may leak and could create an ozone hazard. A leak could cause illness, although not much is known about the chronic health effects of ozone.

The greatest drawback with ozone treatment is its lack of an ozone residual time. With ozone treatment, disinfection occurs primarily at the point of contact between the ozone and the water and does not occur beyond the treatment unit. This contrasts with chlorination treatment where the residual chlorine remains in the water and continues the disinfection process for some time. Because ozone is so unstable, it does not produce a reliable residual. Ozone has an active residual time measured in minutes, whereas the active residual time for chlorine is measured in hours.

7.5 Solutions to Water Distribution Challenges

The O&M of different components of the distribution system with various issues to be addressed happen in dynamic and complex environment with many influencing factors and competing objectives. Thus, it is necessary to put the system in place to plan and guide O&M actions to have optimal inputs by addressing the different issues and implementing the action plans.

7.5.1 Solution to Technical Challenges

The organisations/agencies are required to evolve a leakage detection and control mechanism to address leakages and other issues. Further, there shall be a clear policy in the municipal bye-laws of not allowing the public standposts in view of 24×7 Pressurised Water Supply with “Drink from tap”. Also, for the same reason, there shall be a clear policy decision in the municipal bye-laws that the household (clear water) sumps will be gradually reduced and entirely removed from the system over a targeted time period.

To mitigate high- and low-pressure regimes in WD today, analysis and design are facilitated using computer-aided software. Installation of some tri-function modern air valves is able to dampen pressure surges and mitigate damages. There is a need for water agencies to carry out water audit programmes: leakage detection programme, non-revenue water programme, head loss/pressure and flow monitoring programme, etc. This will enable water agencies to understand the extent of losses in supply and in revenue, inability to meet consumer demands, high repair and maintenance costs and how best to address them.

At the end of the water audit, water agencies and government must address leakages by gradually replacing old meters and ageing WD pipeline networks. There are smart meters that can relay leakages and bursts to a SCADA, Geographic Information System (GIS), water agency asset management, etc. There are now HDPE pipes with fusion welds at joints (thus mitigating leakages at joints) and are of 12 m long (thus minimising the number of joints) that can be used. This pipe type has better flow characteristics: minimal head loss, high strength to withstand high hydrostatic pressures, non-corrosive, and chemically inert for encrustations to form.

The use of an appropriate technology means that advantage of economies of scale can be used to produce more water at the same capital and running costs, thereby bringing down the unit cost of potable water delivered to consumers.

Water quality should be monitored continuously, and when necessary, pipelines and SRs should be flushed/cleaned and disinfected periodically even if there are no bursts.

7.5.2 Solution to Environmental Challenges

A good approach is to lay pipelines deep enough to avoid exposure to flooding, erosion, and bush burning damages. In addition, there is the need for engineers and managers in the water industry to start planning on how to cope with variability in rainfall, drought, etc., particularly how to use the available WDSs to ration supply in the near future. A new approach may involve the laying of parallel lines for recycled water that can serve non-potable purposes.

7.5.3 Solution to Economic Challenges

Funding of water systems should be given a top priority by governments and financial institutions. Consumers are often willing to pay for services that they enjoy. Any funding of water distribution pipeline networks is recoverable. It is a good and worthwhile investment.

7.5.4 Solution to Social Challenges

The solution to social challenges in WD still remains that of proper enlightenment. The slogan “Water is life” has been misunderstood by many and needed to be replaced with something like “Water is money”, “Water has a cost”, or “Water is our wealth”. The important message is that when people see water wasting through pipe bursts or leakages, they know money is being wasted and should be stopped. This may even encourage the reporting of illegal connections and their prosecution. Illegal connections can be detected easily where smart meters have been installed. To serve as a deterrent, the costs associated with illegal connections and the volume of water consumed should be compounded and recovered from culprits. In addition, water agencies should improve on maintenance culture.

7.5.5 Solutions to Administrative Challenges

It is very important for engineers, managers, and operators involved in WD to have commensurate motivating remunerations, flexible and convenient work schedules, appropriate training and re-training programmes, etc., to motivate them to work.

Management should thrive to provide SCADA, Digital Twins Technology, non- destructive flowmeters, GIS, etc., to enhance data analysis and management while facilitating decision-making. The challenges facing WD are numerous and cannot be exhausted and so are their corresponding feasible solutions. New challenges will crop up as the future unfolds, especially those relating to climate change. Governments and financial institutions should continue to invest in WD because such an action is worthwhile, reliable, profitable, recoverable, and socially lifestyle-enhancing.

7.6 O&M Schedule

An effective strategy for efficient O&M has to be in place, and following actions are to be taken for designing an efficient operations schedule:

7.6.1 Preparation Studies

I. Mapping and Inventory of Pipes and Fittings in the Water Supply System

Availability of updated distribution system maps with contours, location of valves, flowmeters, and pressure gauges or taping points is the first requirement for preparation of operation schedule. The agency should set up routine procedures for preparing and updating the maps and inventory of pipes, valves, and consumer connections. Any addition of valves, connection, or tapping should be recorded and updated in the map. The maps shall be exchanged with other public utilities agencies to contain information on other utility services like electricity, communications, etc.

The activities involved in mapping are as follows:

i. Establishment of consultative process with the management of other utility services like electricity, communications, etc.
ii. Definition of maps such as layout, scale, representation of pipes, valves, connections, etc.
iii. Establishment of procedures for storage and retrieval and updating of maps and inventory information including intersections.
iv. Setting up procedures for collecting map information in the field including field verification for compliance of the as-built drawings with design.
v. Setting up procedures for updating maps when any changes are made in the distribution system.

II. Procedure for Preparation and Updating of Maps

a. Contents of Maps

Comprehensive maps prepared for a scale of 60 m/cm to 120 m/cm are used for O&M of distribution system. They provide an overall view of the system with location of reservoirs, pumping stations, valves and hydrants, etc. Valve location maps apart from indicating their location also show the direction to open the valve, number of turns to open, make of valve, and date of fixing of valve. At times, plan and profile drawings are also available which show the depth of pipe, pipe location vertical and horizontal, and distance from reference point. Hydraulic gradient contour maps are also prepared to indicate the pressures in the system in peak demand period. They can be used for identifying high pressure or problem areas with low pressures.

b. Field Survey

Existing maps are used or conventional survey is employed for preparation and updating the maps. As an alternative to traditional survey and map preparation, “total station method” is gaining popularity. Total station instruments can be used for survey and mapping of towns where data is not readily available.

c. GIS Maps

GIS is a computer programme that combines mapping with detailed information on physical structures with geographic areas. GIS has also compatibility with AutoCAD design systems. The remote sensing maps can be used to prepare base map of the utilities by using GIS. The GIS creates a database within a mapped area such as streets, valve chambers/manholes, pipe networks, and pumping stations. The attributes can be address, number of valve chamber/manhole, pipe length, diameter, invert and quadrant co-ordinates and can also include engineering information, maintenance information, and inspection information. The utility staff will get facility to update the maps and retrieve information geographically. These maps can be used to inform the maintenance crew to locate the place of work. The utility can use a work order system for new/repair works so that after the completion of work, such as a line is added, a valve is fixed, or a new connection is given, the work order can be used by the map unit for updating the map and its attributes. These maps are used to indicate layers of maps for water lines, sewers, power cables, telecom cables, etc.

7.6.2 Routine Operations of the Water Supply Distribution System

The efficiency and effectiveness of a water supply system depends on the operating personnel's knowledge of the variables that affect the continuity, reliability, and quantity of water supplied to consumers. The operational staff should be able to carry out changes in the hydraulic status of the system as required depending on those variables promptly and effectively. Routine operations shall be specified, which are activities for adjusting the valves and operation of pumps to match the prevailing conditions (flows, pressures, levels, and operation of pumps). Valve and pump operations will have to be controlled as per schedule. The schedule shall contain procedures for operating the distribution system. It should contain procedures to obtain, process, and analyse the variables related to water flows, pressures, and levels as well as the consequences of manipulating control devices, such as operation of valves and pumps, so that the hydraulic status of the system can match the demand for water. Flow of information such as closure of a valve for repair or maintenance purpose, any unscheduled activity started in an ongoing shift, etc., should be exchanged while switching over the shift for better O&M. Digital Twin Technology along with SCADA and various sensors can be effectively used for developing the operations schedules.

7.6.3 Operation under Emergency Conditions

Operations other than routine, viz., during breakdowns and emergencies have to be specified and should be carried out in specific circumstances when normal conditions change, i.e., when flows, pressures and levels, and operation of pumps change. A standard operating procedure for valves should be prepared and emergency conditions should be considered into it.

The objective of developing a programme for managing in times of shortage of water is to reduce the excessive use of water particularly when the source is limited due to adverse seasonal conditions.

The water managers play an important role in managing the water supplies during emergencies. Their role can be fulfilled by:

(i) Giving an emergency condition notification so that people could get aware
(ii) Defining new policies to balance the demand and supply of water so that at least basic needs of every person can be fulfilled
(iii) Water quality should be monitored properly by the water managers so that water should be safe
(iv) Water managers must see that emergency response plan includes a well- prepared communication strategy
(v) A proper vulnerability assessment of every affected area should be done
(vi) Special monitoring, vigilance, and response action team should be made to reduce the wastage and equitable distribution of water and verify that the policies made are properly followed
(vii) Alternative water sources available near the affected area must be looked into

7.6.4 Monitoring of Flows, Pressures, and Levels

It will be necessary to monitor regularly operational data concerning flows, pressures, and levels to assess whether the system is functioning as per requirements. Analysis of data may reveal over withdrawal of water to some reservoirs and/or bulk consumers. At such places appropriate flow control devices may be introduced to limit the supplies to the required quantity. A list of priority points in water supply system have to be identified such as installation of meters to measure flows, pressures, and levels. A detailed map showing location for each measuring point has also to be prepared. The degree of sophistication of the devices used at each measuring point with regard to indication, integration, recording, transmission, and reception of data depends mainly on the skills of O&M personnel available with the agency and affordability of the agency.

I. Evaluation of Hydraulic Conditions

A continuous evaluation of the hydraulic conditions of the water supply system can be done by the O&M personnel after obtaining the data on water volumes and flows at various points in the system, the water pressures and levels in the reservoirs and comparing with expected performance. This evaluation shall lead to identification of operational problems and/or system faults. Depending on the type of problems, action have to be initiated to ensure that the system functions as per the requirement.

II. System Pressures

Maintenance of a continuous positive pressure at all times (during supply timings) to consumers is the main concern of O&M. Negative pressures can cause contamination of water supplies especially in intermittent supplies. Very high pressures may damage the pipelines and valves, which can be corrected with pressure reducing valves (PRVs). Complaints from consumers about low pressures have to be promptly investigated, if necessary, by measuring pressures with pressure gauges. Low pressures may be under the following circumstances:

- Purposefully or accidentally a line valve is left closed or partly closed or blockage due to any material causing loss of pressure.
- Too high velocities in small pipelines.
- Low water levels in SR.
- Failure of pumps/booster pumps (either due to power failure or mechanical failure) feeding the system directly.

III. Sampling for Quality of Water

The agency operating the water supply system is charged with the primary responsibility of ensuring that the water supplied to the consumer is of an appropriate quality. To achieve this objective, it is necessary that the physical, chemical, and bacteriological tests are carried out at frequent intervals. Samples should be taken at different points on each occasion to enable overall assessment. In the event of epidemic or danger of pollution more frequent sampling may be required, especially for bacteriological quality. For each distribution system, a monitoring programme has to be prepared showing the location of sampling points. Based on historic records of a system it will be possible for the manager of the system to decide locations for bacteriological sampling and residual chlorine testing. Details are provided in Section 8.4 of Chapter 8: Drinking Water Quality Monitoring and Surveillance in Part B of this manual.

Online monitoring system like pH, turbidity, chlorine sensors can be installed in the pipeline which can provide real time water quality data for analysis and quick rectification.

7.6.5 O&M of DMA's and Operational Zones

The entry of DMA is fitted with flowmeter to record the inflow. With the addition of consumer meters, the amount of water billed to the consumer in the area can be measured against the amount of water supplied to the DMA. The difference between the two figures represents the water volume not accounted for NRW. This helps in localising the leakage. Prompt repairs to the leakage should be arranged. Replacement of damaged pipelines should be scheduled. The flowmeters should be calibrated in regular intervals. Pressure zones should be created with pressure monitors like pressure probes inserted in the pipe at certain critical points. This can be done to avoid pipes in lower ground having higher pressure than needed, and pipes in higher elevations having insufficient pressure to satisfy consumers.

Proper DMA operation helps in longer-lasting pipelines, lower energy consumption and fewer pipe bursts. In addition, due to the increase in data obtained from zoning, operational efficiency and asset management are also improved. These data-driven analytics can give timely alert in case of leakage.

I. Ensuring/Confirming DMAs are Hydraulically Discrete

A district metered area (DMA) is defined as a discrete area of a WDN usually created by the closure of isolation valves in which the quantities of water entering and leaving the area are metered. In other words, DMA is a sub-division of a large network, created by closing isolation valves interconnecting the surrounding network and thus isolating area, called DMA. DMA receives water from separate pipeline coming from SR and supplies continuous water through 100% metering of consumers.

II. Check for Losses

For effective control of water losses, NRW of every DMA is to be determined by dividing OZs. A city is divided into number of OZs which are further divided into number of sub-zones called as DMAs. Each DMA is then critically studied for different demand patterns, leakages, and unaccounted for water. Thus, the problem is divided into sub-problems and effective control measures are taken to provide effective solution for each sub-problem to solve the problem in total. The measures for reduction of both apparent and real losses in the WDNs are (i) pressure management, (ii) active leakage control, (iii) improved system management, and (iv) improved response time for leak repairs. Each DMA is discrete in terms of WDN usually by creating isolation valves the losses in each DMA can tackled separately.

III. Re-configuring of DMA

For re-configuring of DMA, the unutilised water due to excessive capacity of existing SR should be utilised by increasing the spread of OZ and if the SR is suffering with low water levels, then it can be balanced by decreasing the range of OZ. All this balancing of SR can be done by distribution of areas based on elevation and demand of water in an area.

IV. Equitable Flow and Pressure

Design of OZ and DMA is made by the approach of whole-to-part and is coupled with demand management by 100% consumer metering and telescopic tariff. The whole-to-part approach is explained below with use of PRVs and flow control valves (FCVs), however, PRVs should be used only when required. PRVs are mainly required in hilly cities like Shimla or where the OZ or DMA is at lower elevations. Maximum head that comes on pipes in the distribution system is the difference between FSL of SR and minimum ground elevation in the OZ of that SR. Class of pipe should be so chosen that working pressure of that pipe is more than the maximum head coming on the pipes in that OZ. Equitable distribution of water with equal pressure is needed in "Drink from Tap" with 24×7 pressurised water supply. It is achieved by whole-to-part approach, in which two stages are involved: (a) from MBR to SRs and (b) from SR to DMAs.

7.6.6 System Surveillance

Surveillance of distribution system is done to detect and correct. Routine surveillance shall reveal:

- sanitary hazards;
- deterioration of distribution system facilities (to detect);
- encroachment of distribution system facilities by other utilities such as sewer and storm water lines, power cables, telecom cables, etc.; and
- damages of the system facilities by vandalism (detecting and correcting).

In addition, checks are carried out under special circumstances for assessing damage of the system after flooding of streets following a heavy storm. All these checks are done for above groundwater facilities such as valves and valve chambers or exposed pipelines. Some less frequent inspection of underground pipelines will also be required, wherein critical areas of the distribution system should be patrolled routinely so that the water utility can watch out for early warning of any adverse conditions of the distribution system. Any activity or situation that might endanger the water facility or water quality shall be investigated and corrective action is to be taken. Surveillance shall also include looking for unauthorised construction activity on or near the utility's pipelines, which may pose a physical threat to the mains. Any digging, excavation, or blasting near the mains shall be closely supervised by the utility staff.

7.6.7 Distribution Maintenance Schedule

Maintenance schedules can be designed considering points summarised below:

I. General

A maintenance schedule is required to be prepared to improve the level of maintenance of WDNs and house connections through improved co-ordination and planning of administrative and fieldwork and through the use of adequate techniques, equipment, and materials for field maintenance.

- The schedule has to be flexible so that it can achieve team action with the available vehicles and tools.
- Co-ordination of activities is required for spares and fittings, quality control of materials used, and services rendered.
- Training of maintenance staff shall include training to achieve better public relations with consumers apart from the technical skills.

II. Activities in Maintenance Schedule

Following activities are to be included in the schedule:

- Establishment of procedures for setting up maintenance schedules and obtaining and processing the information provided by the public and the maintenance teams.
- Formation of maintenance teams for each type of service with provision for continuous training.
- Establishment of repair procedures for standard services.
- Specification of appropriate tools.
- Allocation of suitable transport, tools, and equipment to each team.
- Establishment of time, labour, and material requirements, and output expected; time required and other standards for each maintenance task.
- Monitoring the productivity of each team.

7.6.8 Preventive Maintenance Schedule

A preventive maintenance schedule for servicing valves and maintenance of valve chambers, maintenance of the pipelines may include tasks, set priorities, issue of work orders for tasks to be performed, list of scheduled tasks not completed, record of when the tasks are completed, and maintaining a record of tools, materials, labour, and costs required to complete each task.

I. Servicing Valves

Seating of valves which are subject to operations several times is likely to become leaky or pass the flow downstream even after closing tight. Periodical servicing will be required for valves on hydrants and public taps, flowmeters, and pressure gauges. Corrosion of valves is a main problem in some areas and can cause failure of bonnet and gland bolts. Leaks from spindle rods occur and bonnet separates from the body. Stainless steel bolts can be used for replacement and the valve can be wrapped in polyethylene wrap to prevent corrosion.

II. List of Spares

A list of spares required for the distribution system maintenance shall be prepared, procured, and kept for use. The list should indicate the minimum level at which action for replenishments should be initiated. The list of probable spares to be kept in stock may include the following: spare check nuts, spindle rods, and assorted bolts, nuts and washers for the flanged joints, gaskets for flanged joints for all sizes of sluice valves installed in the distribution system, spare manhole covers and consumables like the gland rope, grease, cotton waste, spun yarn, pig lead and lead wool, O-rings, mechanical joints and fittings, etc.

III. List of Tools

The necessary tools to properly repair and correct both the routine problems and for facilitating repairs and replacements in a distribution system have to be identified and provided to the maintenance staff. Some of the tools for the maintenance work in a distribution system are: key rods for operation of all sluice valves, hooks for lifting manhole covers, pipe wrench of appropriate sizes (200, 300, or 450 mm), double ended (DE) spanner set, ring spanner set, screw drivers, pliers, hammers, chisels, caulking tools for lead and spun yarn, ladles and pans for melting and pouring lead joints, excavation tools such as crow bars, spades, iron baskets, buckets, and dewatering pumps.

IV. Maintenance of Valve Chambers for Appurtenances

Valve chambers are generally filled with leakage in the glands, shafts, etc., and the stagnant water if not drained properly can be sucked into the distribution system. Hence, these chambers required robust drainage arrangement and regular maintenance to keep them clean and hygienic.

Valve chambers shall be checked to ensure that they are not damaged, nor filled up with earth nor buried in pavement. Covers of valve chambers are stolen or broken up by vandalism or by accident resulting in damage to the valves or may lead to accidental fall of a person into the open valve chamber, such situations have to be corrected on priority. Road improvement works require constant attention of water utility staff since the valves may be lost or at times the valve chambers in the roads have to be reconstructed to match the renewed road surface.

Precaution shall be taken to provide the valves where absolutely essential because maintenance of valve chambers is a herculean task in the distribution system. These valve chambers are becoming dustbins and point of contamination of the water. Alternatively, valve chambers can be constructed based on the essentiality (access required for regular operation) otherwise, can be buried after inserting a pipe or similar type of any special above the spindle so that O&M team can access wherever there is requirement.

7.6.9 Maintenance Schedules of Pipelines

Maintenance schedules of pipelines are summarised as below:

I. Main Breaks

Pipeline bursts/main breaks can occur at any time and the utility shall have a plan for attending to such events. The repair plan must be written down, disseminated to all concerned and the agency must always be in readiness to implement the plan immediately after the pipe break is reported. After a pipe break is located, a decision is to be taken as to which valve is to be closed to isolate the section where the break has occurred. Every consumer (some important consumers may be having an industrial process dependent on water supply which cannot be shut down as fast as the water supply lines are cut off) should be notified about the break and informed about the probable interruption in water supply and also the estimated time of resumption of water supply. After the closure of the valve, the dewatering/mud pumps are used to drain the pipe break points. The sides of trenches have to be properly protected before the workers enter the pit. The damaged pipe is removed, and the accumulated silt is removed from inside the pipe and the damaged pipe is replaced and the line is disinfected before bringing into use. After every pipe break, a report shall be prepared in regard to the cause of such break, the resources required for rectification and the time and cost required for repairing, etc., so that the agency can follow up with measures for avoiding such breaks and also modify their plan to address such breaks in the future.

II. Deterioration of Pipes

Pipes deteriorate on the inside due to corrosion and erosion on the outside due to corrosion from aggressive soil and water/moisture. Depending on the material of pipes, these are subjected to some deterioration, loss of water carrying capacity, leaks, corrosion and pitting, tuberculation, deposition of sediment and slime growth. Preventive maintenance of distribution system assures the twin objectives of preserving the bacteriological quality of water in the distribution system and providing conditions for adequate flow through the pipelines. Incidentally, this will prolong the effective life of the pipeline and restore its carrying capacity.

III. Flushing of Pipelines

Flushing is done to clean the distribution lines by removing impurities or sediment that may be present in the pipe. Routine flushing of terminal pipelines is often necessary to avoid taste and odour complaints from consumers. It is advisable that a programme for flushing is prepared and followed so that water mains are flushed before consumers start complaining. The routine for flushing can be prepared by taking into consideration the consumer complaints and type of deposits found while cleaning. Since in distribution system, flushing is not the only solution for water quality problems; proper operation of treatment process and cleaning of SRs supplying water to the distribution system shall also be planned along with the flushing of distribution system. Flushing is usually done during low water demand, when the weather is favourable. This is very essential in flat terrain with low pressure otherwise the silt particle settles in the pipe and create frequent contamination of water. Prior planning and good publicity with public will allow the flushing to proceed quickly and without confusion.

IV. Cleaning of Pipelines

Mechanical cleaning devices such as swabs and pigs are sometimes used if flushing does not improve the water quality. Scrapers or brushes are used in pipelines with hardened scales or extensive tuberculation. Sometimes scrapers and brushes are used before taking up lining works.

V. Cement Mortar Lining

The present trend is to use cement mortar lined ductile iron (DI) pipes or mild steel (MS) pipes so that they will not lose their carrying capacity with use and age. Still many new pipelines are proposed with unlined metallic pipes and there are several existing pipelines with bare metal surface such as CI or MS. With passage of time, these pipelines deteriorate and require rehabilitation. Cement mortar stifles corrosion through its ability to develop high alkalinity. The application of cement mortar lining to pipe in place is done by a lining machine, containing a device that projects cement mortar against the pipe wall. Directly behind this device are mechanically driven rotating trowels, which give the surface smooth finish. In situ cement mortar lining of existing metallic water mains has been beneficial where:

- pipe carrying capacity may reduce due to tuberculation;
- water quality is affected due to release of corrosion products from the pipes to the water; and
- leaks occur through joints and pipe walls.

7.6.10 Leakage Control

Wastage of water in the system and distribution network occurs by way of leakage from pipes, joints, fittings, reservoirs, and overflow from reservoirs and sumps. The objective of leakage control programme is to reduce the wastage to a minimum and minimise the time that elapses between the occurrence of a leak and its repair. The volume of water lost through each leak should be reduced by taking whatever action is technically and economically feasible to ensure that the leak is repaired as quickly as possible. To achieve this, the organisation shall prescribe procedures for identifying, reporting, repairing, and accounting for all visible leaks. It will be beneficial for the agency if the procedures involve the conscious and active participation of the population served by the agency apart from its own staff. The management has to process the data and evaluate the work on detection and location of leaks and for dissemination of the results and initiate actions to control the overall problem of water loss. Interim measures for reduction/control of leakage can be initiated by controlling pressures in the WDS where feasible.

A pipe replacement programme in a distribution system is a proactive approach to ensure the efficiency and longevity of the water supply infrastructure. This programme involves identifying old and deteriorating pipes in the distribution network and replacing them with new ones. The primary objective of this programme is to improve the water quality, reduce leaks, and ensure uninterrupted water supply to customers. In addition, the replacement of old pipes can also reduce maintenance costs and mitigate the risk of water contamination. The programme typically involves a comprehensive assessment of the distribution network, including pipe material, age, and condition, to identify the areas that require urgent attention. It is an essential aspect of water management and a significant investment in the long-term sustainability of the distribution system.

7.6.10.1 Step Test

Step testing is an effective, flow-based method of localising water loss within a zoned distribution system. It is particularly suited to identifying areas of high leakage and to use on plastic pipe materials, where leak noise is absorbed, and conventional acoustic methods are less effective. To perform a step test the inflow into a zone must be monitored. This can be achieved by deploying a data logger upon the inlet water meter to automatically transmit flow data to the operative in the network. Alternatively, an additional operator can be left upon the inlet meter to manually record flow and network activity. Once a method of monitoring has been established, then valves are closed to cut off sections of the zone known as “Steps”. This demonstrates how much water is consumed in each step. Each step has an estimated customer consumption which is compared to the drop in flow at the inlet meter. If the difference between the actual drop in demand and estimated consumption is significant, this provides an indication to the operative that leakage is contained within that step. Step tests should be carried out when demand is at its lowest. This tends to be at night time between the hours of 01:00–04:00. This helps contributes to a more accurate step test as fluctuations in demand are minimised. Before a step test is implemented all valves required must be located on site. Once located then the integrity of the valve must be tested. This will include ensuring the valve is accessible and operable. A zero pressure test (ZPT) can conclude if the valve can be closed completely without passing any water, this helps contributes to further reassurance of an accurate step test. There are three types of valves when operating a step test:

(1) Valves that are permanently shut to create a zone. These can sometimes be called boundary valves or zone valves.

(2) Valves that need to be shut before the start of the test in order to create “Steps” that can be closed off during the test with a single valve, as sometimes it is not possible to shut off a section by using only one valve closure. These valves are only shut for the duration of the test and re-opened once the test is completed. They are sometimes

known as circulating valves.

(3) The final type of valve is one that isolates a step from the zone. They are numbered according to the order that they need to be shut in during the test. Step 1 is typically the "Step" that is the farthest away from the meter and the last step closure is the one nearest the meter.

To evaluate the level of leakage in the DMA, it is required to calculate the system's Net Night Flow (NNF). The value of NNF is then obtained by subtracting the Legitimate Night Flow (LNF) from the Minimum Night Flow (MNF). The MNF is the lowest flow into the DMA over a 24-hour period, which generally occurs at night when consumption is minimum (Ranhill NRW Manager's Handbook, 2008).

Precautions to be Taken before Test

Before conducting a STEP test, ensure that the DMA is perfectly hydraulically discrete. This can be ensured by conducting the "*zero pressure test*" keeping all valves including the inlet are closed and checking if the pressure in the DMA drops to zero. It confirms the water entering from the other area if the pressure does not drop to zero (Yukun Hou, 2018). It is used to check whether a particular DMA is watertight. The procedure is as follows:

1) Indicate the boundary valves with different colour.
2) Inform the consumers about the test and arrange the test at night, say between 1 am to 4 am.
3) Plans of DMA boundary, boundary valves, and the DMA inlet valve should be kept ready.
4) Set up a pressure gauges at key locations within DMA.
5) Close the DMA entry valve to isolate the DMA.
6) The pressure at the pressure gauge will drop. If the drop of pressure is immediate, the DMA is isolated perfectly.
7) If the pressure does not fall, then inspect the boundary valve and find the culprit valves.
8) Faulty valves should be replaced.
9) After the test is over, and water supply is restored, pressure gauge should indicate correct pressure.
10) If there is zero water pressure through the DMA, it means the boundaries of that area are watertight.
11) The isolation valves to be used for making segments must be tested for its functioning, they should be leakage proof.

DMA is divided into small sections by closing valves. Each small section is shut off at night. Before any valves are closed, the MNF is recorded. It is called as "START" MNF value. Then, as each valve is closed systematically, this is called a "STEP" and the new MNF is recorded. The difference between the start and the new flow is the "STEP" value which is approximate NRW value.

7.6.10.2 Isolation Valve System

The mechanical reliability of WDNs is a relevant technical and scientific issue. During planned maintenance or unplanned interruptions, the affected area must be isolated by valves shutdown. This operation involves the alteration of the network structure, i.e., the domain of the hydraulic system, and for this reason the isolation valve system (IVS) plays a central role. Some studies started to consider the presence of the IVS in WDNs reliability analysis.

The IVS is a crucial element in WDNs because it activates segments, i.e., isolated portions of the network, when pipe failures occur, or maintenance is required. During the repair time, the failed pipes are hydraulically isolated from the rest of the network. Shutdown modifies the WDN connectivity structure, then the IVS is closely related to the mechanical reliability of WDNs. This means that for the reliability assessment of WDNs, the IVS analysis is mandatory. In many reliability studies, pipe failure is modelled by removing individual pipes from the network, i.e., by assuming the presence of two isolation valves at the ending nodes of each pipe (Walski et al., 2006). This assumption is not quite realistic because the isolation valves are usually smaller in number and, generally, they are designed to activate segments when one or more pipes need to be repaired. Then the real position of the valves has to be considered in the analysis. Many researchers already studied reliability analysis using graph theory, considering the classic modelling, where links represent pipes and nodes represent vertices. This representation cannot describe the real effect of a pipe failure, since the presence of the IVS entails that many pipes are isolated when failures or ordinary maintenance occur. To account this fact, Walski (1993) introduced a new representation of the network using the segment graph, i.e., a graph where the isolation valves represent the edges, and the vertices represent segments activated by the IVS.

There are several different variations on the approach depending on the technology available, whether it is important to maintain supply and the configuration of the network.

I. Leakage Through House Connections

Leakage can be controlled at the point of house connection and in the consumer pipe by adopting correct plumbing practices and improving the methods used for tapping the main and giving house connection and strict quality control on the pipe material used for house connection. An analysis of leaks in house connections and an investigation into the reasons for leaks in the house connections shall be carried out to initiate action on reducing the leakage through house connections.

II. Procedures for Reporting Visible Leaks

The water utility has to establish procedures whereby the population served by the agency can notify the visible leaks. The agency staff can also report visible leaks found by them while carrying out other routine works on the water supply system. Utility has to establish procedures for prompt repair of leaks and for attending efficiently and accurately to the leaks. Critical areas where leaks often occur have to be identified and appropriate corrective measures have to be implemented.

III. Procedures for Detecting Invisible Leaks

Establishment of procedures for detecting and locating non-visible leaks shall be compatible with the technological, operational, and financial capability of the agency. Selection and procurement of equipment for detection and location of leaks must take into account the cost-effectiveness and the financial capability of the organisation.

This detection can also be carried out by testing residual chlorine simultaneously over a grid around the compliant spot. A team of trained staff were deployed with handheld chloroscopes. This gives an idea of the origin of pollution entry when a sudden drop in residual chlorine is detected. Thereafter, the grid is narrowed down and further narrowed and the location of pollution is identified. Thereafter, simultaneous testing in all the house ends is tested and this shows the actual ingress of pollution. All these are non-invasive.

The observation of late-night flow can also be a useful method for detecting leakage in a WDN. This method is based on the fact that during the night when water demand is low, the flow rate in the distribution network should also be low. If there is a significant flow during this time, it could be an indication of a leak.

However, it is important to note that there could be other reasons for increased flow rates during the night, such as unauthorised use of water or operational reasons, so further investigation is required to confirm the presence of a leak. The observation of late-night flow can be a valuable tool for detecting leaks in a WDN, but it should be used in conjunction with other methods to confirm the presence of a leak and to identify its location.

IV. Active Leakage Control

Following steps are implemented for active leakage control:

(i) Locate the failure.

(ii) Close all related isolation valves.

(iii) Ensure safety for working using appropriate signs, barriers and traffic diversions.

(iv) Excavation of failed pipe sections with ensuring workers safety and avoiding further damage to the pipe.

(v) Drain out the water, solids, and sludge by use of an extractor pump.

(vi) Repair the failed pipe section using an appropriate method.

(vii) Ensure that the exposed and new sections are carefully cleaned and disinfected.

(viii) Open slowly one or more of the closed isolation valves as well as hydrant or valve to allow air to escape.

(ix) Ensure that all isolation and scour valves opened or closed are reinstated to their correct state.

(x) Flush the section using a hydrant in order to ensure the contaminants and solids are removed.

(xi) Inspect the repair of leaks once the section is under pressure.

(xii) Reinstate the pipe bedding, blanket, and backfills using appropriate placing and compaction methods and materials.

(xiii) Complete the pipe repair reports including an analysis of likely cause of the failure and keep the report for future actions.

For detection and control of leakage, refer subparts of Section 4.4.4 of Chapter 4: “Transmission of Water” and Section 11.8 of Chapter 11: “Water Audit, Monitoring and Control of NRW” in Part B of this manual shall be referred.

7.7 Monitoring System Performance

Normally, the managers of O&M of water utilities monitor levels in SRs, pressures, and flows in the distribution system and operation of pumps such as hours of pumping, failure of pumps and monitor water quality by measuring residual chlorine. The manager usually uses telephone line or wireless unit to gather the data, maintain records analyses, uses his discretion gained with experience and takes decisions to ensure that the system is operating with required efficiency. Manual collection of data and analysis may not be helpful in large undertakings if water utilities have to aim at enhanced customer service by improving water quality and service level with reduced costs. In such cases, monitoring system performance can be done with the use of Telemetry and SCADA and Digital Twins.

I. Quality of Pipe Material for House Connection

The water utility shall ensure that the connection and communication pipe from the street main up to the consumer premises is laid as per correct plumbing practices and adopt improved methods for tapping the main. Strict quality control is required on the pipe material used for house connection. The bye-laws shall lay down rules for defining the ownership and responsibility for maintaining the point of connection and the communication pipe. In several utilities, the communication pipes are leaking since they are corroded; however, these are not replaced by the consumer or by the utility particularly where the O&M responsibility for consumer pipe rests with the consumers.

II. Contamination Through House Connection

While laying the consumer connection pipes, there is a need to avoid contamination of water supplies. This can be achieved by maintaining horizontal and vertical separation between the water supply communication pipe and the sewer/drain. In some instances, a sleeve pipe may be required to be provided to the consumer pipes crossing a drain. It is always recommended to provide a non-corrodible pipe material for the consumer connection. Contamination by possible backflow can also be prevented by ensuring provision of double check/non-return valves at the consumer end.

III. Rules for Consumer Connections

The water utility shall formulate rules for sanction of consumer connection. Tapping the branch line and laying the connection piping. At no circumstances, a consumer connection is permitted from the mains. On unavoidable circumstances, a separate parallel pipeline/rider pipeline has to be drawn from the nearby existing distribution system. Water utility shall undertake inspection of the consumer premises before releasing the connection to ensure that the internal plumbing system of the consumer conforms to the National Building Code. Water utility shall supervise the process of drilling/tapping of the main for giving connection and laying of the consumer piping. The process of submission of applications for connections by consumers and carrying out the connection work through licensed plumbers is also prevalent in some utilities. In such cases, the utility shall formulate procedures for licensing the plumbers including the qualifications to be possessed by the plumber, facilities, and tools to be available with the plumber for the work to be undertaken by the plumber. The utility shall closely observe the quality of materials used and works done by him and he should act as per procedures laid down in the bye-laws for approval of the connection works, renewal, or cancellation of the plumbers' licenses or any other requirement depending on their performance or non- performance. For all the service connections, ferrule should be provided/fixed with saddles and compression fittings to avoid leakages from the connection joint.

7.8 Records and Reports

I. Record System

A record system has to be developed which should be realistic and apply to the operating problems involved in the distribution system. Management must be clear as to why the data/information is collected, as to who will review the data, and who will respond to the results of review. The most efficient way to keep records is to plan what data is essential and then prepare the formats followed by the persons concerned for filling of the data, frequency, and to whom the record is to be sent for review and report. The agency should make a repository of real time data at the discretion of the authority in managing and taking an appropriate decision of the system. Sample records to be maintained are given below for guidance:

- Updated system map.
- Pressure and flow readings at selected monitoring points.
- Persistent low pressure or negative pressure areas.
- Age of pipes/quality of pipes.
- Pipelines to be replaced.
- Presence of corrosive water in the system.
- Water budget for each zone served by one SR.
- Number of connections given.
- Number of meters out of order.
- Status of fire hydrants and public taps.
- Quantity measured at outlet of reservoir.
- Quantity distributed/measured or billed.
- Source of leaks and persistent leak points.
- Status of bulk meters – function or not.
- Status of consumer meters.
- Facilities for repairs of consumer meters.
- Number of unauthorised connections.
- Residual chlorine levels at the pre-selected monitoring points.
- Bacteriological quality of the water sampling points.
- Persistent areas where residual chlorine is absent/where bacteriological samples are unwholesome.
- Record on carrying out repairs on the following works and its cost:
    - The pipeline leaks or replacement of pipes.
    - Change of gland ropes of the valves in distribution system.
    - Replacement of parts.
    - Replacement of manhole covers.
- Record on man-hours spent on routine operations in the distribution system in the previous year and the cost thereof.
- Record on total cost of repairs and replacements in previous year along with break-up of material cost and labour cost with amount spent on outside agencies for repairs and replacements.
- Record on when the exposed piping was last painted and the cost of materials and labour cost thereof.
- Record on the unserved areas – extension of pipelines – need for interconnections.

II. Reports

With the accumulation of all essential data a report can be prepared evaluating the O&M of the facility. The report can identify the deficiencies in the system and its appurtenances, and then plan future repairs to the network or valves and other equipment or for replacement of defective valves or other equipment or additions and extensions to the distribution network.

III. Computerised Maintenance Management System (CMMS)

Computerised Maintenance Management System (CMMS), also known as Computerised Maintenance Management Information System (CMMIS), is a software package that maintains a computer database of information about an organisation's maintenance operations.

This information helps in maintenance of the system by determining which component (pipes, machinery, instruments, chemicals, manpower, etc.) requires maintenance and where the spare parts are. The CMMS also keeps track of all the maintenance work involved by generating work orders, procurement orders, vendor orders, stores inventory, as well as the cost involved in all the activities thus help to accurately calculate the budget needed for O&M.

CMMS also allows to keep record and geotagging of the components in the system which can be linked to GIS and network model, which in turn helps to analyse and keep track of various maintenance works.

7.8.1 Checks to be Carried Out

A programme has to be prepared for each zone of the distribution system which shall contain procedures for routine tasks, checks and inspections at intervals, viz., daily, weekly, quarterly, semi-annually, or annually. This plan shall fix responsibility, timing for action, ways and means of completing the action as to when and who should take the action and mention the need to take these actions. Simple checklists for use by the managerial staff can be prepared to ensure that the O&M staff has completed the tasks assigned to them as shown in Table 7.2.

Table 7.2: Sample Checklist

S. No.	Checks required/undertaken	Status	Suggested frequency of reporting
1.	Check whether the operation of valves is smooth without any abrupt stoppage during closure or opening.	OK/Not OK	Daily
2.	Check whether closure of a valve results in complete stoppage of flow or if any flow passes the valve	OK/Not Ok	Daily
3.	Check for status of scouring and then proper closure of washout valves.	OK/Not OK	Daily
4.	Check for leaks through pipes.	Yes occurring/Not	At every pressure/flow drop

S. No.	Checks required/undertaken	Status	Suggested frequency of reporting
		occurring	
5.	Check for leakage through valves at gland, bolts, or any other place.	OK/Not OK	Daily or at every pressure/flow drop
6.	Check for leaks at the appurtenances.	OK/Not OK	Daily or at every pressure/flow drop
7.	Check for any signs of corrosion of pipelines.	OK/Not OK	Yearly
8.	Check for the status of manhole covers over the chambers; are they corroded.	OK/Not OK	Yearly
9.	Inspect for any possibilities of pollution of the distribution system water stored.	OK/Not OK	Monthly
10.	Status of out-fall drain for scour and overflow.	OK/Not OK	Daily or at every such instance
11.	Assess the need for painting of the piping work.	Required/not required	Every 3 years
12.	Check for availability of spares for valves, pipes, and jointing materials.	Available/not available	Check monthly bill of quantity
13.	Preparation of water budget for each OZ/DMAs.	Y/N	Annual (yearly)
14.	Number of connections given.	No./Nil	Monthly
15.	Number of meters out of order.	No./Nil	Monthly
16.	Status of hydrants and PSPs.	Working/ Not working	Yearly
17.	Status of OZ and DMAs.	OK/Not OK	Yearly or on every addition/removal of connection
18.	Review of hydraulic conditions.	OK/Not OK	At pressure/flow drop
19.	Water quality.	OK/Not OK	Daily
20.	Identify source of leakage.	OK/Not OK	At pressure/flow drop
21.	Metering.	OK/Not OK	Monthly
22.	Status of bulk metering and consumer	OK/Not OK	Monthly
23.	Review facilities for repair of consumer meters.	OK/Not OK	Monthly or on abrupt billing/reading
24.	Unauthorised connections if any.	Yes/no	Monthly
25.	Status of fire hydrants and PSPs.	OK/Not OK	Yearly
26.	Availability of updated system map.	Yes/no	On every addition/alterations
27.	Need for any interconnections.	Yes/no	For balancing when abnormal pressure/flow fluctuations noticed

CHAPTER 8 : DRINKING WATER QUALITY MONITORING AND SURVEILLANCE

8.1 Introduction

Safe potable water is the first step to promoting the good health of a community. Experience has shown that community health and water quality are directly related. An improvement in drinking water quality helps in improving the community's health. Manmade activities, rapid industrialisation, intermittent water supply, and agrochemical contamination increasingly affect the quality of water resources, viz., groundwater and surface water. Despite significant achievements in water supply coverage, many factors make good quality water unsafe by the time it reaches the consumer. Poor operation management of the water supply and unsatisfactory sanitary practices are the key areas responsible for water contamination.

The quality of drinking water is a concern in urban areas of India, with cities facing water contamination problems. Contamination of water sources is mainly due to naturally occurring compounds (As, Fe, Cr, U, F, S, Pb, etc.), land-use practices (pesticides, chemical fertilisers), manufacturing processes with toxic wastewater discharged by industries, depletion and degradation of groundwater resources, disposal of untreated sewage/wastewater (microbes, organics, nutrients), storm water runoff (oil, grease, etc.) and inadequate maintenance of water distribution systems. Public water supply service agencies are required to treat the water to make it potable for human consumption and safe for other purposes. While adding chemicals to make water safe is widely practised, any residual amount of these chemicals, their contaminants or by-products also can pose a health risk if not monitored appropriately.

Part A, Chapter 7 on “Water Quality Testing and Laboratory Facilities” explains in detail the aspects of water quality parameters, sampling, testing, laboratory analysis, critical assessment points, staffing, infrastructure, water quality index and water safety plan.

This Chapter outlines the standard procedures for various components of drinking water quality monitoring and surveillance and sanitary surveillance (inspection) activities to be undertaken.

8.2 Objectives

The responsibility of the drinking water utility is to ensure that the water supply is safe and of acceptable standards. Hence, the key objectives are to provide integrated water quality monitoring to maintain consistency across the ULB. It describes various components of water testing laboratory management practices to ensure that the data generated are scientifically correct and can be used to plan and implement interventions to improve water quality. The data collected through periodic monitoring can help undertake requisite corrective measures in existing water supply systems and plan the preventive actions for any proposed extension of distribution systems.

8.3 Water Quality Monitoring and Surveillance

Monitoring is a programmed process of sampling, measuring, and subsequently recording or signalling of water characteristics. It involves laboratory and field testing of water samples collected from various sampling locations in the water supply system, including the source, water treatment plants, service reservoirs, distribution systems and consumer end, representative of the condition of the water at the point and time of collection. Continuous water quality monitoring involves good operating practices and preventive maintenance, routine testing to ensure compliance with standards. Water quality monitoring is carried out with following major objectives:

- Determining the water quality of various surface and groundwater sources, at water treatment plants, service reservoirs, distribution network in DMA and when it emerges from pipes, taps, etc., for drinking purposes.
- Establishing whether the limit/standard of specific water quality parameters has been complied.

Water quality monitoring programme is generally based on the following three interrogative W's:

(a) When to observe (how often): Frequency of observation is used to describe how often something is observed.
(b) Where to sample: Locating the sampling points.
(c) What to measure: Define the parameters to be monitored.

Surveillance is a continuous and attentive public health assessment and evaluation of drinking water supplies' safety and social acceptance. Surveillance is an investigative activity usually undertaken by a separate agency, either by an independent section of the department or a third party, to identify and evaluate factors posing a health risk to drinking water. The surveillance agency should communicate with the water supply agency/department, pinpoint the risk areas, and advise remedial actions. It should also maintain good communication and co-operation with the water supply agency/department to detect risk areas.

Following are the outcomes of monitoring and surveillance:

- Generating information that permits rational decisions to set priorities for water quality management programmes and strategise for improving the quality of drinking water supply services incrementally. It is critical to developing a strategy for managing surveillance, collating, analysing & tabulating the data and reporting & disseminating findings and recommendations for corrective measures.
- Generate evidence necessary to make sound decisions on managing water quality at present and in the future and to ensure that corrective actions are taken.
- Alert to current, ongoing and emergency problems, determine compliance with drinking water quality standards and protect other beneficial water uses.
- Help water managers and regulators develop water policies, determine if water is getting better or worse, and formulate new policies to protect human health better.
- Protect public health by improving the quality, quantity, accessibility, coverage, affordability, and continuity of water supplies (also known as service indicators). It works in conjunction with the drinking water supplier quality control function.
- Assist in the preparation and implementation of an improvement plan if water quality monitoring indicates a contaminated water source.
- Follow up water quality monitoring after implementing the improvement plan to determine the efficacy of the plan in providing safe water to the community.

8.4 Water Sampling

The details of water quality parameters, laboratory structure, equipment, staffing pattern, etc., are explained in detail in Chapter 7, "Water Quality Testing and Laboratory Facilities", Part A of this manual. The methodology of sampling and other details essential for water quality monitoring during the operational phase of a water supply project are provided hereunder.

8.4.1 Methodology of Sampling

The following factors are essential for the accurate analysis of the sample (Figure 8.1):

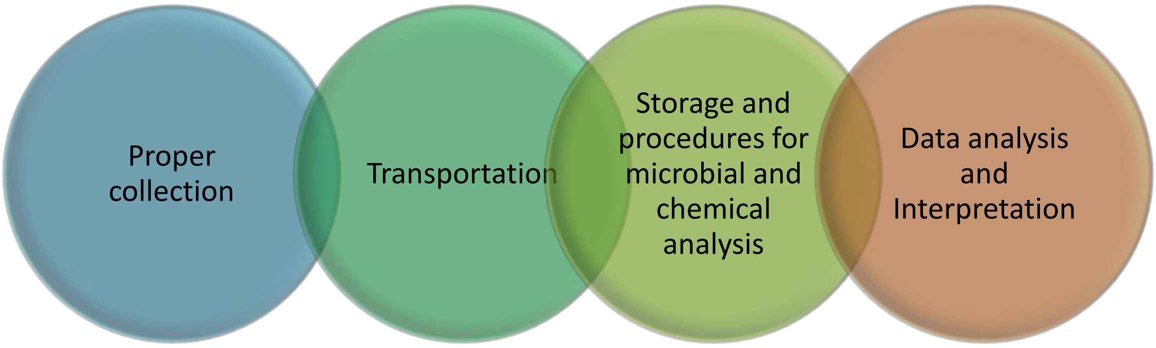


Figure 8.1: Factors involved in sample analysis

Bureau of Indian Standards, i.e., IS-3025/1622 – 2019, IS-10500: 2012 and/or “Standard Methods for the Examination of Water & Wastewater” – latest edition [published jointly by American Public Health Association (APHA), and American Society for Testing and Materials (ASTM)] should be referred for detailed information on sampling and testing procedures.

8.4.2 Water Sampling Locations and Frequency

Water quality sampling aims to obtain reliable and valuable data, so every precaution should be taken in identifying sampling locations at representative points in the water supply chain or distribution network. As mentioned in Section 7.5 of Chapter 7: "Water Quality Testing and Laboratory Facilities" of Part A, it is recommended to provide the following critical points to assess the water quality:

i) at the intake/tube well (water source);
ii) at the inlet and outlet of the treatment plant;
iii) at the inlet and outlet of service reservoirs such as ESRs/MBRs/GSRs;
iv) inlet and at the farthest point in each District Metered Area (DMA);
v) at discrete locations in the network/DMA.

Water quality monitoring at source is very important as this provides types and concentration of pollutants for designing water treatment plants to meet drinking water quality standards. The performance efficiency of a treatment plant is to be checked by taking samples from various locations within the facility. The distribution system in an urban piped water supply is complex, and sampling can be done at different locations regularly. Sanitary surveillance (inspections) and water quality analyses are typically performed to provide insight into contamination and its causes. In an urban distribution network, house connections branch off the sub mains. Each DMA should be considered independent when selecting sampling locations.

It is necessary to divide the urban area into various water supply zones based on vulnerability/ criticality and drinking water supply arrangements. The zoning system should include population levels within the urban area, including informal settlements, to direct resources to the most significant public health improvements (or benefits).

8.4.3 Frequency of Sampling

The level of variation in the water quality of the source determines the sampling frequency. If there are significant variations over a short period, a higher frequency is required to cover them. The following sections discusses the frequencies of sampling.

8.4.3.1 Water Sources

For the sampling of surface and groundwater sources, samples should be taken at regular intervals to ensure no significant quality changes occur between sampling times. Streams are continually subjected to forces and environmental changes, resulting in variations in chemical water quality. These variations may be relatively small in areas subjected to intensive weathering for extended periods.

Surface waters (e.g., rivers and reservoirs) and groundwater are the primary drinking water sources. Natural contaminants derived from the native rocks/minerals through which water traverses and microorganisms and chemicals contributed by anthropogenic sources are present in water at variable concentrations. Contaminants from anthropogenic sources can be classified as point and diffuse (non-point) sources. Industrial wastewater and sewage treatment plants are typically designated as point sources, while agricultural land and paved surfaces, such as highways, are known as diffuse sources.

There are two water quality variations i) random and cyclic, and ii) seasonal. The increased frequency of sampling may not help much in the case of random variations, such as those caused by sudden rainfall in the catchment or sudden release of water from the dam, because such variations are highly unpredictable. As a result, covering such variations within the available resources is not cost-effective. More frequent sampling is justified in the case of water bodies that experience cyclic variations more recurrently. However, frequent monitoring is not required for all water bodies with consistent water quality throughout the year. Water quality sampling locations should regularly analyse a combination of general parameters, nutrients and oxygen-consuming substances (particularly of surface water sources), and major ions. Other parameters such as micro-pollutants, pesticides, or other site-specific variables may be included at a lower frequency depending on the industrial activities anticipated upstream of the sampling station. It is necessary to identify such sampling locations.

Water samples should be collected as close to the intake well in case of surface water sources, whereas sampling point should be from or as close to the outlet of tubewell/ borewell for groundwater.

The water quality varies according to the seasons, and these seasonal changes have both positive and negative effects on water quality. The varying seasons are associated with various temperature fluctuations. All other physical and chemical factors of water vary with the change of seasons, just like the temperature. The seasons from a water quality sampling perspective are classified as follows:

i. post-monsoon (October–November);
ii. winter (December–January);
iii. summer or pre-monsoon (April–May); and

iv. monsoon (June, July, August, and September, except in parts of southern states such as Tamil Nadu, in which the southeast monsoon has a substantial proportion of rain).

Sampling frequency, particularly of a water source, should consider seasonal variation.

Table 8.1 lists the suggested minimum frequencies of monitoring specific parameters for **surface water and groundwater sources**. In case a combination of sources (e.g., surface and groundwater sources), frequency applicable to both the types of sources should be considered.

Table 8.1: Frequencies and parameters for analysis of surface water and groundwater sources (CPCB guideline 2007-08)

Frequency as per the water source	Parameters
Perennial rivers and lakes/reservoirs: 4 times a year Seasonal rivers: 3 times during the flow period (at equal time intervals). Lake/pond/springs or any other surface water source: 4 times a year	**Pre-monsoon:** Once a year. General: Colour, Odour, Temperature, pH, Electrical Conductivity (EC), Dissolved Oxygen (DO), Turbidity, Total Dissolved Solid (TDS). Nutrients: NO3, PO4 Demand parameters: Bio-chemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) Major ions: Sodium (Na^+), Potassium (K^+), Calcium (Ca^{++}), Magnesium (Mg^{++}), Carbonate (CO3), Bicarbonate (HCO3), Chloride (Cl), Sulphate ($SO4^-$). Other inorganic: Other location-specific parameters, if any Microbiological: Faecal coliforms/Thermotolerant coliforms Pesticides residues: As per Table 7.4 (Part A Manual, Chapter 7) Metals: As, Cd, Hg, Zn, Cr, Pb, Ni, Fe, Mn, Ag, Cu, Se **Rest of the year** (Quarterly sampling) General: Colour, Odour, Temperature, pH, Electrical Conductivity (EC), Dissolved Oxygen (DO), Turbidity, Total Dissolved Solid (TDS). Nutrients: NO3 Demand parameters: Bio-chemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) Major ions: Sodium (Na^+), Potassium (K^+), Calcium (Ca^{++}), Magnesium (Mg^{++}), Carbonate (CO3), Bicarbonate (HCO3), Chloride (Cl), Sulphate ($SO4^-$). Other inorganic: Other location-specific parameters, if any Microbiological: Faecal coliforms/Thermotolerant coliforms.

Frequency as per the water source	Parameters
Groundwater: Twice a year in pre- and post-monsoon season. The frequency may be reviewed after three years of monitoring	**Pre-monsoon** General: Colour, odour, pH, Electrical Conductivity (EC), Turbidity, Total Dissolved Solid (TDS), Major ions: Sodium (Na^+), Potassium (K^+), Calcium (Ca^{++}), Magnesium (Mg^{++}), Carbonate (CO3), Bicarbonate (HCO3), Chloride (Cl), Sulphate ($SO4^-$), Nitrate ($NO3^-$), Other inorganic: Other location-specific parameters such as fluoride, if any Microbiological: Faecal coliforms/Thermotolerant coliforms. Pesticides residues: As per Table 7.4 (Part A Manual, Chapter 7) Metals: As, Cd, Hg, Zn, Cr, Pb, Ni, Fe, Mn, Ag, Cu, Se **Post-monsoon** General: Colour, odour, pH, Electrical Conductivity (EC), Turbidity, Total Dissolved Solid (TDS), Nitrate Major ions: Sodium (Na^+), Potassium (K^+), Calcium (Ca^{++}), Magnesium (Mg^{++}), Carbonate (CO3), Bicarbonate (HCO3), Chloride (Cl), Sulphate ($SO4^-$). Other inorganic: Other location-specific parameters such as fluoride, if any Microbiological: Faecal coliforms/Thermotolerant coliforms.
Note: Emerging contaminants have to be handled separately	

8.4.3.2 Sampling at Water Treatment Plants

The water source is presumed to be protected, and a conventional water treatment plant is provided to remove naturally occurring contaminants. Other sources of contaminants are either properly treated before disposal, or sufficient dilution is available in recipient water bodies.

In case geogenic contaminant is not present in groundwater, it requires only disinfection as treatment before consumption. A specific treatment is essential if geogenic contaminant is present in water. Groundwater requires less extensive treatment than surface water. For surface water sources, water treatment involves aeration, coagulation, flocculation, sedimentation, filtration, and disinfection. Water treatment for geogenic contaminants can be categorised based on treatment processes such as filtration, electrocoagulation, adsorption, etc.

The minimum frequency of key water quality parameters for surface and groundwater sources at the inlet and outlet of water treatment plants are presented in Table 8.2. In case blended water (surface and groundwater are used in a treatment plant), water quality parameters for both surface and groundwater sources as mentioned in Table 8.2 should be monitored.

Table 8.2: Frequencies and water quality parameters for water treatment plants

Frequency as per the water source for water treatment plant	Parameters
	Everyday General: Colour, Odour, Turbidity, EC/Total Dissolved Solid

Frequency as per the water source for water treatment plant	Parameters
Rivers and lakes/reservoirs	(TDS), Free residual chlorine (at the outlet of treatment plant only) Microbiological: Faecal coliforms/Thermotolerant coliforms. **Once a month** Metals: Aluminium Other: As per the quality of source water such as metals, etc. (to be decided by the concerned ULB)
Ground water	**Everyday** General: Colour, Odour, Turbidity, EC, Total Dissolved Solid (TDS), Free residual chlorine (at the outlet of treatment plant only) Microbiological: Faecal coliforms/Thermotolerant coliforms. **Once a month** Toxic Metals: Aluminium Other: As per the quality of groundwater such as fluoride, arsenic, etc. (to be decided by the concerned ULB)

8.4.3.3 Water Quality Sampling at Balancing Reservoirs and DMA/Distribution Network

The distribution network (system) is the most important element of the water supply system. Water is transported from the treatment plant by a pipeline under pressure. The primary aim of the network is to supply water to consumers in pre-defined quantities at sufficient pressure. A distribution network connects pipes, storage/service reservoirs, intermediate pumping systems, valves, and household service connections.

Water after treatment is stored in reservoirs to have sufficient pressure to transport water in the distribution network. Chlorination is also provided at these reservoirs to maintain an appropriate residual chlorine level (0.2–0.5 mg/L) to compensate for chlorine loss in the distribution network. Water quality monitoring needs to be done at the inlet and outlet of storage reservoirs (MBR, ESR, GSR or any other storage reservoir) and following water quality parameters should be monitored as per IS1622 (for Bacteriological parameters) and IS 3025 (relevant parts for other parameters):

i) Turbidity (Nephelometry)
ii) Conductivity/Total Dissolved Solids (TDS) (Gravitimetry)
iii) pH (Electrometric and colorimetric methods)
iv) E. (Escherichia) coli /Thermotolerant coliforms (MPN or MFT method)
v) Free/residual chlorine (DPD method)

Water quality significantly deteriorates in the distribution system/network primarily due to intermittent supply, breakages in pipelines and cross-connections. Flowing/Impounded water surrounding the pipe gets into it because of backflow during non-supply hours, as the pipeline during these hours is not pressurised. The backflow of water happens due to lower pressure in the distribution network compared to atmospheric pressure. Water quality deterioration in the distribution system is a serious concern due to inadequate maintenance and low chlorine residual. Rapid and haphazard urbanisation often leads to overwhelming water demand, thus, unplanned expansion of distribution systems. Intermittent and erratic water supply, inadequate disinfection residual, leakages, low pressure, and corrosion/incrustation of the pipelines largely contribute to water quality deterioration in the distribution system. Major contaminants of concern are turbidity and pathogens in the water distribution system.

Although water quality should be monitored at as many as sampling locations in distribution systems, resource constraints often restrict the number of samples. The following minimum sampling frequency and number of samplings in distribution system are provided at Table 8.3.

Table 8.3: Minimum Sampling Frequency and Number from Distribution System

Population Served	Maximum interval between successive sampling	*Minimum no. of samples to be taken from entire distribution system	Parameter	Test to be Carried out
Up to 20,000	Seven days (minimum four samples per month)	One sample per 5,000 of population per month	All 5 parameters mentioned above	As per section 8.4.3.3
20,000–50,000	Four days (minimum eight samples per month)			
50,000–1,00,000	Two days (minimum 15 samples per month)			
More than 1,00,000	One day	One sample per 10,000 of population per month plus 10 samples		

* Wherever online water quality parameters are monitored, the laboratory water quality test may not be required for such parameters

For a city of 5,50,000 population, 65 (55+10) water samples need to be collected and analysed in a distribution system (at the inlet to the households) every month. These 65 samples should be distributed over a month. Hence, two samples must be analysed from the distribution system daily. A roster system can be adopted (e.g., sampling in different DMAs on different days) so that water sampling locations are generally not repeated and entire distribution system is well represented.

This sampling frequency is only for guidance purposes, and it is recommended that the water quality sampling be carried out daily for a city having population more than 1,00,000 (estimated as per the base year of 2021 for current scenario, and through next Census as and when available) so that the entire city is covered within a month. This will help in capturing any water quality contamination episode quickly. As highlighted earlier, water quality in the distribution system is compromised, and a large sampling interval will likely miss these water quality contamination episodes. In case of water quality episodes (reported cases of water borne diseases), number of sampling locations should be increased, and water quality monitoring should be carried out daily irrespective of population served.

The estimated monthly number of water samples should be equally distributed over one month.

The locations from which samples are collected must be representative of the water supplied in an area. Criteria for selection of sampling points are as follows:

- DMA entry points.
- Number of samples in a particular DMA/Zone shall be proportionate to the number of quality related complaints received.
- Location has to be decided considering the history of contamination of water supply in any area (contamination hotspot).
- Connections that are downstream of old pipelines crossing nallas/stream/polluted area.
- In the case of District Metered Areas (DMA) with high Non-Revenue Water (NRW) the number of samples can be decided considering the magnitude of NRW.
- House connection ferrule points are considered as the potential leaking points and these points can also be considered as the sampling locations.
- Locations reported to have water borne diseases. The local hospitals should be consulted periodically to identify such locations.
- Roster system should be adopted which means a sampling location should not be repeated in one year (sampling location can only be repeated if water borne diseases are reported in a nearby area subsequent to sampling in that year). In case this sampling location is repeated in the same year, it should not be considered while counting number of sampling locations. Hence, all the sampling locations estimated through Table 8.3 should be discrete sampling points irrespective of number of samples collected at any location.

The following water quality parameters should be monitored in water distribution systems:

i. Turbidity
ii. Conductivity/TDS
iii. pH
iv. E. coli/Thermotolerant coliforms
v. Free/residual chlorine (this will also indicate the status of contamination due to wastewater)

The microbiological tests give the status of contamination in the distribution system, however, require about 24 hours to get the results. In such case the residual chlorine is taken as indirect indicator about the status of contamination. Hence, immediate action can be taken if “zero” residual chlorine is detected at some point in distribution system.

Each laboratory should keep record of each sample in format as given in **Annexure 8.1**.

8.4.3.4 Water Quality monitoring at consumer underground sumps

Due to intermittent water supply system most of the consumers store water in the ground level sumps. As per the study conducted by CPHEEO, many such sumps were found to be contaminated with faecal coliforms due to seepage. These underground tanks will be continued till the stabilisation of 24x7 pressurised water supply system. Therefore, it is the responsibility of the ULBs to monitor water quality parameters as mentioned in section 8.4.3.3 quarterly for about 5% of the household sumps in a DMA, especially the consumer sumps that are found to be heavily leaking/ complaints regarding contamination and advise the consumers to replace or repair the underground tanks to make them watertight. When the system is stabilised for 24x7 pressurised water supply, these sumps can be bypassed.

8.5 Establishing Monitoring and Surveillance Mechanism

Several institutions are catering to water quality monitoring and surveillance requirements and imparting training related to these aspects. These institutions are functional at different levels, e.g., at National, State and ULB levels having specialisation in water quality monitoring and surveillance. Water quality laboratories are the main backbone of water quality monitoring and surveillance programme. Well- located and well-equipped analytical laboratories with competent staff are essential to evaluate water utility services' efficiency in terms of water quality. Therefore, the provision of safe drinking water warrants a strong laboratory network within the state for water quality assessment. Some institutions that may assist ULBs in undertaking water quality monitoring and surveillance are given subsequently.

8.5.1 Dr Syama Prasad Mookerjee National Institute of Water and Sanitation (SPM-NIWAS)

Dr Syama Prasad Mookerjee National Institute of Water and Sanitation (SPM-NIWAS) is set up on 8.72 acres of land at Joka, Diamond Harbor Road, Kolkata, West Bengal. The Institute is envisaged as a premier institute to develop capacities in States/UTs in public health engineering, drinking water, sanitation, and hygiene through training programmes. Such capabilities are envisaged for the frontline workforce engaged in implementing the Swachh Bharat Mission and Jal Jeevan Mission and the representatives of rural and urban local bodies. Accordingly, suitable infrastructure has been developed, including training infrastructure, R&D block, and a residential complex. Working and miniature models of Water Sanitation and Hygiene (WASH) technologies are also installed to facilitate the training at the Institute.

The Institute was earlier known as National Centre for Drinking Water, Sanitation and Quality (NCDWSQ).

SPM-NIWAS will function as a scientific institution of Department of Drinking Water and Sanitation (DDWS) in training, education and research, and development in the water and sanitation sector. It is also proposed to set up a National Level State-of-Art R&D Water Quality Laboratory to assess all aspects of drinking water quality to meet the standards as per IS 10500: 2012 and ISO/IEC 17025.

8.5.2 Existing Institutes/Laboratories at National and State Levels

In addition to SPM-NIWAS, the Central Ground Water Board (CGWB), Central Water Commission (CWC), Central Pollution Control Board (CPCB), and Council of Scientific and industrial research (CSIR) through a network of institutions operate water quality testing laboratories. These laboratories have instrumentation facilities and trained human resources to monitor various water quality parameters and have been serving for several years. ULBs can utilise the services of these laboratories in monitoring specific water quality parameters. Moreover, these institutes, particularly CGWB, CWC and CPCB, maintain databases of water quality parameters. The water quality data set mainly related to the water sources will be of immense use for ULBs in identifying the appropriate source for designing/augmenting water supply schemes.

There are several water quality monitoring laboratories which carry out similar activities. Some of these laboratories are operated by State Government agencies such as PHED. ULBs also carry out water quality monitoring and surveillance almost independently and differently. The functions and responsibilities of various water quality monitoring and surveillance agencies are given in **Table 8.4**.

Table 8.4: Functions and Responsibilities of Agencies for Water Quality Monitoring and Surveillance

Agency	Function	Responsibilities
Surveillance Agency 1. State PHED 2. Urban Local Body 3. Local Health Authority, CMO/Health Officer 4. State Pollution Control Board	Surveillance of drinking water quality	• To ensure that the drinking water is free from contaminants. • To find out what is wrong. • To assist in setting things right in both rural and urban systems.
Water Supply Agency 1. State PHED/Water Boards/Urban Development Department 2. Urban Local Bodies/Authority 3. Autonomous Agencies	Supply of potable water	• To provide sufficient potable water to the population at an adequate pressure
Central Pollution Control Board and State Pollution Control Board/Authority	Controlling pollution of the water source	• To protect the raw water sources from being unduly polluted

There is a necessity to have a more significant number of laboratories to meet the water quality testing requirement. There are only few water supply systems with testing facilities for water quality. Synergy and co- ordination with these institutions should be ensured to maximise coverage of the city/town and minimise resource consumption.

ULBs may tie up with water testing laboratories (NABL accredited), which are in the private sector for water quality tests. Public-Private Partnerships can be explored wherein the ULB may collaborate with NABL-accredited private laboratories, i.e., those laboratories with testing facilities with NABL accreditation as Support Organisations (SO) and utilise their strengths following all SOPs as per government procedure. Engagement with private laboratories can only be initiated if services of government laboratories are not available. Further, water quality testing facilities may be set up in science colleges/universities/technical institutions, and all such laboratories may be brought under the water quality testing network.

8.5.3 Water Quality Monitoring and Surveillance Team

Team can be created for monitoring and surveillance of the water supply system at various levels as given in Table 7.11 of Chapter 7: "Water Quality Testing and Laboratory Facilities", Part A of the Manual.

8.6 Planning and Implementation

Systematic planning is necessary to implement a drinking water quality control programme successfully.

8.6.1 Analytical Quality Assurance and Quality Control

The primary objective of water quality testing and analysis at the laboratory is to produce accurate data describing the water samples' physical, chemical, biological, and microbiological characteristics under study. A checklist for effective analytical quality assurance/sample inspection report is given in Table 8.5, which is of "Yes/No" type; if the answer is "No" for any of the below items, necessary improvements have to be made.

Table 8.5: Checklist for Quality Assurance

S. No.	Parameter	Check points
1.	**Do laboratory personnel have**	Clearly defined responsibly? Requisite qualifications? Essential experience? Sufficient training?
2.	**Is space**	Adequate for the types and number of analyses being undertaken?
3.	**Is equipment**	Adequate? Regularly serviced and maintained? Calibrated and used only by authorised personnel?
4.	**Are materials**	Desired quality? Purchased from a reliable supplier, who carries out quality control?
5.	**Are there proper facilities**	For the receipt and storage of samples and systems for coding and identifying them?
6.	**Is data**	Retrievable? Archived?
7.	**Are methods**	Validated? Documented? Monitored?
8.	**Is safety assured by**	Adequate working and waste disposal procedures? Training of staff? Proper maintenance of equipment? Proper supervision of staff?

Source: *DDWS, Oct 2021 "Drinking Water Quality Monitoring & Surveillance Framework", https://jalshakti-ddws.gov.in/sites/default/files/WQMS-Framework.pdf*

Quality Assurance (QA): a system of documented procedures and plans established to ensure that the water monitoring programme produces data of known precision and without bias. This includes staff training programmes, calibration processes, written procedures (SOPs) and record keeping.

Quality Control (QC): operational activities that confirm the quality assurance methods are functional and that information collected is accurate, precise, and properly recorded. Therefore, consistent QA/QC activities produce data of known quality. Table 8.6 represents QA/QC in water quality testing.

Table 8.6: QA/QC in Water Quality Testing

Step	Quality Assurance	Quality Control
Staff are properly trained	Staff are appropriately trained in an induction and provided with field/lab procedures	Supervision of new staff
Use of specialised equipment	Calibration procedures – all water monitoring equipment is calibrated using controlled standard solutions prepared in a NABL accredited laboratory Equipment maintenance procedures are in place	Limits placed on calibration results Any equipment failing calibration is not used until the problem resolved Equipment maintained as per appropriate specific manual for that equipment
Sample collection	Provide training in sampling techniques Controlled record worksheets with clear site locations and the appropriate samples for each location Controlled and accurate sample labelling Controlled use of consumables – defined bottles appropriate for samples being collected	Use of field blanks
Record keeping	Data 'double recorded' – manually on worksheets and electronically within equipment memory	Data validation – data checked by second technical officer after being entered into the database
Storage and transport	Defined methods for storage of samples (e.g., use of ice, foil, and minimisation of time between collection and storage)	Fridges and freezers monitored by use of data loggers
Sample analysis	Samples analysed using defined methods (including outsourced to a NATA accredited laboratory) Methods based on text: "Standard Methods for the Examination of Water and Wastewater"	Use of calibration standards and laboratory blanks

8.6.1.1 Additional Safety/Hygiene Requirements

- Safety instructions and precautions to be followed in the laboratory must be displayed inside the laboratory.
- BIS specifications (IS 10500) – Drinking Water Specification, IS 3025 – Method of Sampling & Test-Physical & Chemical, IS 1622 – Methods of Sampling & Microbiological examination of water) and the latest edition of APHA Manual (American Public Health Association,

American Water Works Association, Water Environment Federation. Lipps WC, Braun-Howland EB, Baxter TE, eds. *Standard Methods for the Examination of Water and Wastewater)* should be made available in each laboratory.

- The date of reagent solutions and the expiry date for each solution prepared should be clearly mentioned on the bottles.
- Under no circumstances sanctity of the laboratory should be violated. Unauthorised persons should not enter the laboratory. Eating should not be allowed in laboratory space meant for analysis.
- A clean and well-maintained toilet must be attached to the laboratory with a hand washing facility and soap.
- The laboratory should also have AC fitted when a significant number of tests are required to be done. Personal hygiene is a must for all laboratory staff, especially microbiologists. All laboratory staff should wear gloves during the solution preparation and testing (the requirement is parameter specific). Staff should be provided white laboratory coat/aprons, which should be washed at regular intervals.
- Drinking water samples should only be tested after proper calibration of the instruments.
- The upkeep of the fish aquarium in the laboratory can indicate the unusual behaviour of the fish during any outbreak of contaminants in the water. Bioassays check for overall bioactivity for a specific pathway or action method, and it is a viable method for evaluating complex samples.
- It is a common practice to analyse water and wastewater samples in one laboratory in ULB. However, this increases chances of cross-contamination. Hence, separate sections should be provided for water and wastewater analysis in a laboratory. Microbiology analysis section should be isolated and separated in the laboratory and minimum Bio Safety Laboratory 2 (BSL 2) facilities should be provided.

8.6.2 Waste Management at Water Quality Testing Laboratories

Wastewater from chemical laboratories is difficult to treat. It is generally composed of organic and inorganic matter and a wide range of chemicals and heavy metals. If chemical waste cannot be transported safely without treatment, it must be treated at its source.

Hazardous chemicals/substances must be disposed of by methods that comply with local environmental regulations. In some cases, on-site treatment has been performed under special permits issued by the regulatory agency. A good safety programme requires constant care in the disposal of laboratory waste. Laboratories should maintain a comprehensive listing of wastewater discharges that includes sources and locations of the discharges and analytical or other data characterising the nature and volume of the discharge.

8.6.3 Turnaround Time

Timely tests are critical in the timely and comprehensive management of testing the water samples. The state government should measure and monitor the turnaround time of test reports. It is recommended that the turnaround time for testing the chemical parameters should not exceed more than 24 hours. In contrast, the turnaround time should not exceed 48 hours for testing the microbiological parameters.

To overcome turnaround time delays, the State/UT government should ensure that the laboratories continually improve operational efficiency and monitor turnaround time at every level.

8.6.4 NABL Accreditation

NABL approval is a form of accreditation which is required for a testing laboratory to prove that the reports developed come with the quality that meets consumers' needs. All ULB laboratories have to ensure NABL approval to meet the requirements of quality standards.

NABL approval is thus a quality assessment that provides technical standard approval when it comes to reports that are produced by the laboratories.

NABL has developed a Government Drinking Water Testing Laboratory Accreditation Program (G-LAP) and have three classifications namely State, District, and Block/Sub- Division level laboratories for rural water supply programme. Similar approach can be adopted for urban water testing laboratories and following categories of laboratories shall receive NABL accreditation:

A typical NABL Accreditation Process is given in Figure 8.2. The infrastructure and processes of water testing laboratories should comply with NABL standards and protocols.

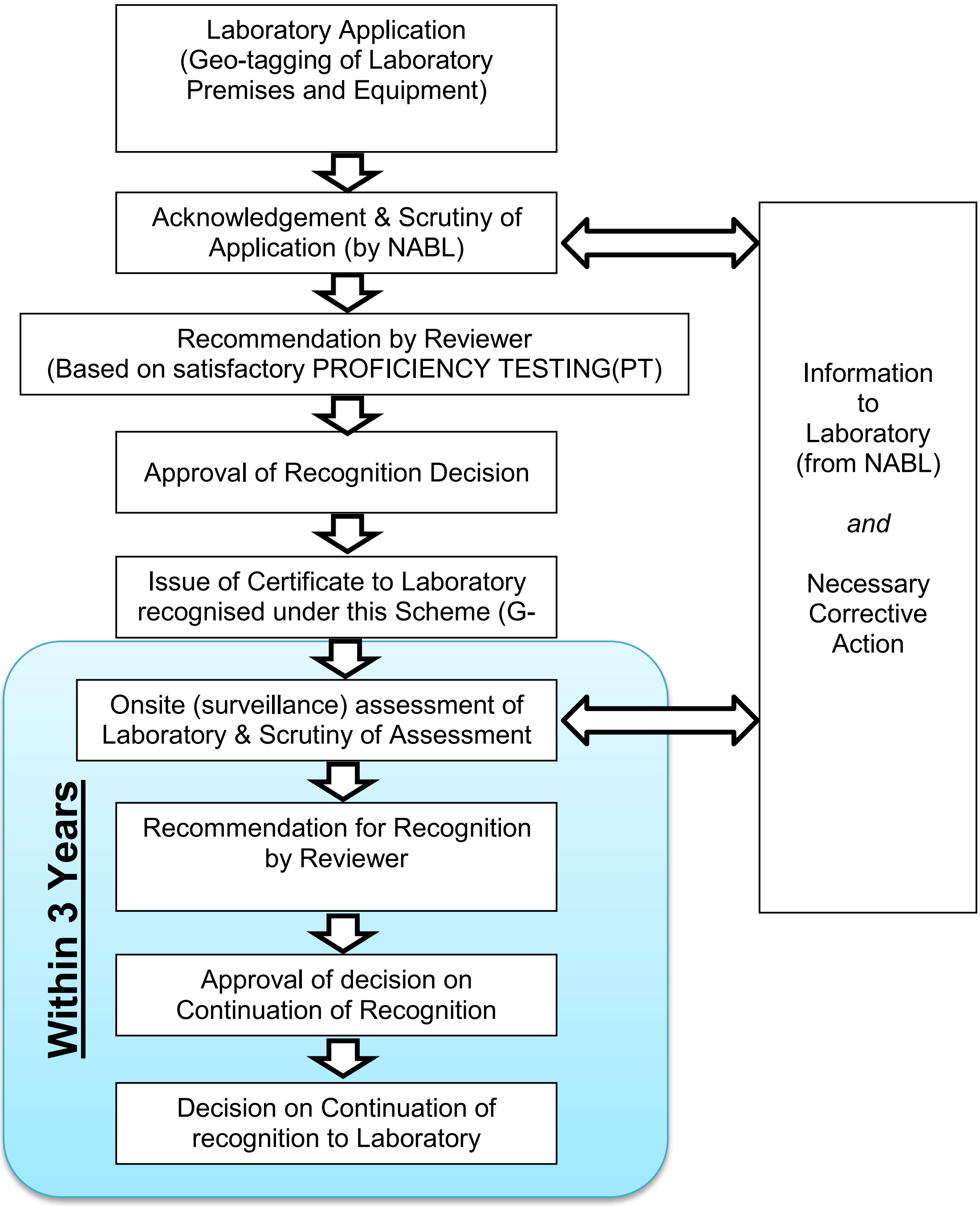


Figure 8.2: Typical NABL Accreditation Process

8.6.5 Financial Support

Sufficient allocation of the fund should be made for maintaining/monitoring water quality and its surveillance, keeping in view the size of the waterworks, the area covered, etc. The cost for establishing a laboratory has to be part of project costing and costs involved in monitoring and surveillance of testing facility to be part of O&M budget.

8.7 Water Safety Plans (WSP)

A comprehensive risk assessment and risk management approach incorporated in a WSP that applies to all steps of a water supply, including the distribution system, is the most effective way to consistently ensure the safety of drinking-water supplies. Developing an integrated WSP that applies to all components, from catchment to treatment and distribution, is standard practice. The goal of WSPs is simple: to ensure the safety and acceptability of drinking water supplies on a consistent basis. Since it is assumed that water is safe to drink at the point of entry in distribution systems, the goal becomes to maintain safety by preventing contamination after treatment (Refer Section 7.10 of Chapter 7**:** Water Quality Testing and Laboratory Facilities, Part A for more details). Water quality data should be immediately shared with relevant teams in ULBs for corrective measures which can form part of water safety plan.

8.7.1 Sanitary Survey

A sanitary survey (also known as sanitary inspection and also mentioned as sanitary surveillance in Section 7.9 of Chapter 7: Water Quality Testing and Laboratory Facilities of Part A Manual) is a periodic audit of all aspects of all water supply systems. A systematic programme of the sanitary survey includes sanitary inspection, water quality analysis and evaluation of data and reporting.

Various factors such as geography, population distribution, access to numerous localities, infrastructure, the number and experience of technical staff and the activity level in the surveillance programme determine the frequency of regular sanitary inspections.

8.7.1.1 Nature and Scope of Sanitary Survey

A sanitary survey is an on-site inspection and evaluation of all conditions, devices and practices used in the water supply system which pose an actual or potential danger to consumers' health and well-being.

The two essential activities of the sanitary survey are sanitary inspection and water quality analysis, which complement one another. The inspection identifies potential hazards, while the analysis indicates the actual quality of water and intensity of contamination.

Mentioned below are guidelines for sanitary surveillance of the water supply systems:

- Sanitary survey should be carried out for all new water sources before they are used for drinking water.
- Survey should be carried out by a suitably trained person using a simple, clear report form. The questions are structured so that the "yes" answers indicate the risk of contamination, and "no" responses indicate that the particular risk is absent. Each "yes" answer scores one point, and each "no" answer scores zero. After the inspection, the points are added up, the higher the total, the greater the risk of contamination.
- Results of sanitary surveys and the remedial actions needed to improve conditions should be discussed with the authority and community.

Sanitary survey (inspection) is indispensable for the adequate interpretation of laboratory results and provides essential information about the immediate and ongoing possible hazards of any water supply system. It is vital to pinpoint target areas for remedial action required to protect and improve the water supply system.

The following eight elements are considered essential for review in the proper conduct of sanitary survey:

i. Source (Protection, Physical Components, and Condition): Assess water supply sources and intake infrastructure to ensure adequate source protection and sufficiency. Also, the conveyance to the treatment system is to be studied.

ii. Treatment: Examine treatment processes, equipment, components, and methods, as well as related chemical addition and management.
iii. Distribution System: Assess the system adequacy, dependability, and safety in delivering water to users. Minimum residual pressure shall also be checked at critical points in the distribution system to achieve the design pressure as per the size of the ULB.
iv. Finished Water Storage: Assess the sufficiency, dependability, and safety of finished water storage.
v. Pumps/Pump Facilities and Controls: Determine the appropriate operation and servicing of water system pumps and pumping systems.
vi. Monitoring/Reporting/Data Verification: Examine tracking data for source and final water quality for bacteriological, physical and chemical parameters, and execute and evaluate field analyses as needed.
vii. Water System Management/Operations: Examine the impact of management practices on system reliability and the credentials of system workers.
viii. Operator Compliance with State Requirements: Explain the relevance of regulations to water systems during a sanitary survey and their relationship to state requirements.

All the sanitary inspections undertaken by the municipality/municipal corporation each quarter, especially during monsoon post-monsoon seasons, should be sent to the State/UT level laboratory.

Sanitary surveys are essential from the point of view of operation and maintenance. **Annexures 8.2 to 8.6** show suggested sanitary survey forms for different water supply components. Frequency of sanitary surveillance for water supply system based on population served is presented in **Annexure 8.7**.

8.7.2 Community Awareness

Community awareness is an essential component of the monitoring and surveillance framework. The primary beneficiary's community can play a critical role in surveillance activity.

An information, education, and communication (IEC) plan should be prepared (materials for social media, TV, radio, newspaper advertisements, banners, handouts, etc.) to create public awareness about water quality near-source water and the distribution system.

To assure the quality of the water supply, the ULB has to arrange that raw and treated water quality may be displayed digitally in prominent places, just like air quality parameters. If the water is taken from the surface water, the quality index of that raw water may also be displayed. Various methodologies for creating awareness and stakeholder engagement are given in Section 5.4 of Chapter 5: Stakeholder Engagement of Part C of this manual.

8.7.3 Reporting of Water Quality Data to Community/Public

Ministry of Environment, Forests and Climate Change (MoEFCC), Government of India mandated communication of water quality data to the consumers through a Notification dated October 4, 2021. Water supply agency, concerned Local Bodies like Public Health Engineering Department (PHED), Jal Nigam, Municipal Corporation, Jal Board, Municipalities, Private and Public Sector Agencies engaged in potable water supply, shall inform the consumers about the water sources and quality including TDS concentration of water being supplied through billing instruments and also through public advertisement in newspaper and other mass media means on regular basis.

In reference to above notification, following quality parameters of water being supplied should be communicated to the community/public through billing instruments every month and also through public advertisement in newspaper and other mass media means on regular basis:

i) Turbidity
ii) Conductivity/TDS
iii) pH
iv) E. coli/Thermotolerant coliforms
v) Free/residual chlorine

ULB should only report levels of nitrate, sulphate, metals and fluoride if these contaminants are reported to be exceeding drinking water quality standards BIS 10500:2012 in treated water. Water quality data collected in the concerned DMA/at nearby locations should be utilised while reporting to consumer/community through billing instruments.

8.7.4 Smart Solutions

Smart solutions, such as information and communication technologies (ICT), in situ sensing, allowing for effective water quality monitoring are commonly referred to as "Smart Water Management". For the management of drinking-water supply processes, such as raw water in lakes, rivers and groundwater, a real-time water quality monitoring system can be used. Advanced data analysis technologies, such as machine learning, also provide useful tools for water quality data management (e.g., water quality change prediction, adjusting chemical dose, etc.).

The idea is to monitor KPIs, ensure a quick response, minimum service delivery output, minimum water loss, and monitor the quantity and quality on a long-term basis. The additional advantage of this data would be to analyse the demand pattern of the user groups over time and use this information for demand management at the aggregate level, minimise non-revenue water, ensure proper management and effective operation and maintenance of water supply systems.

To capture the functionality, it is proposed to implement 'sensor-based monitoring system' that collects data from field locations, transmits to the central server that can be used to monitor the functionality at a central location in States.

In-pipe water quality monitoring based on Internet of Things (IoT) technology, GIS, Digital Twin Technology can be employed. This can be used for testing water samples and the data uploaded over the Internet are analysed. The system can provide an alert to a remote user, when there is a deviation of water quality parameters from the pre- defined set of standard values.

Smart Water Management in water supply system can improve utility's ability to detect variations in water quality at stages of supply and distribution. Reasons to implement Smart Water Management:

i. To provide real time information to facilitate the protection of water supply.
ii. To observe long-term trends in source water quality.
iii. To respond to contamination.
iv. To support regulatory compliance.
v. To identify pollution sources and responsible parties for pollution.

A similar smart water management system has been implemented in Puri which has been explained in Section 7.5.4 of Chapter 7: Water Quality Testing and Laboratory Facilities in Part A of this manual.

8.8 Record Keeping

Records are the documents that provide objective proof that all work was carried out and reported according to approved procedures. Maintaining accurate, up-to-date, and easily retrievable records of laboratory activities are essential for reducing future liability. All laboratory records, reports and other supporting documentation should be safely stored as hardcopy or electronic records and held securely. Following records should be maintained:

- equipment maintenance records;
- instrument logbooks;
- instrument calibration data;
- calibration records;
- certificates of purity/composition for all standards and reference materials;
- standard operating procedures;
- standard preparation logbooks;
- chain-of-custody forms;
- raw analytical data, both electronic and handwritten;
- QC results and final reports;
- O&M Records.

Each laboratory should keep record of each sample in format as given in **Annexure 8.1**. Apart from this the Utility/ULB must develop a MIS system to keep track of all the Testing results. General Guidelines for record keeping of samples are as follows:

- The laboratories are to keep records of submitted samples and completed analysis in a manner that provides easy data retrieval ability. All laboratory data sheets shall be dated and signed by the concerned Chemist and the Head of the Laboratory or his designee.
- The water analysis report for all drinking water sources to mention the acceptable and permissible limits of IS 10500:2012 and its further ammendments for all basic water quality parameters along with actual observation of each physical/chemical/microbiological constituent.
- Test Reports should be sent to the concerned engineers for taking up corrective action.
- Automated alerts are sent to the concerned engineer of Water Quality Testing and Surveillance Team (ref. chapter 7: Water Quality Testing and Laboratory Facilities in Part A of this manual) in case of samples that are found to have contamination beyond permissible limits.

- State laboratory may also consider to undertake regular technical evaluation checks/audits of all the ULB laboratories/mobile laboratories – e.g., quality of analysis, repeatability statistics, etc., to maintain a quality assurance oversight in the data as confidence in the quality of the data is key to the effectiveness and reputation of the water quality monitoring and surveillance systems.
- The water analysis report for all drinking water sources shall mention the desirable and permissible limits of IS-10500:2012 along with actual observation of each physical/chemical/bacterial constituent. There shall be a footnote indicating the fitness of drinking water for human consumption.
- The database shall have a feature of generating special reports for assessing the performance of a laboratory periodically.
- Reporting should also include action taken if source is found contaminated. Follow-up monitoring results should also be included.

8.9 Water Quality Management Information System (WQMIS)

Data or information generation must be appropriately interpreted and communicated promptly. Global networking has become a powerful means of data communication, storage, and utilisation. The Digital Twin technology can be used in conjunction with SCADA and IoT (quality sensors) to take decisions on corrective measures needed to maintain water quality.

A state-level digital Water Quality Management System (WQMIS) should be developed which will be further integrated into national water quality database. The digital data for the entire state, which is produced and reported by different laboratories, need to be archived in the following databases, as follows:

- Raw Water Quality Database (intake)
- Water Treatment Plant Database (outlet)
- DMA Water quality database (inlet)
- Tap Water Quality Database (distribution system) Digital database platforms should also harness the benefits
- Automated data flow of water sample test results can help in assuring the safe supply of drinking water
- Initiate remedial action in case samples tested do not conform to stipulated standards as per BIS 10500-2012
- Easy management of inventories, human resources and financial transactions of the laboratories
- Renewing NABL accreditation
- Access to all stakeholders to the nearest laboratories through online mode

The WQMIS shall be designed to capture water quality test results by ULB water testing laboratories and Mobile water testing laboratories. All these test results are required to be integrated into the system and shared with the relevant authorities and stakeholders. The results shall be accessible online for data and trend analysis.

It is proposed to develop WQMIS connecting all the ULBs for collation and dissemination of water quality and surveillance data.

CHAPTER 9 : PUMPING STATION AND MACHINERY

9.1 Introduction

Pumping machinery and pumping station are very important components in a water supply system. Pumping machinery is subjected to wear, tear, erosion, and corrosion due to their nature of functioning and therefore are vulnerable for failures. Generally, a greater number of failures or interruptions in water supply are attributed to pumping machinery than any other component. Therefore, correct operation, timely maintenance and upkeep of pumping stations and pumping machinery are of vital importance to ensure uninterrupted/continuous 24×7 pressurised water supply, so that ‘Drink from Tap’ initiative is achieved. Sudden failures can be avoided by timely inspection, follow up actions on observations of inspection and planned periodical maintenance. Downtime can be reduced by maintaining inventory of fast-moving spare parts. Efficiency of pumping machinery reduces due to normal wear and tear. Timely action for restoration of efficiency can keep energy bill within reasonable optimum limit. Proper record keeping is also very important.

Breakdown maintenance is probably the worst pump reliability strategy. Maintaining equipment only after it breaks can mean unexpected downtime, emergencies, rush charges, overtime, and replacement of expensive parts. The best pump reliability strategy is not either preventive or predictive maintenance, it’s a combination of the two, strategically applied.

Preventative maintenance is any variety of scheduled maintenance to a pump or other piece of equipment. Generally, it includes scheduled routine maintenance, such as equipment calibration, greasing, oil change, and analysis.

One of the biggest ways to prevent failures is to make sure the equipment is properly aligned and balanced. Misalignment and pump unbalance are the two most common reliability problems for rotating equipment. Laser alignment also fits within this category since it is a service completed upon installation, setting the pump up for success. These programmes are designed to keep the maintenance costs low by preventing costly failures before they happen. In practice, it is experienced that a higher percentage (about 50% or more) of damage to rotating machinery is directly related to misalignment. Misalignment can cause increased vibration, premature seal and bearing failure, and increased power consumption. An unbalanced pump causes similar issues, such as vibration, which can be easily avoided with the right preventive maintenance measures.

Predictive maintenance services are used to monitor the condition of equipment over time. Vibration analysis, for example, measures the vibration of the equipment while it is still in service. This allows the technician to see the change in vibrations over time to predict when a problem may occur, and why. Predictive maintenance should be part of routine maintenance for pumps and rotating equipment that absolutely can NOT go down. Operators and maintenance managers get a glimpse into the future life of the pump as it is running today. This allows to plan for repairs and avoid unexpected downtime.

Due attention needs to be paid to all such aspects for efficient and reliable functioning of pumping machinery. This chapter discusses procedures for operation and maintenance and addresses pertinent issues involved in O&M of pumping machinery and associated electrical and mechanical equipment.

9.1.1 Components

The components include pumping installations, pumping station building, Intake/sumps, suction and delivery piping and header, pipe assembly, machines and facilities, control units located in the building and auxiliary equipment.

The components in the pumping station can be grouped as follows:

(i) Pumping station

- Sump/intake/dug well/tube well/bore well
- Pump house
- Screen
- Penstock/gate
- Stop log gate
- Belt conveyor and chute

(ii) Pumping machinery

- Pumps and other mechanical equipment, i.e., valves, pipe work, vacuum pumps
- Motors, switchgear, cable, transformer, and other electrical accessories

(iii) Ancillary equipment

- Lifting equipment
- Water hammer control devices
- Flowmeters
- Diesel generating set
- Silt removal equipment
- Ventilation equipment

(iv) Electrical substation

9.1.2 Type of Pumps

The following types of pumps are used in water supply systems.

(i) Centrifugal pumps

a) IS 6595: Part 2 : 1993, Reaffirmed in 2022 specifies the technical requirements for horizontal centrifugal pumps for handling clear cold fresh water for general purposes other than agricultural and rural water supply

b) IS 8418 (1999, Reaffiremd 2019): Horizontal centrifugal self-priming pumps standard specifies the technical requirements for horizontal/vertical, single/multi stage centrifugal self-priming pumps for handling clear cold water

c) IS 9542 (1980, reaffirmed 2017): Horizontal centrifugal monoset pumps for clear, cold, fresh water specifies the technical requirements for horizontal centrifugal moonset pumps for handling clear, cold and fresh water for general purposes other than agricultural purposes

(ii) Vertical turbine pumps (IS 1710:2021)– Vertical Turbine Mixed and Axial Flow, for Clear

Cold Water covers the requirements for vertical turbine (radial and Francis) mixed and axial flow type pumps for clear cold water.

- Oil lubricated
- Self-water (pumped water) lubricated
- Clear water lubricated

(iii) Submersible pumps

a) IS 8034 (2018, reaffirmed 2011 2022) prescribes the technical requirements for submersible pump sets commonly used in boreholes (borewells or tube wells) for handling clear, cold water;

b) IS 9283 (2013, Reaffiremd 2018): Motors for Submersible Pump sets standard specifies technical requirements of submersible motors for submersible pump sets commonly used in bore holes (bore-wells or tube wells) and submersible pump sets commonly used in open wells for handling clear, cold and fresh water for application in agriculture, water supply, etc.

c) IS 14220 (2018, reaffirmed 2022): Open well Submersible Pump sets specifies the technical requirements for single or multistage submersible pump sets, commonly used in open wells for handling clear, cold water for application in agriculture, water supply, etc.

d) IS 14536: 2018 Selection, Installation, Operation and Maintenance of Submersible Pumpset — Code of Practice (First Revision). This standard lays down the general guidelines for selection, installation, operation and maintenance of borewell submersible pumpsets and openwell submersible pumpsets covered in IS 8034 : 2018, reaffirmed 2022: 'Submersible pumpsets — Specification' and IS 14220 : 2018, reaffirmed 2022:'Openwell submersible pumpsets' respectively.

e) IS 9283: 2023 Motors for Submersible Pumpsets- This standard specifies technical requirements of submersible motors for submersible pumpsets commonly used in bore holes (bore-wells or tube wells) and submersible pumpsets commonly used in open wells for handling clear, cold and fresh water for application in agriculture, water supply, etc. This standard shall be read in conjunction with IS 8034: 2018, reaffirmed 2022 -'Submersible pumpsets — Specification' and IS 14220: 2018, reaffirmd 2022--'Openwell submersible pumpsets — Specification' as the submersible motor and the submersible pump together form a complete set. Coordination in the selection of motor and pump with respect to their size, rating and output, etc, is necessary for satisfactory and efficient operation of the pumpset.

f) The general requirements of 3-phase induction motors are covered in IS 12615:2018 - Line Operated Three Phase a.c. Motors (IE CODE) "Efficiency Classes and Performance Specification" and 'requirements of single-phase motors' are specified in IS 996: 2009, reaffirmed 2019 --'Single-phase ac industrial motors for general purpose'. The requirements of 3-phase squirrel cage induction motors for centrifugal pumps are covered in IS 7538: 1996, reaffiremed 2017 -- 'Three-phase squirrel cage induction motors for centrifugal pumps for agricultural applications'. The detailed procedure for conducting tests on motors are given in IS 4029: 2010, reaffiremed 2016 --'Guide for testing three-phase induction motors' and IS 7572: 1974, reaffirmed 2017-- 'Guide for testing single-phase ac and universal motors' as relevant.

(iv) Vertical bore well type pump-motor set

(v) Monobloc open well type pump-motor set

a) IS 9542 (1980, reaffirmed 2017): Horizontal centrifugal monoset pumps for clear, cold, fresh Specifies the technical requirements for horizontal centrifugal monoset pumps for handling clear, cold, fresh water for general purposes other than agricultural purposes

b) IS 9079 (2002): Electric Monoset Pumps for Clear, Cold Water for Agricultural and Water Supply Purposes specifies the technical requirements for electric monoset pumps for handling clear cold water for agricultural and water supply purpose.

(vi) Jet pumps

a) IS 12225 (1997, Reaffirmed 2002): Centrifugal jet pump specifies the requirements of single stage and multistage centrifugal jet pumps used for pumping water from wells beyond suction capacity of horizontal/vertical end suction centrifugal pumps.

b) IS 12699 (1989): Selection, installation, operation and maintenance of centrifugal jet pump - Code of practice lays down general guidelines for selection, installation, operation and maintenance duplex and packer type jet centrifugal pump combinations.

(vii) Reciprocating pumps

a) ISO 16330 (2003, reaffirmed 2020) Reciprocating positive displacement pumps and pump units — Technical requirements" specifies the technical requirements, other than safety and testing, for reciprocating positive displacement pumps and pump units. It applies to pumps which utilise reciprocating motion derived from crankshafts and camshafts and also direct- acting fluid driven pumps. It does not apply to reciprocating positive displacement pumps, nor pumping water, where the whole pump is lubricated with the liquid being pumped.

(viii) Positive displacement pumps
(ix) High-Pressure Pumps
(x) Immersion pumps

The IS: 10572 (1983, Reaffirmed 2020): Methods of sampling of pumps prescribes process control requirements to ensure a uniform product quality and the methods of sampling and the criteria for conformity for acceptance of the lot offered for inspection of pumps.

The "IS 11346 (2002): Tests for Agricultural and Water Supply Pumps – Code of Acceptance" lays down broad basis for testing set up and testing procedures for agricultural and water supply pumps conforming to the Indian Standards.

Guidelines on Testing Procedure for Solar Photovoltaic Water Pumping System issued by the Ministry of New and Renewable Energy vide circular no. No. 41/3/2018-SPV Division dated 17.7.2019 lays down basis for testing set up and testing procedures for Solar Photovoltaic (SPV) water pumping system. The SPV water pumping system covered are centrifugal pumps of all types up to 10 HP capacity.

(xi) Solar Photovoltaic water pumping system

(a) IS 17018 : Part 1 : 2022 Solar Photovoltaic Water Pumping Systems - Specification Part 1 Centrifugal Pumps-- This specification (Part 1) covers design qualifications and performance specifications for Centrifugal Solar Photovoltaic (SPV) Water Pumping Systems from 0.75 kW up to 7.5 kW to be installed on a suitable bore-well, open well, water reservoir, water stream, etc.

(b) Guidelines on Testing Procedure for Solar Photovoltaic Water Pumping System issued by the Ministry of New and Renewable Energy vide circular no. No. 41/3/2018-SPV Division dated 17.7.2019 lays down basis for testing set up and testing procedures for Solar Photovoltaic (SPV) water pumping system. The SPV water pumping system covered are centrifugal pumps of all types up to 10 HP capacity.

Other required pump sets' code of practices if not available under BIS then corresponding ISO code shall be followed.

9.1.3 Coverage in the Chapter

The chapter covers the following aspects regarding the operation and maintenance of components of the pumping station and pumping machinery.

(i) Pumping machinery

- Operation including starting and stopping of pumps and associated electrical and mechanical equipment
- Preventive maintenance
- Trouble shooting
- Inventory of spares, oil, and lubricants
- Tools and testing equipment
- Inspection and testing
- Record keeping

(ii) Ancillary equipment

- Operation, maintenance, and testing of:
  - * Lifting equipment
  - * Water hammer (surge) control devices
  - * Valves

(iii) Pumping station

- Maintenance of the following:
  - * Screen
  - * Sluice-gate
  - * Pump house
  - * Pre-settling tank
- Housekeeping

9.2 Operation of the Pumps

9.2.1 General Points for Operation

The following points are observed while operating the pumps:

(a) Dry running of the pumps should be avoided.

(b) Centrifugal pumps have to be primed before starting.

(c) Pumps should be operated only within the recommended range on the head- discharge characteristics of the pump.

- If a pump is operated at a point away from the duty point, the pump efficiency normally reduces.
- Operation near the shut-off should be avoided, as the operation near the shut-off causes substantial recirculation within the pump, resulting in overheating of water in the casing and, consequently, in overheating of the pump.

(d) Voltage during operation of the pump-motor set should be within ±10% of the rated voltage. Similarly, the current should be below the rated current as per the nameplate on the motor.

(e) Whether the delivery valve should be opened or closed at the time of starting should be decided by examining the shape of the power-discharge characteristic of the pump. Pump of low and medium specific speeds draws lesser power at the shut-off head, and the power required increases from shut- off to the normal operating point. Hence, a pump of low or medium specific speed is started against the closed delivery valve (i.e., shut off condition) to reduce starting load on the motor.
Normally, the pumps used in water supply schemes are of low and medium specific speeds. Hence, such pumps need to be started against a closed delivery valve (shut-off condition).
The pumps of high specific speed draw more power at shut-off. Such pumps should be started with the delivery valve open.

(f) The delivery valve should be operated gradually to avoid sudden changes in flow velocity, which can cause water hammer pressures.
It is also necessary to control the opening of the delivery valve during the pipeline-filling period so that the head on the pump is within its operating range to avoid operation on the low head and consequent overloading. This is particularly important during charging of the pumping main initially or after shutdown. As the head increases, the valve shall be gradually opened.

(g) When the pumps are to be operated in parallel, the pumps should be started and stopped with a time lag between two pumps to restrict the change of flow velocity to a minimum and to restrict the dip in voltage in the incoming feeder. The time lag should be adequate to allow to stabilise the head on the pump, as indicated by a pressure gauge.

(h) When the pumps are to be operated in series, they should be started and stopped sequentially, but with a minimum time lag. Any pump next in the sequence should be started immediately after the delivery valve of the previous pump is even partially opened. Due care should be taken to keep the air vent of the pump next in sequence open before starting that pump.

(i) The stuffing box should let a drip of leakage to ensure that no air passes into the pump and that the packing is getting adequate water for cooling and lubrication. When the stuffing box is grease sealed, an adequate refill of the grease should be maintained.

(j) The running of the duty pumps and the standby should be scheduled so that no pump remains idle for a long period and all pumps are in ready-to-run condition. Similarly, unequal running should be ensured so that all pumps do not wear equally and become due for overhaul simultaneously.

(k) If any undue vibration or noise is noticed, the pump should be stopped immediately, and the cause for vibration or noise be checked and rectified.

(l) Bypass valves of all reflux valves, sluice valves, and butterfly valves shall be kept in a closed position during the normal operation of the pumps.

(m) Frequent starting and stopping should be avoided as each start causes overloading of the motor, starter, contactor, and contacts. Though overloading lasts for only a few seconds, it reduces the life of the equipment.

9.2.2 Undesirable Operations

Following undesirable operations should be avoided.

(i) Operation at Higher Head

The pump should never be operated at a head higher than the maximum recommended. Such operation results in excessive recirculation in the pump and overheating of the water and the pump. Another problem arising in a centrifugal pump with volute is that when operated at a head higher than the recommended maximum head, the radial reaction on the pump shaft increases, causing excessive unbalanced forces on the shaft, which may cause the failure of the pump shaft. As a useful guide, appropriate marking on the pressure gauge should be made. Such operation is also inefficient, as efficiency at the higher head is normally low.

(ii) Operation at Lower Head

Generally, any pump if operated at lower head, draws higher power and delivers higher discharge. If a centrifugal pump is operated at the lower head than the recommended minimum head, radial reaction on the pump shaft increases, causing excessive unbalanced forces on the shaft, which may cause the failure of the pump shaft. As a useful guide, appropriate markings on both the pressure gauge and ammeter be made.
Such operation is also inefficient, as efficiency at the lower head is normally low.

(iii) Operation on Higher Suction Lift

If the pump is operated on a higher suction lift than permissible value, pressure at the eye of the impeller and suction side falls below vapor pressure. This results in the flashing of water into vapor. These vapor bubbles during passage collapse, which result in cavitation in the pump, pitting on the suction side of the impeller and casing, and excessive vibrations. In addition to mechanical damage due to pitting, discharge of the pump also reduces drastically.

(iv) Throttled operation

At times if the motor is continuously overloaded, the delivery valve is throttled to increase the head on the pump and reduce the power drawn from the motor. Such operation results in inefficient running as energy is wasted in throttling. In such cases, it is preferable to reduce the diameter of the impeller, resulting in reduction in the power drawn from the motor.

(v) Operation with Strainer/Foot Valve Clogged

If the strainer or foot valve is clogged, the friction loss in the strainer increases to a high magnitude which may result in pressure at the eye of the impeller falling below the water vapor pressure, causing cavitation, and pitting similar to operation on a higher suction lift. The strainers and foot valves should be periodically cleaned, particularly during monsoons.

(vi) Operation of the Pump with Low Submergence

Minimum submergence above the bell-mouth or foot valve is necessary to prevent air entry into the suction of the pump, which gives rise to the vortex phenomenon causing excessive vibration, overloading of bearings, and reduction in discharge and efficiency. As a useful guide, the lowest permissible water level be marked on the water level indicator.

(vii) Operation with Occurrence of Vortices

If vibration continues even after taking all precautions, a vortex may be the cause. All parameters necessary for vortex-free operation should be checked. Section 5.2.8 of Chapter 5: Pumping Station and Machinery in Part A of this Manual discusses these aspects in detail. In addition, Figure 9.5 in this Chapter details remedial measures to eliminate vortex problems in existing sumps.

9.2.3 Effect of Speed Variation

As per affinity laws, doubling the speed of the centrifugal pump will increase the power consumption by eight times. Conversely, a small speed reduction will result in a drastic reduction in power consumption.

The affinity laws provide a good approximation of how pump performance curves change with speed but to obtain the actual performance of the pump in a system, the system head curve also has to be considered. Subsection 9.3.11.1 elaborates affinity laws.

9.2.4 Effects of Impeller Diameter Change

Changing the impeller diameter gives a proportional change in peripheral velocity. There are equations, similar to the affinity laws, for the variation of performance with impeller diameter D:

$$\frac{Q_1}{Q_2} = \frac{D_1}{D_2}$$

$$\frac{H_1}{H_2} = \left(\frac{D_1}{D_2}\right)^2$$

$$\frac{P_1}{P_2} = \left(\frac{D_1}{D_2}\right)^3$$

Where Q, H, D, and P are discharge, head, diameter, and power; subscript 1 and 2 stand for full and reduced impeller diameters.

Efficiency varies when the diameter is changed within a particular casing.

Reducing the speed by 50% typically reduces efficiency by 1 or 2 percentage points. The reason for the small loss of efficiency with the lower speed is that mechanical losses in seals and bearings, which generally represent less than 1%–1.5% of total power, are proportional to speed rather than speed cubed. It should be noted thatsquared and cubic relationships are accurate up to a diameter change of 5%, and for precise calculations, the pump manufacturer's performance curves should be referred to.

9.2.5 Procedure for Reducing Impeller Diameter

9.2.5.1 Preventing Throttling of Pump

If the motor gets overloaded, field engineer usually resorts to throttling the pump to prevent the overloading of the motor. The effect of throttling is shown in Figure 9.1(a). Throttling shifts the operating point from “A” to “B”, preventing the motor from overloading, and reducing discharge, resulting in more pumping hours and an increase in energy cost. If the impeller diameter is reduced by following affinity laws, the purpose of preventing overloading of the motor can be achieved with the same power requirement, and higher discharge can be obtained. Affinity laws are stated in 9.2.4.

The points A and B at intersections of the H-Q curve and system head curves in Figure 9.1(a) show operating points without throttling and with throttling. Point C in the figure shows the operating point of reduced impeller diameter. It is seen that the discharge Qc is much more than QB (throttled operation) at the same power, resulting in significant savings in energy.

The above affinity laws are practically accurate for small reductions up to 2%–3% from the maximum impeller diameter of the Model. Corrections as per Figure 9.1(b) below from Pump Handbook are applicable for calculated reduction of impeller diameter. It is seen from the Figure that the correction characteristic is a straight line (linear). The equation for correction can be given by:

$$D_{CORR} = (D_2 + 12.5) \times 0.88888$$

Where;

D_{CORR} = Corrected diameter for D_2 in percentage

D_2 = Calculated reduced diameter in percentage as per the affinity laws

Table 9.1: The Results of Correction as per the figure and Equation

D2 %	DCORR %	Whether Tallies with Correction Figure	Reduction for Calculated D2 %	Corrected Reduction %
80	82.22	Tallies	20	17.78
90	91.11	Tallies	10	8.89
95	95.55	Tallies	5	4.45
99	99.11	Tallies	1	0.89

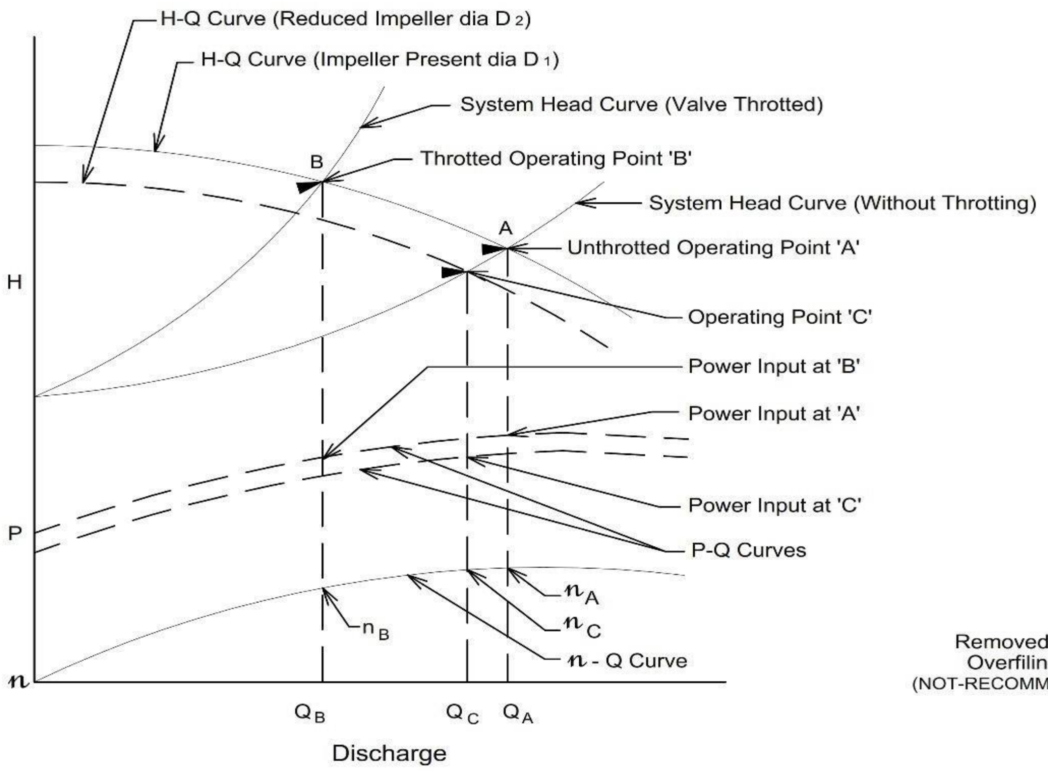


Figure 'a' : Reduction in Impeller Diameter to avoid Throtting

Conclusions : Due to reduced Impeller diameter,

Power input at C = Power Input at B

and $Q_C >> Q_B$

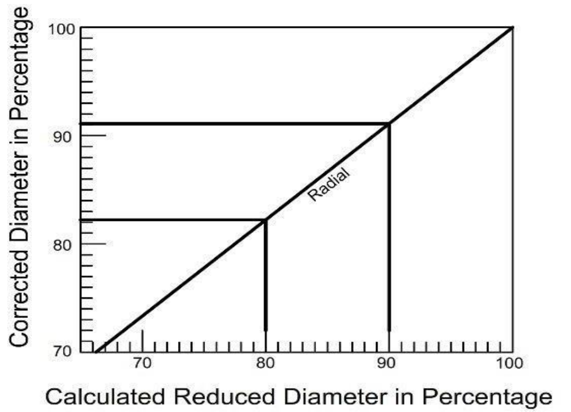


Figure 'b' : Corrections for Calculated Impeller Diameter Reductions

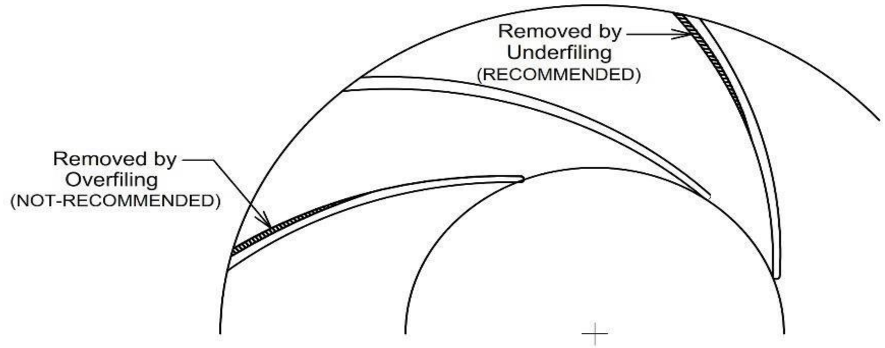


Figure 'c' : Finishing Blade Tips by Underfilling

Figure 9.1: Reducing Impeller diameters

9.2.5.2 Finishing Blade Tips after Diameter Reduction

If the discharge tips of the impeller blades are thick, performance can usually be improved by filing over a sufficient length of the blade to produce a long, gradual taper. The blade tips shall be finished by underfilling, i.e., filing inside of impeller vanes as shown in Figure 9.1(c), and not by overfilling. Chamfering or rounding the discharge tips may increase the losses and should never be done.

9.2.6 Pump Start

9.2.6.1 Checks Before Starting

The following points should be checked before starting the pump:

- If the pump is not operated for longer period or repaired, check whether the direction of rotation is correct. If the direction is not correct, interchange leads of two phases.
- First bowl of VT pump should be below low water level. In respect of submersible pump, entire pump motor assembly should be below static water level/low water level.
- Power is available in all three phases.
- Trip circuit for relays is in a healthy state.
- Check the voltage in all three phases.
- The voltage in all phases should be almost the same and within ±10% of rated voltage, as per permissible voltage variation.
- Check functioning of lubrication system specifically for oil lubricated and clear water lubricated VT pumps and oil lubricated bearings.
- Check the stuffing box to ensure that it is packed properly.
- Check and ensure that the pump is free to rotate. Check the overcurrent setting if the pump is not operated for a week or longer period.
- Before starting it shall be ensured that the water level in the sump/intake is above low water level and inflow from the source or preceding pumping station is adequate.

9.2.6.2 Starting and Operation of Pumps

Procedures for starting and operating different types of pumps are as follows:

a) Centrifugal Pump (of low and medium specific speed) (Figure 9.2)

(i) To start a centrifugal pump, the suction pipes and the pump should be fully primed irrespective of the fact whether the pump is with positive (flooded) suction or suction lift.
The centrifugal pump with positive suction can be primed by the opening valve on the suction side and by letting out air from the casing by opening the air vent. Centrifugal pump on suction lift necessitates close attention to prime the pump fully. To achieve this, the suction pipe and the pump casing must be filled with water, and entire air in the suction piping and the pump must be removed. If the vacuum pump is provided, the pump can be primed by operating the vacuum pump till a steady stream of water is let out from the delivery of the vacuum pump. In absence of a vacuum pump, priming can be done by pouring water into the casing and evacuating air through the air vent or by admitting water from the pumping main by opening bypass of the reflux valve and delivery valve. Check all joints in the suction pipe and fittings.

(ii) Close the delivery valve and then loosen it slightly.

(iii) Switch on the motor, and check that direction of rotation is correct. If the pump does not rotate, or direction is incorrect, it should be switched off immediately and rectified.

(iv) Check the vacuum gauge if the pump operates on a suction lift. If the pointer on the gauge gradually rises and becomes steady, the priming is proper.

(v) The pressure gauge should be observed after starting the pump. If the pump is working correctly, the delivery pressure gauge should rise steadily to shut off head.

(vi) When the motor attains a steady speed, and the pressure gauge becomes steady, the delivery valve should be gradually opened in steps to ensure that the head does not drop below-recommended limit. (In the absence of recommendations, the limit shall be about 85% of the duty head for a centrifugal pump).

(vii) Check that the ammeter reading is less than the rated motor current.

(viii) Check for undue vibration and noise.

(ix) When in operation for about 10–15 minutes, check the bearing temperature, stuffing box packing, and leakage through the mechanical seal and observe vibrations, if any.

(x) Voltage should be checked every half an hour and should be within the limit.

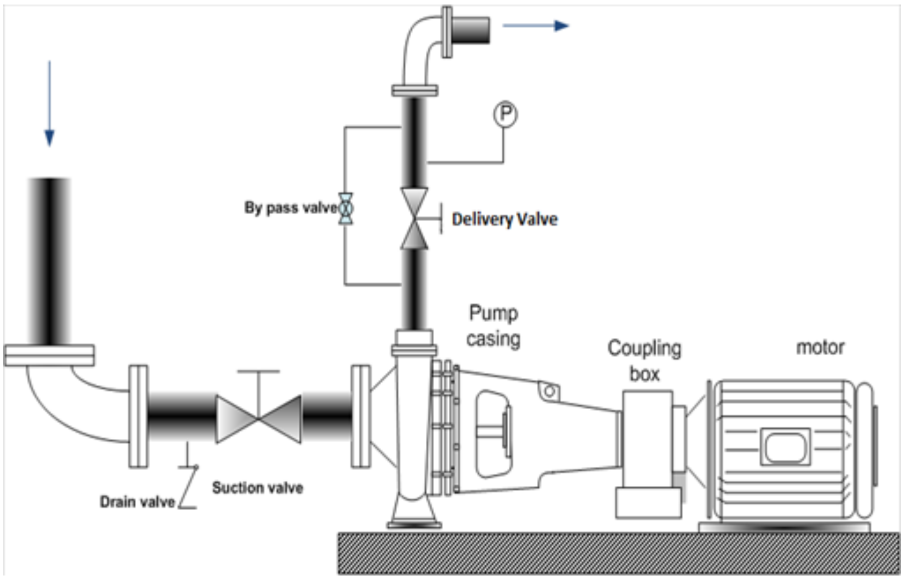


Figure 9.2: Centrifugal Pump System

b) Centrifugal (Axial flow) Pump (High specific speed)

As the shut-off power of axial flow pumps are higher than power at best efficiency point (BEP), such pump should be started with open delivery valve, so as not to overload the motor during starting. Such type of pump should not be operated in parallel and individual delivery should be extended to discharging point.

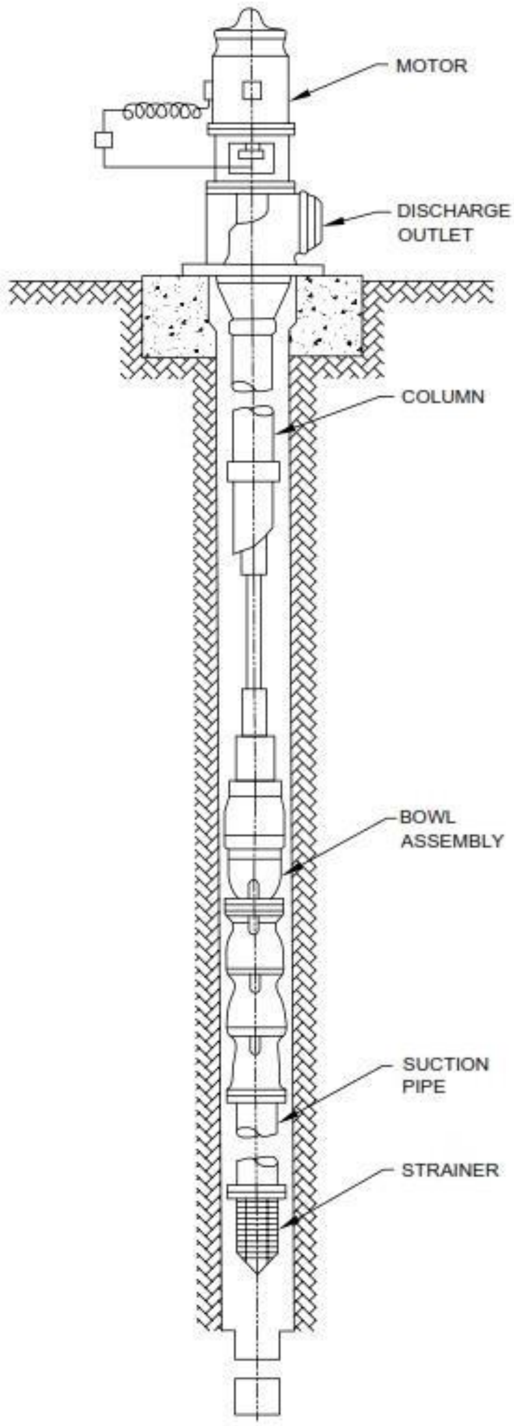


Figure 9.3: Vertical Turbine Pump

c) Vertical Turbine Pump (of low and medium specific speed)

(i) Close delivery valve, and then loosen slightly.

(ii) If the pump is oil-lubricated, check the oil in the oil tank and open the cock to ensure that oil is flowing at the rate of 2–4 drops per minute.

(iii) If the pump is self-water-lubricated and the length of column assembly is long (15 m or above), external water shall be admitted to wet and lubricate the line shaft bearings before starting the pump.

(iv) If the pump is external clear water lubricated, the clear water lubricating pump should be started before starting the main pump.

(v) Open the air vent in the discharge/delivery pipe.
(vi) Switch on the motor and check the correctness of the direction of rotation. If the pump does not rotate or direction of rotation is incorrect, it should be switched off immediately and corrective action taken.
(vii) Check that oil is flowing into the column pipes of the pump through the sight glass tube. The number of drops/min. should be as per the manufacturer's recommendations (normally 2–4 drops/minute).
(viii) For a clear water lubricated pump, check that clear lubricating water is passing into the column assembly.
(ix) Check pressure gauge reading to ensure that the pump has built up the required shut-off head.
(x) When the motor attains a steady speed, and the pressure gauge becomes steady, the delivery valve should be gradually opened in steps to ensure that the head does not drop below-recommended limit. (In absence of recommendation, the limit shall be about 75% of duty head for VT and submersible pump).
(xi) If a steady water stream is let out through an air vent, close the air vent.
(xii) Check that the ammeter reading is less than the rated motor current.
(xiii) Check for undue vibration and noise.
(xiv) When in operation for about 10–15 minutes, check bearing temperature, stuffing box packing, and observe vibration, if any.
(xv) Voltage should be checked every half an hour and should be within the limit. Figure 9.3 shows Vertical Turbine Pump.

d) Vertical Turbine (Axial flow) Pump (of High specific speed)

As the shut-off power of axial flow pumps are higher than power at BEP, such pump should be started with open delivery valve, so as not to overload the motor during starting. Such type of pump should not be operated in parallel and individual delivery should be extended to discharging point.

e) Submersible Pump

Starting of a submersible pump is similar to a vertical turbine pump except that step (ii) is not applicable. Since the motor is not visible, the correctness of the direction of rotation is judged from a pressure gauge reading which should indicate the correct shut-off head.

f) Jet Pump

The procedure for starting jet pumps is similar to centrifugal pumps, except that priming by vacuum pump is not possible. Priming needs to be done by filling the pump casing and suction line from an external source or by pouring water.

g) Vacuum Pump

The procedure for starting a vacuum pump is similar to a centrifugal pump, except that priming is not necessary, and valves on both the suction and delivery side of the vacuum pump should be fully open.

h) Reciprocating Pump

The steps stipulated for the centrifugal pump are equally applicable to the reciprocating pump. However, exceptions, as follows, are applicable:

- The pump should be started against a partially open delivery valve.

- The pump should never be started or operated against a closed delivery valve.

9.2.7 Stopping the Pump

9.2.7.1 Stopping the Pump Under Normal Condition

A. Centrifugal and VT pumps of Low/Medium Specific Speed and Submersible Pump

Steps to be followed for stopping a pump of low and medium specific speed are as follows:

(i) Close the delivery valve gradually (sudden or fast closing should not be resorted to, which can give rise to water hammer pressures).
(ii) Switch off the motor.
(iii) Open the air vent in case of V.T. and submersible pump.
(iv) Stop lubricating oil or clear water supply in case of oil lubricated or clear water lubricated VT pump as applicable.

B. Centrifugal and VT Pumps of High Specific Speed (Axial Flow Pumps)

As the shut-off power of Axial flow pumps are higher than power at BEP, such pump should be stopped with open delivery valve, so as not to overload the motor during stopping.

C. Reciprocating Pump

Steps to be followed for stopping a reciprocating pump are as follows:

(i) Close the delivery valve gradually but keep it partially open.
(ii) Switch off the motor.
(iii) Check and stop lubricating oil.

9.2.7.2 Stopping After Power Failure/Tripping

If the power supply to the pumping station fails or trips, the actions stated below should be immediately taken to ensure that the pumps do not restart automatically on resumption of power supply. Though no-volt release or undervoltage relay is provided in the starter and breaker, the possibility of its malfunctioning and failure to open the circuit cannot be ruled out. In such eventuality, if the pumps start automatically on resumption of power supply, there will be a sudden increase in flow velocity in the pumping main, causing a sudden rise in pressure due to the water hammer, which may prove disastrous to the pumping main. Secondly, due to sudden acceleration of flow in the pumping main from the no-flow situation, the acceleration head will be very high, and the pumps shall operate near shut off region during the acceleration period, which may last for a few minutes for long pumping main and cause overheating of the pump. Restarting all pumps simultaneously shall also cause overloading of the electrical system.

Hence, precautions are necessary to prevent auto-restarting on resumption of power. The following procedure should be followed.

(i) Close all delivery valves on delivery piping of pumps, if necessary, manually as actuators cannot be operated due to non-availability of power.
(ii) Check and ensure that all switches, breakers and starters are in open condition, i.e., off-position.
(iii) Open air vent in case of V.T. or submersible pump and close lubricating oil or clear

water supply in case of oil lubricated or clear water lubricated V.T. pump.

(iv) Information about power failure should be provided to all concerned, particularly to upstream pumping stations, to stop pumping to prevent overflow.

9.2.8 Solar Pumps

Solar-powered water supply schemes will have fewer breakdowns and much less intensive maintenance than generator or electricity-driven schemes.

Issues in a solar pump can be identified by following change in their working:

1. The pump is making unusual noises.
2. Change in the rate of pumping.
3. The system is pumping less water, even though the solar panels are clean.

Maintenance of Solar Pumps:

1. Check the references of all components of the system to ensure that the installed components are those provided in the design.
2. Examine the orientation and inclination of the panels, as well as shadow the Solar PV generator. The orientation and inclination values must be close to those calculated during the sizing calculation. The allowable variances will be less than 5° for the inclination and 15° for the geographic North-South orientation.

Figure 9.4: Cleaning of Panels

3. Check the cleanliness and protection of the wiring and its compliance with the standards.
4. Inspect the civil works (castle, basin, trough, solar supports, etc.), pipelines, valves, and all other vital elements that could jeopardise the system's performance.
5. Clean the panels on a regular basis to eliminate collected dust and other debris such as bird droppings. This increases the rate of pumping. A gentle sponge and water should be used to clean. SOAP SHOULD NOT BE USED. Cleaning should be done more frequently during the dry season. Cleaning of Panels at a site is shown in Figure 9.4.

9.3 Preventive Maintenance of Pumping Machinery

Lack of preventive and timely maintenance or poor maintenance can cause undue wear and tear of fast-moving parts, and premature failure of the equipment. Such premature failure or breakdown causes immense hardship to the consumers and staff, and avoidable increase in repair cost. The shortcomings in maintenance can also result in increase in hydraulic and power losses and low efficiency. Inefficient running of the pump increases burden of power cost. Importance of preventive maintenance, therefore, need not be overstressed.

Appropriate maintenance schedule and procedure need to be prescribed for all electrical and mechanical equipment based on manufacturers' recommendations, characteristics of the equipment, site and environment conditions i.e., temperature, humidity, dust condition, etc. The maintenance schedule also needs to be reviewed and revised in the light of experience and analysis of failures and breakdown at the pumping station. The preventive maintenance schedule shall detail the maintenance to be carried out at regular intervals i.e., daily, monthly, quarterly, half yearly, yearly etc. or operation hours. The schedule shall also include inspections and tests to be performed at appropriate interval or periodicity.

General guidelines for maintenance schedules for pumps and associated electrical and mechanical equipment are enlisted below. The guidelines should not be considered as total, full-fledged and comprehensive as characteristics of equipment and site conditions differ from place to place. For example, in dust laden environment or places where occurrence of storms is frequent, blowing of dust in motor, renewal of oil and grease in bearing shall have to be done at lesser intervals than specified in general guideline.

1. **Check Water Seal and Packing Glands for Leakage** – See that the packing box is protected, with a clear water supply from the outside source; make sure that water seal pressure is at least 3 m or 0.3 kg/cm^2 greater than the maximum pump discharge pressure. Allow a slight seal leakage when pumps are running to keep them cool and in good condition. Sixty drops of water per minute is a good rule of thumb. If serious leakage continues, renew the packing shaft or shaft sleeve.
2. **Check Grease in Sealed Packing Glands** – When grease is used as packing gland seal, maintain constant grease pressure on packing during operation. When a spring-loaded grease cup is used, keep it loaded with grease.
3. **Operate Pumps Alternately** – If two or more pumps of the same size are installed, alternate use to minimise their wear, keep motor windings dry and distribute lubricant in bearing.
4. **Inspect Pump Assembly** – Check floats control, noting how they respond to rising water.
5. **Check Motor Condition.**
6. **Clean Pump** – First lock out power and tag switch. Clean-out hand holes are provided on the pump volute. To clean the pump, close all valves. Then drain the pump and remove all solids.
7. **Check Packing Gland Assembly** – Packing gland assembly is the unit's most abused and troublesome part. Remove the packing and thoroughly inspect the shaft sleeve if the stuffing box leaks significantly when the gland is pulled up with mild pressure. If grease sealing is used, completely fill the lantern ring with grease before putting the remaining rings of packing in place.
8. **Check Mechanical Seals** – Mechanical seals usually consist of two sub- assemblies:
   - a rotating ring assembly;
   - a stationary assembly.

   If any part of the seal needs replacing, replace the entire seal.
9. **Inspect and Lubricate Bearings** – Unless otherwise specifically directed for a particular pump model, drain lubricant and wash out oil wells and bearings with solvent.
10. **Check Operating Temperatures of Bearings** – Check bearing temperature with the thermometer, not by hand. If anti-friction bearings are running hot, check for over-greasing and relieve, if necessary. If the sleeve bearings run too hot, check for lack of lubricant agent.
11. **Check Alignment of Pump and Motor** – If misalignment frequently occurs, inspect the piping system. Vertical pumps usually have flexible shafting, which permits slight angular misalignment. However, if solid shafting is used, align exactly.
12. **Inspect and Service Pumps –**
    - Remove the rotating element of the pump and inspect thoroughly for wear.

- Remove deposits or scales, if any. Clean out the water seal piping.

13. **Check wearing ring clearance** – Examine the wearing rings. Replace the seriously worn wearing rings to improve efficiency. Also, check the wearing rings for clearance. Refer to Table 9.3 for wearing ring clearance.

9.3.1 Maintenance of Pumps

9.3.1.1 Daily Observations and Maintenance

(a) **Daily Maintenance**

- Clean the pump, motor, and other accessories.
- Check stuffing box, gland, etc.

(b) **Routine observations of irregularities**

The pump operator should be watchful and should take appropriate action on any irregularity noticed in the operation of the pumps. Particular attention should be paid to the following irregularities.

(i) Changes in sound of running pump and motor
(ii) Abrupt changes in bearing temperature
(iii) Oil leakage from bearings
(iv) Leakage from stuffing box or mechanical seal
(v) Changes in voltage
(vi) Changes in current
(vii) Changes in vacuum gauge and pressure gauge readings
(viii) Sparks or leakage current in motor, starter, switchgears, cable, etc.
(ix) Overheating of motor, starter, switchgear, cable, etc.

(c) **Record of operations and observations**

A logbook should be maintained to record the hourly observations, which should cover the following items:

i) Timings when the pumps are started, operated, and stopped during 24 hours.
ii) Voltage in all three phases.
iii) Current drawn by each pump-motor set and total current drawn at the installation.
iv) Frequency.
v) Readings of vacuum and pressure gauges.
vi) Motor winding temperature.
vii) Bearing temperature for pump and motor.
viii) Water level in intake/sump.
ix) Flowmeter reading.
x) Daily Power Factor (PF) over 24 hours duration. Power factor is an expression of energy efficiency. Power factor (PF) is the ratio of working power, measured in kilowatts (kW), to apparent power, measured in kilovolt amperes (kVA). Apparent power, also known as demand, is the measure of the amount of power used to run

machinery and equipment during a certain period. It is found by multiplying (kVA = V × A). The result is expressed as kVA units. It is usually expressed as a percentage—and the lower the percentage, the less efficient power usage is. A 96% power factor demonstrates more efficiency than a 75% power factor. PF below 95% is generally considered inefficient.

xi) Any specific problem or event in the pumping installation or pumping system, e.g., burst in pipeline, tripping or fault, power failure. The typical pumping station operation log is shown in Table 9.2:

Table 9.2: Typical Pumping Station Operation Log

Typical Pumping Station Operating Log				
Date:				
Operators:				
Pump Unit No	No-1	No-2	No-3	Remarks
Motor Start Time				
Motor Stop Time				
Motor Reading				
Voltage				
Amps				
Hours run				

9.3.1.2 Monthly Maintenance

i) Check free movement of the gland of the stuffing box; check gland packing and replace if necessary.
ii) Clean and apply oil to the gland bolts.
iii) Inspect the mechanical seal for wear and replacement if necessary.
iv) Check the condition of bearing oil/grease and replace or top up if necessary.
v) Check coupling bushes/rubber spider.

9.3.1.3 Quarterly Maintenance

i) Check alignment of the pump and the drive. The pump and motor shall be decoupled while correcting alignment, and both pump and motor shafts shall be pushed to either side to eliminate the effect of end play in bearings.
ii) Clean oil lubricated bearings and replenish them with fresh oil. If bearings are grease lubricated, the condition of the grease should be checked and replaced/ replenished to the correct quantity. An anti-friction bearing should have its housing so packed with grease that the void space in the bearing housing should be within one-third to half. A fully packed housing will overheat the bearing and will result in the reduction of life of the bearing.
iii) Tighten the foundation bolts and hold down bolts of the pump and motor mounting on the base plate or frame.
iv) Check vibration level with instruments if available; otherwise, by observation.
v) Clean flow indicator, other instruments, and appurtenances in the pump house.

9.3.1.4 Annual Inspections and Maintenance

A very thorough, critical inspection and maintenance should be performed once a year. The following items should be specifically attended to:

i. Clean and flush bearings with kerosene/solvent and examine for flaws developed, if any, e.g., corrosion, wear, and scratches. Check end play. Immediately after cleaning, the bearings should be coated with oil or grease to prevent the ingress of dirt or moisture.
ii. Clean bearing housing and examine for flaws, e.g., wear, grooving, etc. Change oil or grease in bearing housing.
iii. Examine shaft sleeves for wear or scour and necessary rectification. If shaft sleeves are not used, shaft at gland packings should be examined for wear.
iv. Check stuffing box, glands, lantern ring, mechanical seal, and rectify, if necessary.
v. Check clearances in wearing ring.

Clearances at the wearing rings should be within the limits recommended by the manufacturer or clearances given in Table 9.3. Excessive clearance reduces the discharge and efficiency of the pump. If the wear is only on one side, it is indicative of misalignment. The misalignment should be set right, and the causes of misalignment should be investigated. General guidelines given in Table below, shall be followed when the clearances have to be restored. Normally, if the clearance in wearing rings increases by about 100% for small pumps and 50-75% for large pumps, the rings shall be renewed or replaced to restore to the original clearance. Wearing ring clearances should also be restored if pump discharge reduces beyond 5%–7%.

The tolerances given in the table are to be strictly followed. For example, while machining the internal diameter of the casing wearing ring of basic size, say 175 mm, the limits for machining would be 175.00 mm minimum and 175.05 mm maximum. For the corresponding outer diameter at the hub of the impeller or impeller ring, the basic size will be with a clearance of 0.4 mm, i.e., 174.60 mm, and the machining limits will be 174.60 mm maximum and 174.55 mm minimum.

Table 9.3: Wearing Ring Diametral Clearance and Tolerance

Inside diameter of wearing ring (mm)	Diametral clearance (mm)	Machining Tolerance (mm)
Up to 100	0.30	0.050
101–150	0.35	
151–200	0.40	
201–300	0.45	0.075
301–500	0.50	
501–750	0.55	
751–1200	0.65	0.100
1201–2000	0.75	0.125

Taking into consideration that part dismantling of the pump is involved in checking wearing ring clearance, and as it is not advisable to dismantle vertical turbine pump every year, the frequency for checking wearing ring in case of V.T. pump shall be once in two years or earlier if discharge test indicates discharge reduction beyond the limit of 5%–7%.

i. Check impeller hubs and vane tips for any pitting or erosion.
ii. Check the interior of the volute, casing, and diffuser for pitting, erosion, and rough surface.
iii. All vital instruments, i.e., pressure gauge, vacuum gauge, ammeter, voltmeter, wattmeters, frequency meter, tachometer, flowmeter, etc., shall be calibrated.
iv. Conduct performance tests of the pump for discharge, head, and efficiency.

v. Measures for preventing ingress of flood water shall be examined. Ingress of flood water in the sump, well, tube well, or bore well shall be strictly prevented. Seal cap shall be provided above tube well/bore well.
vi. Check vibration level.

Inspection reports should be prepared for each water pumping station according to the equipment installed. A format for annual inspection report for the pumping station is shown in **Annexure 9.1**.

9.3.1.5 Overhaul of Pump

It is difficult to specify the periodicity or interval for an overhaul in the form of a period of service in months/years or operation hours, as deterioration of pump depends on nature of service, type of installation, i.e., wet-pit or dry-pit, quality of water handled, quality of the material of construction, maintenance, experience with particular make and type of pump, etc.

However, following operational hours may generally be taken as broad guidelines for overhauling.

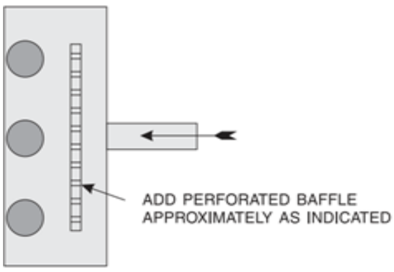
- Submersible pump – 5000–6000 hours
- Vertical turbine pump – 12000 hours
- Centrifugal pump – 15000 hours

9.3.1.6 Long Column Pipes in VT Pump

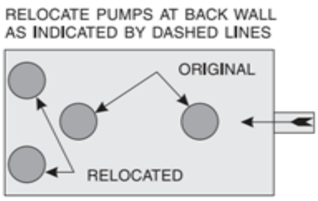
Very long column pipes in VT pump at river intake or intake well-constructed in an impounded reservoir are required to be provided due to large fluctuations in water level from minimum water level in summer to the high-water level in monsoons. Such long column pipes (if the length exceeds about 15 m) are usually because of the problem of fast wearing of line- shafts bearings in case of water lubricated pumps. Such longer suspended assembly is also more prone to rotation or swinging of column assembly due to vortices.

Precautionary measures as follows may be taken.

(a) **Prevention of premature wear of water lubricated bearings in column pipes**: Water lubricated bearings are usually made of rubber or neoprene and wear fast if dry running occurs during starting of VT pumps. Therefore, to avoid dry running, water is admitted from an external source (usually a tank near the pump provided for the purpose) into the column pipe for about 3–4 minutes so as to wet the bearing before starting the pump.
(b) **Preventing rotation or swinging in column assembly due to vortex phenomenon**: A cone, as shown in Figure 9.5 (c), or splitter, as shown in Figure 9.5 (g), shall be provided underneath the bell mouth.



(a)



(b)

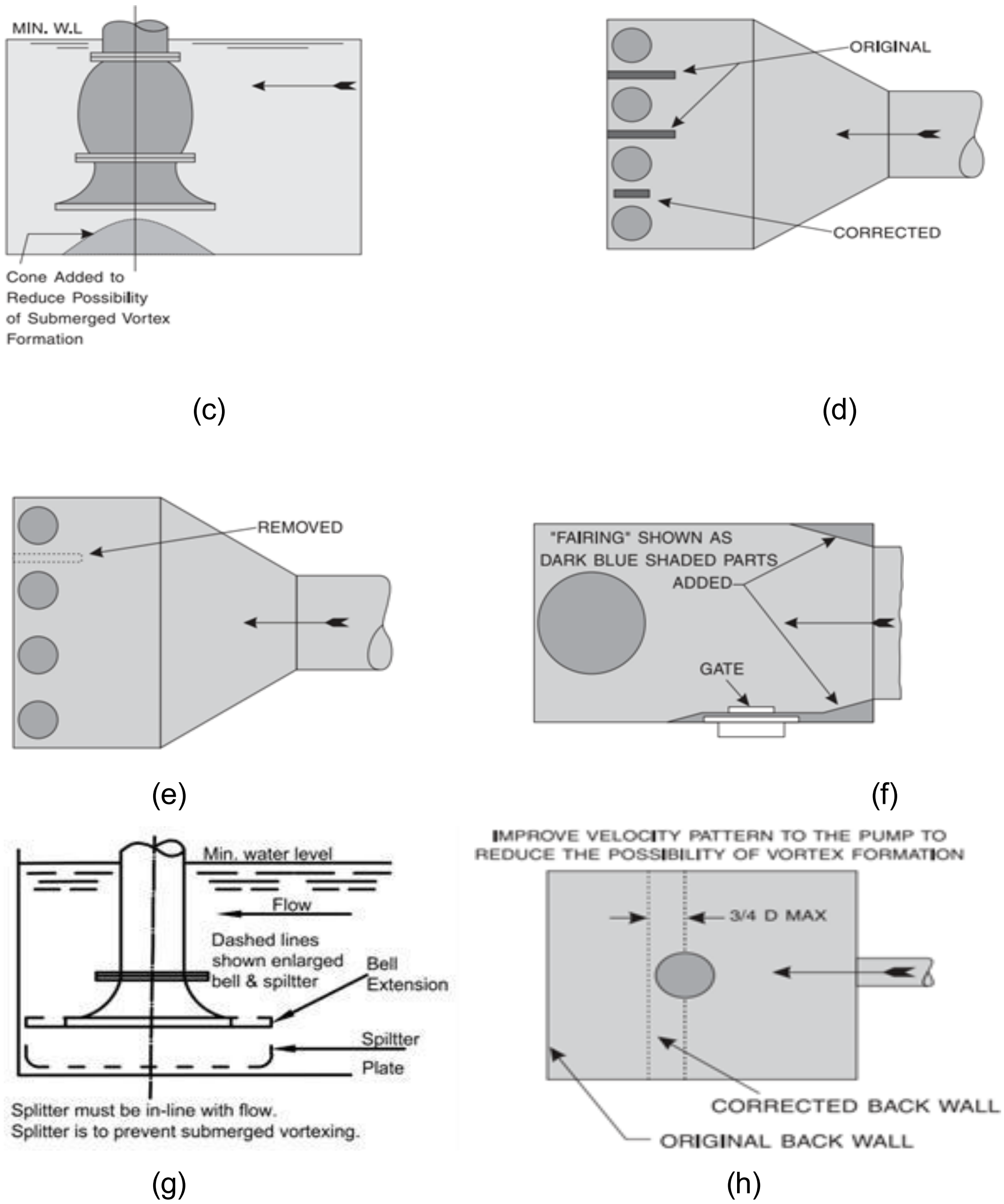


Figure 9.5: Remedial Measures for Vortex-Free Operation in Existing Sumps

Under no circumstances the column assembly be tied or fixed at any point other than the discharge head from which it is suspended, as such measure shall result in misalignment.

9.3.1.7 Sludge Water/Filter Wash Recirculation Pump

Due attention should be paid to the proper selection of the pump and material of construction to avoid operational problems and premature wear due to abrasive material in pumped water. The impeller should, preferably be of stainless steel of grade CF 8 M and wearing ring of CF 8. The pump should preferably be VT type.

9.3.1.8 Hydraulic Condition in Centrifugal Pump

Due attention should be paid while operation that *Net Positive Suction Head Available* (NPSHa) exceed the pump's *Net Positive Suction Head Required* (NPSHr) parameter for the chosen operating conditions to ensure that cavitation is avoided. The sub parts of Section 5.7 of Chapter

5: Pumping Stations and Pumping Machinery of Part A of this manual may be referred where this has been discussed in detail.

NPSH is defined as the total head of fluid at the centre line of the impeller less the fluid's vapour pressure. The purpose of NPSH is to identify and avoid the operating conditions which lead to vaporisation of the fluid as it enters the pump – termed as *flashing*. In a centrifugal pump, the fluid's pressure is at a minimum at the eye of the impeller. If the pressure here is below the vapour pressure of the fluid, bubbles are formed which pass on through the impeller vanes towards the discharge port. As the bubbles of vapour are transported into this higher-pressure region, they can spontaneously collapse in a damaging process called *cavitation*. The repeated shock waves produced by this process can be a significant cause of wear and metal fatigue on impellers and pump casings.

NPSHr is quoted by pump manufacturers, which is a minimum suction pressure that must be exceeded for the pump to operate correctly and minimise flashing and cavitation. NPSHa is calculated from the suction-side system configuration. It is essentially the suction-side pressure less the vapour pressure of the pumped fluid at that point. Normally, a safety margin of 0.5 to 1 m is required to take into account the following:

- changes in the weather (temperature and atmospheric pressure);
- any increases in friction losses that may occur occasionally or gradually during the lifetime of the system.

The following actions should be taken to rectify:

- Assess the depletion in water level in tank/ sump.
- Clean clogged filters or strainers.
- Clear blockage in the pipe.
- Ensure that the pump is not running too far right on the pump curve.

9.3.1.9 History Sheet

The history sheet of all pumps shall be maintained. The history sheet shall contain all important particulars and records of all maintenance, repairs, inspections, tests, etc. It shall generally include the following.

i. Details of the pump, rating, model, characteristic curves, performance test report, etc.
ii. Addresses of manufacturer and dealer with phone and fax numbers and e-mail addresses.
iii. Date of installation and commissioning.
iv. Brief details and observations of monthly, quarterly, and annual maintenance and inspections.
v. Details of breakdown, repairs with fault diagnosis, replacement of major components, i.e., impeller, shaft, bearings, wearing rings.
vi. Results of annual performance test including discharge and efficiency.
vii. Yearly operation hours of the pumps.
viii. Brief findings of the energy audit.

9.3.1.10 Thermal Imaging

Thermal imaging as preventive maintenance over time allows for detecting any unusual condition for further inspections. This, in turn, reduces any unusual break in service due to equipment failure, reduces the expenditure on the repair of equipment, and extends the lifespan of the equipment. Blown fuses are a good example of such a situation.

A. Inspecting Pump/Motor Bearings

The motor housing with several motor bearings is worn out and produces heat as time passes. The readings are recorded and compared with the database of readings. The bearing is replaced or lubricated when the thermal images indicate an overheated bearing, which reduces the possibility of costly assembly failure.

B. Spotting Leakage in Seals and Gaskets

Similar to the above, a leakage will show a large change in temperature along the seal or gasket, indicating a loss of heat.

9.3.2 Maintenance Schedule for Motors

9.3.2.1 Daily Maintenance

(i) Clean the external surface of the motor. Cleaning terminal boxes attached to motors are recommended. Their terminals should be free of oxidation and in fine mechanical condition, with no dust in any vacant space.

(ii) Examine earth connections and motor leads.

(iii) Check the temperature of the motor and check whether it is overheated. If the permissible maximum temperature is above the level, then temperature observation should be taken with Resistance thermometers, or thermal imager. (Note: In order to avoid opening up motors, a good practice is to observe the stator temperature under normal working conditions. Any increase not accounted for by a seasonal increase in ambient temperature should be suspected).

(iv) In the case of oil ring lubricated bearing.

- Examine bearings to check whether oil rings are working or not.
- Note bearing temperature. Add oil if necessary.
- Noise and vibration in the bearings signal potential problems such as insufficient lubrication, dirt accumulation, and wear and tear.

9.3.2.2 Monthly Maintenance

(i) Check belt tension. In case this is excessive, it should immediately be reduced.

(ii) Blow dust from the motor.

(iii) Examine oil/grease for contamination by dust, grit, etc. (this can be judged from the colour of the oil).

(iv) Check functioning and connections of anti-condensation heater (space heater).

(v) Check insulation resistance by meggering (Megger is an electrical instrument that is used for testing insulation resistance and machine windings to safeguard all electrical equipment from major damage).

9.3.2.3 Quarterly Maintenance

(i) Clean oil lubricated bearings and replenish fresh oil. If bearings are grease lubricated, the condition of the grease should be checked and replaced/replenished in sufficient quantity. An anti-friction bearing should have its housing so packed with grease that the void space in the bearing housing should be within one-third to half. A fully packed housing will overheat the bearing and will result in the reduction of life of the bearing.

(ii) Wipe brush holders and check the contact faces of brushes of slip-ring motors. If the contact face is not smooth or is irregular, file it for proper and full contact over slip rings.

(iii) Check insulation resistance of the motor.

(iv) Check the tightness of the cable gland, lug, and connecting bolts.

(v) Check and tighten foundation bolts and hold down bolts between motor and frame.

(vi) Check vibration level with the instrument if available; otherwise, by observation.

9.3.2.4 Half Yearly Maintenance

(i) Clean winding of the motor, bake and varnish if necessary.

(ii) In case of slip ring motors, check slip rings for grooving or unusual wear, and polish with the smooth polish paper if necessary.

9.3.2.5 Annual Inspections and Maintenance

(i) Clean and flush bearings with kerosene/solvent and examine for flaws developed, if any, e.g., wear and scratches. Check endplay. Immediately after cleaning, the bearings should be coated with oil or grease to prevent the ingress of dirt or moisture.

(ii) Clean bearing housing and examine for flaws, e.g., wear, grooving, etc. Change oil or grease in bearing housing.

(iii) Blow out dust from windings of motors thoroughly with clean, dry air. Ensure the pressure is not so high as to damage the insulation.

(iv) Clean and varnish dirty and oily windings. Revarnish motors are subjected to severe operating and environmental conditions, e.g., operation in a dust-laden environment, polluted atmosphere, etc.

(v) Check the condition of the stator, stamping, insulation, terminal box, fan, etc.

(vi) Check insulation resistance to earth and between phases of motors windings, control gear, and wiring.

(vii) Check air gaps.

(viii) Check resistance of earth connections.

9.3.2.6 History Sheet of Motor

Similar to the history sheet of the pump, the history sheet of the motor should be maintained. The history sheet should contain all important particulars, records of periodical maintenance, repairs, inspections, and tests. It shall generally include the following:

(i) details of motor, rating, model, class of duty, class of insulation, efficiency curve, type test result, type test certificate, etc.;

(ii) date of installation and commissioning;

(iii) addresses of manufacturer and dealer with phone and fax numbers and e-mail addresses;

(iv) brief details of monthly, quarterly, half yearly, and annual maintenance and observations of inspections about insulation level, air gap, etc.;

(v) details of breakdown and repairs with fault diagnosis;

(vi) running hours at the time of major repairs.

9.3.3 Miscellaneous O&M Aspects

9.3.3.1 Lubrication

Pumps, motors, and drives should be oiled and greased in strict accordance with the recommendation of the manufacturers.

9.3.3.2 Mechanical Seals

Mechanical seals serve the same purpose as packing, i.e., these prevent leakage between the pump casing and shaft.

9.3.3.3 Bearings

Pump bearings usually last for years if serviced/maintained properly and used in their proper application. Several types of bearings are used in pumps, such as ball bearings, roller bearings, and sleeve bearings. The type of bearing used in each pump depends on the manufacturing design and application.

Bearing failure may be caused by:

a. Fatigue failure
b. Contamination
c. Brinelling
d. False brinelling
e. Thrust failures
f. Misalignment
g. Electric sparking
h. Lubrication failure
i. Cam failure

9.3.4 Valves

The following five types of valves are generally used in pumping installations:

a) Foot valve. {IS 4038 (1986, Reaffirmed 2020) Specification for Foot Valves for Water Works Purposes covers requirements for flanged and screwed end foot valves of both swing and lift type for use with centrifugal pumps for water works purposes. It covers screwed end valves from 25 to 150 mm nominal sizes ‘and flanged end valves from 50 to 450 mm nominal sizes.}
b) Sluice valve and Knife gate valve. { IS 14846 (2000, Reaffirmed 2020): Sluice Valve for Water Works Purposes (50 mm to 1200 mm Size) covers requirements for non-rising stem type sluice valves from 50 to 1200 mm sizes used for water supply up to 45°C and having double flanged ends for connections; and IS : 778 (1984, Reaffirmed 2020) Indian Standard Specification For Copper Alloy Gate, Globe And Check Valves for Waterworks Purposes covers requirements of copper alloy gate, globe and check valves of nominal sizes 8 to 100 mm suitable for working temperatures up to 45ºC and non-shock working pressure up to 1·6 MPa (16 kg/cm^2), for waterworks purposes.}
c) Reflux (non-return) valve {(a) IS 5312-1 (2004): Swing Check Type Reflux (Non-Return] Valves for Water Works Purposes, Part 1: Single-Door Pattern covers requirement for flanged reflux valves of single door, swing check type used for water works purposes of

sizes 50 to 600 mm, Double disc check and lift check valves are not covered under the scope of this standard; and (b) IS 5312-2 (2013, Reaffirmed 2018):Swing Check Type Reflux (non- return)Valves for Water Works Purpose, Part 2: Multi-Door Pattern covers requirements for flanged reflux valves of multi-door, swing check type used for water works purpose of sizes from 400 mm to 1200 mm.

d) Dual Plate Check Valve (DPCV)

e) Butterfly valve. {IS 13095: 2020): Butterfly valves for general purposes covers double flanged and wafer type of metal seated, resilient seated cast iron, ductile iron and carbon steel and lined butterfly valves for general purposes. Valves covered under this standard are manually, pneumatically, hydraulically or electrically operated.}

Maintenance shall be carried out for various types of valves as follows:

a) **Foot Valve**

These valves include a suction strainer to prevent extraneous items from entering the suction line and blocking it or damaging the water pump.

- Clean foot valve once in 1–3 months, depending on the ingress of floating matters.
- The clean flap of the foot valve once in 2 months to ensure leak-proof operation.
- Inspect the valve thoroughly once a year. Check for leakage through the foot valve after priming and observing the level in the volute casing.
- The valve should always be checked for corrosion. Signs of corrosion can lead to the valve malfunctioning or leaking. This may cause a lot of damage to the entire pumping system.

b) **Sluice valve and Knife gate valve**

- Check gland packing of the valve at least once a month. It should be ensured that packings inside the stuffing box are in good trim and impregnated with grease. Changing the packing as often as necessary may ensure that the leakage is within the limit.
- Grease should be applied to reduction gears and grease lubricated thrust bearing once in three months.
- Check tight closure of the valve once in 3 months.
- A valve normally kept open or closed should be operated once every three months to the full travel of the gate, and any jamming developed due to long non-use shall be freed.
- Inspect the valve thoroughly for flaws in the guide channel, guide lugs, spindle, spindle nut, stuffing box, etc., once a year.
- Important DON'T for a valve is that it should never be operated with an oversize hand wheel or cap or spanner as this practice may result in rounding of square top, and hand wheel or cap or spanner may eventually slip.
- An important DON'T for a valve is that it should never be operated under throttled, i.e., partially open condition, since such operation may result in undue chatter, wear, and failure of the valve spindle.

c) **Reflux (non-return) valve**

- Check proper operation of the hinged door and tight closure under no-flow conditions once in 3 months.
- The valves should be checked for:
  - leakage;

- signs of corrosion and rust;
- opening and closing of valves to make sure these are not seizing;
- ensuring these are not close to or over the rated limit for the valve.

- The valve shall be thoroughly inspected annually. Particular attention should be paid to hinges and pins and the soundness of the hinged door.
- Condition of dampening arrangement should be thoroughly examined once a year, and necessary maintenance and rectification as per manufacturers' instructions shall be carried out.
- In case of dampening arrangement, check for oil leakage and replace oil once a year.
- The valve should be properly lubricated with a specified lubricant.

d) **Dual Plate Check Valve (DPCV)**

- Check for body damage or any external leakage through the body wall.
- Check that the valve gasket faces are not damaged.
- Check that the disc movement is not restricted.
- Check that there are no gouge marks on the hinge pin or disc from the spring component.
- Inspect the body and disc seating surfaces to ensure no gouges or scratches.
- Check there is no damage to the spring bearing component.
- For safety considerations, check the body wall thickness once a year.

e) **Butterfly valve**

- Check seal ring and tight shut-off once in 3 months.
- Lubricate gearing arrangement and bearing once in 3 months.
- Inspect the valve thoroughly, including complete operations once a year.
- Change oil or grease in gearing arrangements once a year.

f) **General**

- Operate bypass valve wherever provided once in 3 months.
- Flange adapter/dismantling joint provided with valve shall be loosened and retightened once in 6 months to avoid sticking.

9.3.5 Valve Actuators

A valve actuator is a mechanical device that uses a power source to operate a valve. This power source can be electric, pneumatic (compressed air), or hydraulic (the flow of oil). There are two main types of valve actuators, they are rotary and linear.

Rotary Valve Actuators

As the name implies, rotary valve actuators produce the rotational motion needed to operate rotary valves such as ball, plug, and butterfly valves. Rotary actuators are available in many different styles, each with its own benefits.

Linear Valve Actuators

Linear valves such as globe, gate, and pinch valves – due to their distinctly different operation – require actuators that are drastically different from the rotary type. These actuators must produce linear motion to operate the valve. They are also available in many styles. For linear valves such as gate and globe valves, the linear motion is achieved directly. Air is used to push the "rising stem" up and down. There are two main styles of linear actuators, they are diaphragm and cylinder (or piston). Both of these styles are also available as spring return or double acting.

The maintenance of the actuator is necessary to:

- Increase the reliability of actuators in use;
- Detect faults before they cause harm to the actuator or impair its operability;
- Reduce overall maintenance costs;
- Allow possibility of making minor repairs, lowering the likelihood of catastrophic shutdowns. Large repairs should be scheduled at convenient times.

9.3.5.1 Quarterly Maintenance

- Declutch and operate a manual hand wheel.
- Check oil level and top up if required.
- Regrease the grease lubricated bearing and gear trains as applicable.
- Check insulation resistance of the motor.
- Check for undue noise and vibration and take necessary rectification measures.
- Tighten limit switch cams and check for settings and readjust if necessary.

9.3.5.2 Annual Inspections and Maintenance

- Examine all components and wiring thoroughly and rectify as necessary.
- Change oil or grease in the gearbox and thrust bearing.
- Check the condition of gears and replace gears if teeth are worn out.

9.3.5.3 L.T. Starters, Breakers, and Panel

Note: Circuit diagram of starter/breaker should be pasted on the door of switch gear, and an additional copy should be kept on record.

(i) Daily

- Clean the external surface.
- Check for any spark or leakage current.
- Check for overheating.

(ii) Monthly

- Blow the dust and clean internal components in the panel, breaker, and starter.
- Check and tighten all connections of cable, wires, jumpers, and bus bars. All carbon deposits shall be cleaned.
- Check relay setting.

(iii) Quarterly

- Check all connections as per the circuit diagram.
- Check fixed and moving contacts and clean with the smooth polish paper if necessary.
- Check the oil level and condition of oil in the oil tank. Replace the oil if a carbon deposit in suspension is observed or the colour is black.
- Check insulation resistance.
- Check the condition of insulators.

(iv) Yearly

- Check and service all components, thoroughly clean, and reassemble.
- Calibrate voltmeter, ammeter, frequency meter, etc.

9.3.6 H.T. Breakers, Contactors, and Protection Relays

Note: Circuit diagram of breaker/relay circuit should be pasted on the door of switch gear, and an additional copy should be kept on record.

The maintenance schedule specified for L.T. breakers also applies to H.T. breakers and contactors. In addition, the following important points shall be attended to for H.T. breakers and contactors.

(i) Monthly

- Check spring charging mechanism and manual cranking arrangement for operation.
- Clean all exposed insulators.
- Check trip circuit and alarm circuit.
- Check opening and closing timing of breaker.

(ii) Quarterly

- Check control circuits, including connections in marshalling boxes of breakers and transformers.
- Check oil level in MOCB/LOCB/HT OCB and top up with tested oil.

(iii) Yearly/Two yearly

- Testing of protection relay with D.C. Injection shall be carried out once a year.
- The HT breaker and contactor will be serviced once in 2–3 years.
- Check the dielectric strength of oil in the breaker and replace it if necessary.
- Check male and female contacts for any pitting and measure contact resistance.

9.3.7 Capacitors

9.3.7.1 Pre-requisites for Satisfactory Functioning

Ensure the following points:

(i) A capacitor should be firmly fixed to a base.

(ii) Cable lugs of appropriate size should be used.

(iii) Two spanners should be used to tighten or loosen capacitor terminals. The lower nut should be held by one spanner, and the upper nut should be held by another spanner to avoid damage to or breakage of terminal bushings and leakage of oil.

(iv) To avoid damage to the bushing, a cable gland should always be used and firmly fixed to the cable-entry hole.

(v) The capacitor should always be earthed appropriately at the earthling terminal to avoid accidental charge leakage.

(vi) Every capacitor unit should have a clearance of at least 75 mm on all sides to enable cooler running and maximum thermal stability. Ensure good ventilation and avoid proximity to any heat source.

(vii) While making a bank, the bus bar connecting the capacitors should never be mounted directly on the capacitor terminals. It should be indirectly connected through flexible leads so that the capacitor bushings do not get unduly stressed.

(viii) Ensure that the cables, fuses, and switchgear are of adequate ratings.

9.3.7.2 Operation and Maintenance

(i) The supply voltage at the capacitor bus should always be near the rated voltage, and the fluctuations should not exceed ±10% of the rated voltage of the capacitor.
(ii) Frequent switching of the capacitor should be avoided, and there should always be an interval of about 60 seconds between any two switching operations.
(iii) The discharge resistance efficiency should be assessed periodically by sensing if shorting is required to discharge the capacitor even after one minute of switching off. If the discharge resistance fails to bring down the voltage to 50V in one minute, it must be replaced.
(iv) Leakage or breakage should be rectified immediately. Care should be taken that no appreciable quantity of impregnation has leaked out.
(v) Before physically handling the capacitor, the capacitor terminals shall be shorted one minute after disconnection from the supply to ensure total discharging of the capacitor.
(vi) Replace capacitor if bulging is observed.

The work on the capacitor bank should be done after switching 'OFF' the capacitor bank fully discharging to a safe value with the insulating earthing rod (wait for 5 minutes before handling) and after providing temporary earth which is left intact till the work is finished. Ensure that no hardware or tools are left inside the assembly.

Annual maintenance of capacitors should include:

- Remove dust deposits, clean all parts, and paint metalwork as required.
- Check fuse condition.
- Check the condition of discharge resistors.
- Check contactor condition and operation – replace as necessary.
- Check isolator connections and operation.
- Check operation of PF Controller.
- Check ambient temperature and equipment ventilation.
- The cleaning of the entry grid is to be checked regularly.

The recommended schedule for Inspection and preventive maintenance of the capacitor bank is shown in Table 9.4:

Table 9.4: Recommended Schedule for Inspection and Preventive Maintenance of Capacitor Bank

Equipment/ item whose inspection/ maintenance is required		Points to be checked/ noted and details of maintenance work to be done		Frequency of inspection/ maintenance	Remarks
1		2		3	4
1	**Capacitor Unit**	a.	Check for cracks or bulging of the relay of Capacitor units.	Weekly	
		b.	Check of leakage of form terminals/lid welded seams	Monthly	If necessary, the capacitor unit may be checked by testing (The IR values and charging current should be within acceptable limits). Repairs may be carried out, if possible. Otherwise, it should be removed from the circuit to avoid damage to other healthy units in proximity.
		c.	Terminal bushings I Examine for cracks and other damages II Remove all silt, paint, and other deposits	Monthly	
		d.	Check for general cleanliness	“	Capacitor units should be properly cleaned when the surface condition deteriorates and warrant repainting.
		e	Repaint capacitor units and supporting structures	As and when necessary	
		f.	Check IR values of the capacitor units		The insulation resistance of the capacitor units between bushing to earth shall be checked half yearly with a megger of not less than 500 volts (preferably 2500 V) Output. The other bushings should be shorted during the test. The readings are compared with those taken at the time of commissioning and on previous occasions. For capacitors

Equipment/ item whose inspection/ maintenance is required		Points to be checked/ noted and details of maintenance work to be done		Frequency of inspection/ maintenance	Remarks
1		2		3	4
					designed and manufactured as per IS, the insulating resistance so determined shall not be less than 50 Mega ohms. In case the value measured is less than 50 Mega ohms, the unit should not be put in service. For the capacitors manufactured according to other specifications, the minimum insulation resistance should be as specified in the supplier's technical literature.
		g.	Check charging current	Half Yearly	The current drawn by the unit at a specified voltage-giving LT supply is measured with the help of an ammeter and voltmeter (or AVO meter)
2	**Capacitor fuse (if external fuses are provided).**	Check for continuity and tightness		Weekly	In the case of capacitor unit being protected through external fuses, it should be ensured that the fuses are of proper design and rating and are properly fitted. They should be fitted in such a way as not to cause unnecessary tension at the joint, where the terminal bushing is fitted at the top of the container. Ensure the availability of spare fuses of current ratings.
3	**Capacitor bank, bus bar connections, and rack.**	a) Post-insulation used for the bus for support. Estimate for cracks and other damages. Remove all dirt, Paint. And Other deposits.		Monthly	
		b.) The bus bar should be Checked for tight connections, deformation, and clearances.		Monthly	
		c.) The racks should be checked for		Monthly	

Equipment/ item whose inspection/ maintenance is required		Points to be checked/ noted and details of maintenance work to be done	Frequency of inspection/ maintenance	Remarks
1		2	3	4
		corrosion and dirt.		
		d) Causes for developing hot spots in the system on account of loose jointing, improper equipment sizes are checked, and remedial measures taken.	Monthly	Tighten up all screws and nuts especially electrical connections so that there are no loose contacts. Tighten the bushing terminal nuts just sufficient to make good electrical contacts. Avoid over-tightening as it may result in rotation of the bushing rod and leakages from the soldered bushings due to excessive stress on the soldered joints
		e) Earthing of the capacitor bank Check	Monthly	Adequate earthing of capacitor units/ rack should be ensured. The capacitor unit case should be properly screwed with the supporting channel making good electrical contacts. It should be ensured that the neutral of star-connected capacitors bank is not earthling.
		f) Check the IR Value of the capacitor bank bus	Half Yearly	

9.3.8 Transformer and Transformer Substation

A power transformer necessitates a variety of routine maintenance chores, including measuring and testing various transformer properties.

Following maintenance schedule shall be applicable for transformer and sub-station equipment, e.g., lightning arrestor, A.B. switch, D.O. or horn gap fuse, sub-station earthling system, etc.

9.3.8.1 Daily Observations and Maintenance

(i) Check winding temperature and oil temperature in transformer and record. (For large transformers above 1000 kV, the temperature should be recorded hourly).
(ii) Check leakages through CT/PT unit, transformer tank, and HT/LT bushings.
(iii) Check the colour of the silica gel. If silica gel is of pink colour, change the same by spare charge and reactivate old charge for reuse.
(iv) Leakage of oil from any point of a transformer.

9.3.8.2 Monthly Maintenance

a. The oil level in the oil cup beneath the silica gel breather must be checked once a month. If the transformer oil inside the cup falls below the set level, the oil must be topped up to the appropriate level.
b. For proper breathing action, breathing holes in silica gel breathers should be checked weekly and carefully cleaned if necessary.
c. If the transformer's bushing is filled with oil, the level of oil inside the bushing must be visually verified in the oil gauge to ensure that it matches the intended level. If oil falls below the desired level, it is filled under shutdown conditions.
d. Check relay contacts, cable termination, connections in marshalling box, etc.
e. Check operation of AB switch and DO fuse assembly.
f. Clean radiators free from dust and scales.
g. Pour three to four buckets (six to eight buckets in summer) of water into the earth pit. The frequency of watering shall be increased to once a week in the summer season. The water for earthling shall preferably contain a small amount of salt in the solution.
h. Inspect lightning arrestor and HT/LT bushing for cracks and dirt.

9.3.8.3 Quarterly Maintenance

i. Check dielectric strength of transformer oil and change or filter if necessary.
ii. Check insulation resistance of all equipment in sub-station and continuity of earthlings and earth leads.
iii. Check operation of tap changing switch.

9.3.8.4 Pre-Monsoon and Post-Monsoon Checks and Maintenance

i. The surrounding drain of the pumphouse/substation/control room is clear, and the surface area is even/plane to drain water.
ii. The surrounding of the transformer should be free from bushes for easy access during monsoon.
iii. The marshalling box is closed properly.
iv. Check insulation resistance of transformer.

v. Test transformer oil for dielectric strength, sludge, etc. If necessary, filtration of oil shall be carried out before the monsoon.
vi. Oil shall be tested for dielectric strength after the monsoon.

9.3.8.5 Half Yearly Maintenance

i. Check dielectric strength of transformer oil in CT/PT and filter or change oil if necessary.
ii. Check contact faces of AB switch and DO/HG fuse; apply petroleum jelly or grease to moving components of AB switch.

9.3.8.6 Annual Inspections and Maintenance

i. Measure resistance of earth pit. Resistance shall not exceed 1 ohm.
ii. Check bus bar connections, clean contact faces, and change rusted nut bolts.
iii. Calibrate the protection relay for functioning. Check the relay setting and correct it if necessary.
iv. Ensure that the sub-station area is not water-logged. If required, necessary earth fillings with metal spreading at the top shall be carried out once a year. Check drainage arrangement to prevent water logging in the substation area and cable trenches.
v. Test transformer oil for acidity test.

9.3.8.7 Special Maintenance

i. Painting of transformer tank and steel structure of sub-station equipment shall be carried out after every two years.
ii. The core of the transformer and winding shall be checked after five years for transformers up to 3000 kVA and after 7–10 years for transformers of higher capacity.

9.3.9 Maintenance of SF6 and Air Circuit Breakers

9.3.9.1 General Instructions for Maintenance of SF6 and Air Circuit Breakers

The equipment shall be inspected at regular intervals in line with the general maintenance schedule. The manufacturer’s recommendations shall also be followed. Manufacturer or specialised contractor shall be selected for SF6 breakers and air blast circuit breakers.

9.3.9.2 General Checks/Maintenance Instructions

(i) External cleaning:
The breaker's insulators should be cleansed of salt and dirt/dust deposition and the cleaning interval should be determined by the polluted atmosphere or the frequency specified in the maintenance programme.

(ii) Rust Protection:
The rust stains shall be cleaned with emery paper, and new rust protection shall be painted or sprayed on. As rust protection, grease G or Tectyl 506 is recommended.

(iii) Tightness check:
Every density monitor switch is provided with an alarm contact which gives an electrical signal if abnormal leakage takes place. With the first inspection, the bolted joints on the breaker and operating mechanism shall be tightened up. All wiring joints in the operating

mechanism's terminal blocks must be re-tightened at regular intervals according to the maintenance plan.

(iv) Lubrication

The lubricants recommended by the manufacturer shall be used for lubrication.

9.3.9.3 Treatment of Gaskets and Sealing Surfaces

Whenever any gasket part is opened, it is to be always replaced with a new one.

General:

- Sealing surfaces and O-rings should be sparsely lubricated to achieve a better seal against this surface while also protecting it from corrosion.
- Material for de-greasing and cleaning: *Dichloromethane.*
- Material for greasing of O-ring*: Grease – G*
- Material for greasing of O-ring and nitrate rubber in moving to seal: *Grease – G*
- The material used to remove contact adhesive: *Acetone*
- The material used for rust prevention of untreated or phosphatised steel: *Valvoline Tectyl 506*

9.3.9.4 Treatment of Contact Surfaces

The contacts of the breaker (moving or non-moving) shall be treated according to the following directions.

a) Silvered contact surfaces: Silvered contact surfaces should be cleaned with a soft cloth and solvent (trichloroethane). Steel brushing or grinding is prohibited.
b) Copper surfaces: Copper surfaces should be cleaned using a cloth and solvent (Trichloroethane) or steel brushing – after steel brushing, the surface should always be wiped with a dry cloth/solvent to remove any loose particles and dust.
c) Aluminium surfaces: Aluminium contact surfaces should be cleaned directly with a steel brush or emery cloth. The surface is then cleaned using a dry cloth to remove particles and dust. Following that, a thin layer of Vaseline is applied.

9.3.9.5 Lubrication

Grease - K is applied in a very thin layer to the male contact and puffer cylinder surfaces. The excess grease is carefully removed.

9.3.9.6 Emptying and Re-filling of Gas

i. **Filling of re-generated SF6 gas in the equipment:**

Service devices must be employed to allow maintenance staff to fill regenerated SF6 from storage tanks in SF6-switchgear. Such a device should grant the following criteria:

- oil-free;
- filling pressure which can be pre-set by a pressure reducer;
- easy handling and mobility.

ii. **Evacuation of SF6 gas Circuit Breakers (CBs):**

After maintenance/overhaul of the Circuit Breaker, it should be evacuated by vacuum pump before filling in the SF6 gas, so that SF6 gas does not mix with ambient air, humidity and dust particles. With a vacuum pump, a final vacuum must be reached less than 5 mbar.

9.3.9.7 Dew Point Measurement

The Dew point is the temperature at which moisture in SF6 gas/air begins to condensate.

i. Equipment and test name: Dew Point Measurements SF6 gas/operating air for CBs.
ii. Purpose: To measure the Dew point of SF6 gas and air for EHV class CBs.
iii. Definition:
iv. Isolation Required:
   - CB should be in “open” condition.
   - Isolators on both sides should be in “open” condition.
v. Precautions:
   a) Ensure that PTW is taken as per norms.
   b) The pipe should be of PTEE (Teflon) or have stainless steel tubing (as per IEC-480).
   c) All the joints/connectors should be dust and moisture free. If required, these should be cleaned with a clean cloth. Dry the joints and pipe with dry air.
vi. Maintenance/Testing Procedure
   a) Connect the kit to the CB pole, ensuring that the regulating valve is fully closed when the Dew Point Kit is connected.
   b) Dew point values for rated pressures are to be monitored by adjusting the valve provided at the dew point kit's outlet.
vii. Evaluation of Test Results
   a) Dew Point Measurement of SF6 Gas in CBs:

      The Dew Point of SF6 gas is an adequate measure for condition monitoring of SF6 gas in a CB because it represents the change in the value of SF6 gas's dielectric characteristics.

      Moisture infiltration into SF6 gas occurs from two causes after filling in CB and during O&M:

      - Exudation of moisture from insulation materials used in Circuit Breakers during production.
      - Moisture permeation via sealed areas such as gaskets, O-rings, and so on.
   b) Frequency of Dew Point Measurement:
   c) Moisture from the organic insulating material is discharged faster at first, and the release rate is almost nil after four to five years of commissioning, with moisture entering the CB pole solely by penetration. In the first year, about 50% of the moisture is released; whereas in about four years, 90% of the moisture is released. Monitoring of Dew Point values:

      The Dew Point of SF6 gas varies with the pressure at which measurement is being carried out. This is due to the fact that Saturation Vapor Pressure decreases with the Pressure of the SF6 gas. As a result, at greater pressures, the dew point of SF6 gas is lower than at atmospheric pressure. Below Table 9.5 shows Conversion of Dew Point at Different Gas Pressures.

Table 9.5: Conversion of Dew Point at Different Gas Pressures

S. No.	Make of CB	Dew Point at rated pressure (Min)	Dew point at Atmospheric Pressure (Limit) (Min)	Remarks
1	BHEL	-15° C	-36° C	At the time of commissioning
		-7° C	-29° C	During O&M
		-5° C	-27° C	Critical
2	ABB	-15° C	-35° C	At the time of commissioning
		-5° C	-26° C	During O&M
3	NGEF	-15° C	-36° C	At the time of commissioning
		-7° C	-29° C	During O&M
		-5° C	-27° C	Critical

d) Dew Point Measurement of air in ABCB (Air Blast Circuit Breaker):

Dew Point of air measurement in ABCBs indicates the moisture content in the air, which is employed as an insulating and arc quenching medium in these breakers. The arc quenching/dielectric qualities of dry air alter as the CB ages, and air quality deteriorates as moist air moves to the circuit breaker's interrupting chamber. This will cause internal insulation to deteriorate, potentially leading to unsuccessful arc quenching due to the interrupting medium's low dielectric strength. As a result, it is required to measure the Dew Point of air in ABCBs. The permissible limit of the dew point of the air in ABCBs is -30º C.

9.3.10 Energy Audit

Pumping installations often consume a large amount of energy, with energy costs accounting for 40%–60% of the total cost of water works operation and maintenance. Hence, it is inevitable to estimate and monitor energy consumption regularly and take steps for energy conservation. Energy audit, in simple terms, means monitoring energy consumption at various units and sub-units and estimating any wastage of energy due to poor efficiency, higher hydraulic loss or power loss, etc.

Water utilities are increasingly using Energy Saving Service Operation (ESCO) models to reduce energy consumption, save costs, and improve operational efficiency. These models typically involve analysing the entire water supply system, including pumps, motors, and other equipment, to identify areas where energy is being wasted. Energy audits are conducted, and data on energy usage is collected and analysed to develop an implementation plan for energy-saving opportunities. An ESCO model is a systematic approach to identifying, implementing, and monitoring energy-saving opportunities in a particular system or facility.

Energy-saving opportunities may include replacing old equipment with more efficient models, optimising pump and motor operation, installing energy-efficient equipment, reducing water loss, and implementing energy management strategies such as demand response. Continuous evaluation of the system’s energy usage is necessary to identify opportunities for further improvement.

For a detailed reference, refer to Chapter 12 on “Energy Audit and Energy Conservation”, Part B of the Manual.

9.3.11 Variable Frequency Drive (VFD)

Variable Frequency Drives (VFDs) are electronic devices that control the speed of pumps and motors in water supply systems, for maintaining flow and pressure at increased demand. In the distribution network, VFDs can be installed at the outlet of the service reservoir to maintain a desired water head.

At the time of operation, controlling the leakages may be challenging, which will cause a sudden pressure drop in DMA/s. VFD shall be programmed to judge any sudden pressure drops in system and accordingly maintain the pressure between 15–21 m (at critical point) instead of continuously increasing the pressure of supply to meet the design head of 21 m.

During low-demand periods pump speed can be decreased to conserve energy. Additionally, VFDs can protect the water supply system by preventing pressure surges and reducing water hammer by adjusting speed gradually to meet demand, extending the life of the system's components.

The use of VFDs in water supply systems has been shown to be an effective strategy for reducing energy consumption and costs, improving operational efficiency, and enhancing system reliability. As such, water utilities around the world are increasingly using VFDs in their distribution networks to achieve these benefits and to supply continuous 24×7 pressurised water supply to implement 'Drink from Tap'.

All VFDs fall into two different NEMA (National Electric Manufacturers Association) classifications:

(i) NEMA 1 is the designation for VFDs with vented sides for proper cooling. These enclosures expose the VFD to dust contamination, which means that dust, filth, and other foreign items might clog ventilation holes and cause damaged heat sinks and cooling fan failure.

(ii) NEMA 12 is the classification for a sealed, dust-tight enclosure.

9.3.11.1 Efficiency Due to Speed Variation

A centrifugal pump is a dynamic device with a rotating impeller that generates a head. As a result, there is a connection between peripheral impeller velocity and generated head. For a fixed impeller diameter, peripheral velocity is directly connected to shaft rotational speed; hence, modifying the rotational speed directly affects pump performance. The affinity laws are the equations that relate the rotodynamic pump performance parameters of flow, head, and power absorbed to speed:

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$$

$$\frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2$$

$$\frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^3$$

Where;

Q = Flow rate H = Head

P = Power absorbed N = Rotating speed
Efficiency is essentially independent of speed

As demonstrated by the preceding laws, power is directly proportional to the cube of speed, and this is the foundation for energy savings in centrifugal pumps with changing flow needs.

9.3.11.2 VFD Preventive Maintenance

VFD preventative maintenance is required once a year. It comprises primarily of visual inspection, cleaning with dry compressed air or vacuuming, verifying connections for proper torque, and establishing a replacement schedule for components with the lowest operational life cycles. VFD cooling fans, for example, should be replaced every three to five years, whereas main bus capacitors should be replaced every seven years.

Scheduled tasks include the following:

- Visual inspection of the VFD and environmental conditions.
- Inspection of the connections.
- Inspection of the ribbon and fibre optic cables.
- Functional inspection of the fan and cooling system.
- Electrostatic Discharge protected cleaning of the VFD.
- Inspection of the ‘emergency stop’ circuit.
- Inspection for the prevention of unexpected start-up circuits.
- Inspection of the fault logger.
- Inspection and storage of the parameters.
- Functional testing of the VFD under normal conditions.
- Basic measurements with supply voltage.
- Inspection of the VFD spare part inventory.
- Reforming of the spare module capacitors.

9.3.11.3 Focus Areas for Maintenance of VFD

These include keeping the VFD clean, cool, dry, and tight.

A. Keep VFD Clean

Variable frequency drives are typically categorised as NEMA 1 (side vents for cooling airflow) or NEMA 12 (sealed, dust-tight enclosure). VFDs of the NEMA 1 category are susceptible to dust contamination. Cleaning electronic components should be done with a non-static spray or a reverse-operated Electrostatic Discharge vacuum to reduce static build-up. Enclosure seals should be inspected on a regular basis and replaced as soon as any damage is discovered.

B. Keep VFD Cool

Heat sink temperatures should be checked on a regular basis. Average temperatures should be recorded, and any temperature increase of more than 3 to 5 °C should be explored.

C. Keep VFD Dry

Moisture will cause variable frequency drive circuit board corrosion, causing the VFD to fail or operate erratically.

D. Keep VFD Connections Tight

Heat cycles and mechanical vibration can cause connections to become loose. Arcing occurs as a result of bad connections, which causes irregular operation, resulting in poor variable frequency drive quality, scrap, machine damage, or even personnel harm.

9.3.12 D.C. Battery and Battery Charger

9.3.12.1 Maintenance Schedule for Batteries

(i) Daily:

Check voltage and specific gravity of the batteries and battery supply for the tripping circuit.

(ii) Monthly:

a. Check the battery charging and fuses and clean contact faces.
b. Apply a thin coating of high-temperature grease to posts and cable connections for added protection.

(iii) Quarterly:

Examine the battery case for noticeable physical damage or warpage. This usually implies that the battery has been overcharged or overheated. Fill the battery with distilled or demineralised water, never with sulphuric acid.

(iv) Yearly:

Examine the rectifier, diode, and rheostat motor thoroughly. For batteries used in seasonal applications and stored for an extended period of time, fully recharge the battery before storing.

9.3.12.2 Operation of Battery Charger

Please check the following:

- The battery was inactive for too long.
- The battery was discharged too deeply.
- The proper capacity of charger is used.
- Check the fuses of the battery charger.
- Check the electric connection of the charger.
- There should be no dampness/moisture in the place of its applications.

9.3.13 Lifting Equipment

Relevant points in the maintenance schedule as follows shall be applicable for lifting equipment, depending on the type of lifting equipment, i.e., chain pulley block, monorail (traveling trolley and chain pulley block), manually operated overhead crane, and electrically operated traveling crane.

i. Daily:

a) Power system:
- Check that all the switches are functioning properly.
- Ensure that all other pushbutton controls operate properly and move in the right direction.

b) Hooks:
- Check for bending or twisting and cracks.
- Ensure that all safety locks are in place and working correctly.
- Check that the hook nut (if visible) is snug and securely fastened to the hook.

c) Bottom block assembly:
- Structural damage
- Cracks on any component
- Sheaves are smooth
- Sheave guards are intact and unbroken

d) Miscellaneous:
- Make sure there are no broken wires.
- Check the wire rope for kinking, cutting, crushing, un-stranding, or thermal damage.
- Check that there are no cracks, gouges, nicks, corrosion, or distortion on any link of the load chain.
- Verify chain sprockets are operating smoothly.
- Check that the bridge and trolley motor brakes are working properly.
- Check that the trolley and bridge are on-track and functioning smoothly.
- Check the crane for any loose items that could fall.
- Check for oil leaks.
- Keep a functional fire extinguisher on hand in case of an emergency.
- Also, make sure all below-the-hook devices are in good working order.

ii. Monthly:

a) Power system:
- With the push button turned off, ensure that the buttons are not stuck and that they operate smoothly. When the button is pressed, it should always revert to the off position.
- Check that the crane warning device works properly with the pushbutton switched on.
- Check that the hoist hook rises when the button is pushed to the “up” position and descends when pushed to the “down” position.

b) Hooks:
- Make sure there is no more than 10% wear on any area of the hook.
- Check that the hook rotates easily and without grinding.

c) Bottom block assembly:
- Capacity markings are present.
- Sheaves rotate freely without grinding.

d) Miscellaneous:
   - Examine the wire rope and load chain by walking around the hook block 360 degrees and inspecting the wire rope/chain.
   - Make sure there is no reduction in diameter.
   - Check for wear at all contact locations.
   - When releasing controls in the up or down position, make sure there is minimal or no hook drift.

iii. Quarterly:

- Check oil level in the gearbox and top up if required.
- Check for undue noise and vibration.
- Lubricate bearings and gear trains as applicable.
- Check insulation resistance of motors.
- Check pendant operation for all three motions, i.e., hoisting, traveling, and traversing.
- Clean external surface of the motor
- Clean limit switches.
- Clean all electrical contacts.

iv. Yearly:

- Change oil in the gearbox.
- Conduct load test of crane for rated load or at least for the maximum load required to be handled. All fast-moving components which are likely to wear should be thoroughly inspected once a year and, if necessary, shall be replaced.

9.3.14 Water Hammer Control Devices

Maintenance requirements of water hammer devices depend on the type of water hammer control device, nature of its functioning, water quality, etc. Type of water hammer control devices used in water pumping installations are as follows:

- Surge tank
- Surge Shaft
- One-way surge tank
- Air vessel (air chamber)
- Zero-velocity valve and air cushion valve
- Surge anticipation valve (surge suppressor)
- Pressure relief valve

General guidelines for maintenance of different types of water hammer control devices are as follows:

9.3.14.1 Surge Tank, Surge Shaft, and One-Way Surge Tank

- Quarterly: Water level gauge or sight tube provided shall be inspected, any jam rectified, and all cocks and sight tube flushed and cleaned.
- Yearly: The tank shall be drained and cleaned once a year or earlier if the frequency of

ingress of foreign matter is high.

- Valve maintenance: Maintenance of butterfly valve, sluice valve, float valve, and reflux valve shall be attended to as specified for valves on pump delivery in para 9.3.4.
- Painting: Painting of tanks shall be carried out once in two years.

9.3.14.2 Air-Vessel

- Daily:
  - Check air-water interface level in a sight glass tube.
  - The air-water level should be within the range marked by upper and lower levels and shall be preferably in the middle.
  - Check the pressure in the air receiver at an interval of every two hours.
- Quarterly:
  - Sight glass tube and cock shall be flushed.
  - All wiring connections shall be checked and properly reconnected.
  - Contacts of the level control system and pressure switches in the air supply system shall be cleaned.
- Yearly:
  - The air vessel and air receiver shall be drained, cleaned, and dried.
  - Repainting of air vessel (inside and outside) and air receiver shall be carried out every five years.
  - Internal surface shall be examined for any corrosion, etc. and any such spot cleaned by rough polish paper and spot-painted.
  - Probe heads of the level control system shall be thoroughly checked and cleaned.
- Accessories:
  - Maintenance of panel, valves, air compressor, etc., shall be carried out as specified for respective appurtenances.

9.3.14.3 Zero-Velocity Valves and Air Cushion Valve

Foreign matters entangled in the valve shall be removed by opening all hand holes, and internal components of the valves, including ports, disk, stem, springs, passages, seat faces, etc., should be thoroughly cleaned and checked once in six months for raw water and once in a year for clear water application.

9.3.14.4 Surge Anticipation Valves

Pilot valves and tubes shall be flushed and cleaned every month.

9.3.14.5 Pressure Relief Valve

The spring shall be checked and freed from jam every month.

9.3.15 Air Compressor

i) Daily:
  - Clean external surface.

- Check oil level and top up if necessary.

ii) Monthly:
- Clean oil filter.
- Clean air filter.

iii) Quarterly:
- Check the condition of the oil and change it if dirty.
- Check grease in bearing housing and replenish/change if necessary.
- Check the condition of the oil in the air filter and change it if dirty.

iv) Half yearly:
- Change oil.
- Change oil filter element.
- Thoroughly clean air filter.
- Clean bearing and bearing housing and change grease/oil.

v) Yearly:
- Thoroughly check all components, piping valve, etc., and rectify if necessary.
- It is necessary to check that the pressure developing capacity of the compressor is more than the working pressure at installation to ensure that the compressor can replenish the air in air vessel.

9.4 Maintenance of Pumping Station

Pumping stations can be grouped as follows:
- Pumping water from a surface water source such as rivers, lakes, etc.;
- For lifting water (high quantity, low pressure) from a well;
- For pumping water into water treatment system, into a water supply network system, elevated water tank or water tower, etc.; and
- To increase pressure.

The right maintenance strategy of the pumping station is critical because it reduces risks and improves efficiency while keeping costs within an affordable range. Also, by adopting the right strategy, there is the opportunity to extend the life of the units/devices/equipment. This process also means that the cost of repairs is reduced, and overall productivity remains higher.
Overall, the maintenance, as follows, shall be carried out for screens, penstock/gate, sump/intake/well, and pump house, including civil works.

9.4.1 Screens and Belt Conveyor

(i) The screen should be cleaned at a frequency depending on the ingress load of floating matters. The frequency in monsoon season shall be more than that in fair season. However, cleaning frequency should be at least once a week, or if the head loss on screen exceeds 0.20 m.

(ii) Care should be taken to remove and dump the screening far away from the pump house.

(iii) Lubricate wheels, the axle of wheel burrows, and the bearing of the belt conveyor.

(iv) The screen, catch tray, screen handling arrangement, wheels, axles, and belt of the belt conveyor shall be thoroughly inspected once in six months, and any item broken, eroded, or corroded shall be rectified.

9.4.2 Penstock/Sluice Gate

Operation of the gates minimises the buildup of rust in the operating mechanism and, therefore, the likelihood of its seizure. During this procedure:

- Check the mechanical parts of the hoisting mechanism—including drive gears, bearings, and wear plates—for adverse or excessive wear;
- Check all bolts, including anchor bolts, for tightness;
- Replace worn and corroded parts;
- Make mechanical and alignment adjustments as necessary.
- The maintenance schedule specified for the valve actuator is also applicable for the electric actuator for the sluice gate.

i) Monthly:
- The penstock/sluice gate normally remains in the open position and closed only when inflow is to be stopped. Since floating matters may adhere to the gate and may accumulate in the seat, it should be operated once a month in order to ensure that gate remains free for operation.

ii) Yearly:
- The gate should be thoroughly inspected once a year, preferably after the monsoon, and components found worn out shall be replaced. Particular attention shall be paid to the seats of the frame and gate.
- The gate should be closed to check the leakages. For this purpose, the sump/intake shall be partly dewatered so that a differential head is created on the gate and a leakage test at the site can be performed.

9.4.3 Sump/Intake Well

i) All foreign floating matters in the sump/intake shall be manually removed at least once a month and shall be disposed of away from the pump house.
ii) Desilting of intake/sump shall be carried out once a year, preferably after the monsoon. Care should be taken to dump the removed silt away from the pump house.
iii) It is generally observed that reptiles like snakes, fish, etc., enter the intake, particularly in monsoons. The intake should be disinfected.
iv) The sump/intake should be fully dewatered and inspected once a year.
v) It is advisable to undertake a leakage test of the sump once a year. For this purpose, the sump shall be filled to FSL, and a drop in water level for a reasonably long duration (two to three hours) should be observed. If leakage is beyond the limit, rectification work shall be taken.

9.4.4 Pump House

i) The pump house should be cleaned daily. Good housekeeping and cleanliness are necessary for a pleasant environment.
ii) The entire pump house, superstructure, and sub-structure shall be adequately illuminated and well-ventilated. Poor lighting, stale air, etc., create an unpleasant environment and have an adverse effect on the will of the staff to work.
iii) Wooden flooring and M.S. grating, wherever damaged, should be repaired on priority.
iv) It is observed that in many places, the roof leaks badly, and at times the leakage water drips on the panel/motor, which is dangerous and can cause a short circuit and electric

accidents. All such leakages should be rectified on priority.

v) All facilities in the sub-structure, i.e., staircase, floors, walkways, etc., should be cleaned daily.

vi) Painting of civil works should be carried out at least once in two years.

9.5 Predictive Maintenance

Predictive maintenance is the term used to examine and predict the likely failure of components. As this requires experience, anticipation, good judgment, and expertise and involves costs for repairs for predicted failures, it can be adopted at important, vital, and large pumping stations.

9.5.1 Pumps And Bearings

Some factual evidence, i.e., declining pump performance, excessive noise or bearing temperature, and an increase in vibration, can indicate that the pump probably needs to be overhauled or the bearing need to be replaced.

Efforts should be made to rectify noise and vibration levels by critical study and adopting measures for rectifications. If noise or vibration persists, the pump should be dismantled and thoroughly checked. If a significant reduction in discharge is suspected, a performance test at the site shall be conducted with calibrated instruments, and the results of the tests are compared with the initial results of the new pump. After fully ascertaining that the performance has considerably declined, the decision to overhaul may be taken.

In some installations, particularly if raw water is corrosive or contains grit or sand, the pump may become prematurely due for overhaul due to deterioration caused by corrosion or erosion. In such cases, the decision for overhaul should be based on circumstantial evidence, i.e., previous history. As a long-term solution, the manufacturer should be consulted for the use of better material for construction for affected components.

9.5.2 Electrical Equipment

The weakening of insulation and failure of winding can be predicted by measuring insulation resistance and judging the trend of weakening of insulation. The predictive maintenance test is recommended for the following components of electrical machinery.

i) Motor winding and insulation – Quarterly

ii) Transformer winding and insulation – Annual

For condition monitoring of motors, the polarisation index shall be checked. The polarisation index is the ratio of megger value after ten minutes and megger value after one minute. The measurement should be taken with the help of a motorised megger. For a healthy motor from an insulation resistance point of view, the value of PI shall be more than 1.25.

9.6 Facilities for Maintenance and Repairs

Facilities, as follows, should be provided for maintenance, inspection, and repairs in the pumping installation.

- Adequate stock of consumables and lubricants
- Adequate stock of spare parts
- Tools and testing instruments

- Lifting equipment
- Ventilated and illuminated adequate space for repairs

9.6.1 Consumables and Lubricants

Adequate stock of gland packing, belts, gaskets, lubricating oil, greases, transformer oil, insulation tape, sealing compound, emery paste, etc., shall be maintained. The consumables and lubricants shall be of proper quality and grade. Quantity shall be decided depending on consumption and the period required to procure and replenish the stock.

9.6.2 Spare Parts

Adequate stock of spare parts should be maintained to avoid downtime due to the non- availability of spares. Generally, spares required for one-two years of maintenance as per the list below shall be kept in stock. The list should not be considered as full- fledged and comprehensive and should be updated and revised in light of manufacturers' recommendations and previous history of repairs undertaken.

- Set of wearing rings
- Shaft sleeves
- Bearings
- Gland packings and gaskets
- Coupling bushes and bolts
- Line shaft bearings and spiders
- Line shaft
- Pump shaft
- Shaft enclosing tube
- Tube tensioning plate
- Gland nut
- Centrifugal pumps: Impellers, diffusers,
- Vertical turbine pumps: thrust bearings, bearing spider,
- impeller, etc.
- Lantern ring
- Coupling for line shaft
- Slip ring unit
- Carbon Brushes
- Fixed and moved contacts
- Lugs
- Gland for cable termination
- Fluorescent tubes and lamps
- Fuses
- Impeller
- Rotating assembly of the pump (for large pumping installation)
- Motors: Bearings
- MCC: Relay, tripping circuit, fuses.
- Transformer: Oil

9.6.3 Tools and Testing Instruments

The pumping installation should be equipped with all necessary tools, testing instruments, and special tools required for repairs and testing. Their quantity and special tools depend on the size and importance of installation. Generally, the following tools and testing instruments shall be provided.

a) Tools
  - Double-ended spanner set and ring spanner set.
  - Box spanner set
  - Hammers (of various sizes and functions)

- Screwdriver set
- Chisel
- Nose plier, cutting plier
- Files of various sizes and smooth/rough surfaces
- Adjustable spanner
- Pipe wrenches
- Bearing puller
- Torque wrench
- Clamps for column pipes, tube, and line shaft
- Specials tools such as grinder, blower, and drilling machine
- Tap and die set
- Bench vice
- Special tools for breakers
- Crimpling tool
- Hydraulic crimpling tool
- Feeler gauge, power torch, portable lamp with wire, vibration testing meter, and sound level testing meter
- Heating stove for heating sleeves

b) Test instruments

- Insulation tester
- Tongue tester
- AVO meter
- Test lamp
- Earth resistance tester
- Wattmeter, CT, and PT
- Dial gauge
- Optical Tachometer

9.6.4 Lifting and Material Handling Aids

The following lifting and material handling aids shall be kept in the pump house.

- Chains
- Wire rope
- Manila rope
- Chain pulley block and tripod
- Other lifting equipment
- Hand cart
- Ladder

9.6.5 Space

A well-ventilated and adequate illuminated space shall be earmarked for repairs. Minimum facilities such as worktable, bench-vice, etc., shall be provided.

9.7 Trouble Shooting of Pumps and Electricals

Troubleshooting check charts for the following equipment's (indicative) are listed below:

i. Pumps (Centrifugal, jet, VT, submersible, vacuum, reciprocating)
ii. Electric motor
iii. Capacitors
iv. Starters, breakers, and control circuits
v. Panels
vi. Cables
vii. Transformer
viii. Batteries
ix. Air compressor

9.7.1 Centrifugal/Jet/VT/Vacuum/Submersible Pumps

The details of troubleshooting for Centrifugal/Jet/VT/Vacuum/Submersible Pumps are explained in **Annexure 9.2**.

9.7.2 Reciprocating Pump

Symptom	Possible Cause (as per list in below paras)
Liquid end noise	1, 2, 7, 8, 9, 10, 14, 15, 16
Power end noise	17, 18, 19, 20
Overheated power	10, 19, 21, 22, 23, 24
end Water in	25
Crankcase	26, 27
Oil leak from the crankcase	11, 12, 28, 29
Rapid packing or plunger wear	3, 11, 30
Pitted valve or seats	31, 32
Valve hanging up	10, 13, 33, 34
Leak at cylinder-valve hole plugs	1, 4, 5, 6

9.7.2.1 Suction Troubles

1. Insufficient suction pressure
2. Partial loss of prime
3. Cavitation
4. Lift too high
5. Leaking suction at foot valve
6. Acceleration head requirement too high

9.7.2.2 System Problem

1. System shocks
2. Poorly supported piping, abrupt turns in piping, pipe size too small, piping misaligned

3. Air in liquid
4. Overpressure or overspeed
5. Dirty liquid
6. Dirty environment
7. Water hammer

9.7.2.3 Mechanical Troubles

1. Broken or badly worn valves
2. Packing worn
3. Obstruction under valve
4. Loose main bearings
5. Worn bearings
6. Low oil level
7. Plunger loose
8. Tight main bearings
9. Inadequate ventilation
10. Belts too tight
11. Driver misaligned
12. Condensation
13. Worn seals
14. Oil level too high
15. Pump not set level and right
16. Loose packing
17. Corrosion
18. Valve binding
19. Broken valve spring
20. Loose cylinder plug
21. Damaged O-ring seal

9.7.3 Delivery Pipes, Header and NRV

S. No.	Trouble	Cause	Remedy
1.	**Undue thrust on pump foundation and bend in the delivery pipe, causing shearing or uprooting of foundation bolts of pumps and thrust on the common header.**	The dismantling joint is not properly designed to counter thrust at the elbow in the pump.	Provide dismantling joint of proper design. The design should ensure that it has long tie-bolts connecting rigid flanges, thus taking up the pull caused by thrust at the pump.

S. No.	Trouble	Cause	Remedy
2.	**Cracks in welded jointed of individual delivery and common header.**	The cracks are caused due to thrust at the dead end and bend at the common manifold.	Provide thrust blocks at dead and bend at the common manifold. If crack still occurs, provide stiffeners (angles/channels) at welded joints of individual delivery piping bends and common manifold
3.	**Reflux valve (NRV) closes with a slam and high noise in the event of shutdown or power failure, or tripping**	• The reflux valve is not designed for non-slam closure.	• Replace with reflux valve designed for non-slam closure. • Take up the issue of the old valve to the valve manufacturer. • Replace the reflux valve with a Dual Plate Check Valve

9.7.4 Electric Motor

The details of troubleshooting for an electric motor are given in **Annexure 9.3**.

9.7.5 Capacitors

The details of troubleshooting for capacitors are given in **Annexure 9.4**.

9.7.6 Starters, Breakers, and Control Circuits

The details of troubleshooting for Starters, Breakers, and Control Circuits are given in **Annexure 9.5**.

9.7.7 Panels

S. No.	Trouble	Cause	Remedy
1.	**Overheating**	• Bus bar capacity inadequate • Loose connection. • Improper ventilation	• Check and provide additional bars in combination with existing bus bars or replace bus bars. • Rectify loose connections by tightening. • Improve ventilation.
2.	**Insulator cracked**	-	

9.7.8 Cables

S. No.	Trouble	Cause	Remedy
1.	**Overheating**	• Cable size inadequate.	• Provide a cable in parallel to the existing cable or higher size cable. • Increase clearance between cables.
2.	**Insulation burning at**	• Improper termination in lug termination	• Check the size of the lug and whether properly crimpled and correct. • Check whether only a few strands of cable are inserted in the lug. Insert all strands using a new or higher size lug if necessary

9.7.9 Transformer

The details of troubleshooting for the transformer are given in **Annexure 9.6**.

9.7.10 Batteries

Battery troubles revealed in service may be due to inadequate maintenance, incorrect operation, and incorrect charging. Many battery troubles can be traced to the charging source. Undercharging or excessive overcharging eventually leads to battery trouble.

S. No.	Trouble	Cause	Remedy
1.	**Readings of specific gravity and voltage are very erratic even after equalising charge for at least 48 hrs.**	• Battery life is over	Check the following • Age of battery. • Capacity. • Appearance of plates. • Depth of sediments below plates.
2.	**Several cells show low charge voltage at the end of the extended charge.**	• Internal short circuit.	• Open cells and examine for damage or displaced separators and lead particles between plates or buckled plates.
3.	**Battery overheats**	• Poor contacts or badly welded joints.	• Clean and tighten all bolted connections, reweld doubtful welded joints.

4.	**Battery damp and dirty, wood trays deteriorated, or metal work corroded.**	• Poor maintenance, overtopping, or lid sealing compound cracked.	• Keep the battery dry and clean. Do not overtop when adding water. Clear away all traces of acid and old sealing compounds from cell lids.
5.	**The hydrometer test (at 27 °C) shows less than 1.200 specific gravity.**		• The battery should be recharged. Provide a high-rate discharge test for capacity. If the cell test OK, recharge and adjust the gravity of all cells uniformly. Check the operation and setting of the voltage regulator, and make a thorough check of the electrical system for short circuits, loose connections, corroded terminals, etc.

9.7.11 Air Compressor

The details of troubleshooting for the air compressor are given in **Annexure 9.7**.

9.8 Desirable Environment and Amenities in Installation

Environment and cleanliness have a tremendous impact on the willingness or unwillingness of the workers. In order to maintain the working environment, following guidelines shall be followed.

- Maintain cleanliness in the installation and surroundings. Cleanliness causes a pleasant atmosphere for work.
- The appearance of the equipment, furniture, walls, etc., should be improved by painting, polishing, etc., at about two-year intervals.
- The colour selected shall be sober and eye-pleasing.
- Good housekeeping is a must for sustaining a pleasant environment.
- High noise is a major irritant and should be kept within the limit by reducing or isolating the noise-emitting sources.
- Following amenities shall be provided at installations.
    - Dress-changing room and locker facilities.
    - Clean toilet and running water supply.
    - Drinking water facilities.
    - Chairs, tables, etc., to rest during work.

9.9 Digital Data Recording

It is recommended to keep maintenance records in MIS as well as Computerised Maintenance Management Systems (CMMS). The maintenance schedule along with the resources needed will be generated through the CMMS. The work orders, inventory and purchase orders can be maintained in the CMMS. Various censors are being used in collecting the real-time data of components of the water supply system, including electromechanical equipment's in SCADA and the data can be analysed Digital Twin Systems for efficient management. This will enhance in improving the O&M of Pumping Stations and Pumping Machinery.

CHAPTER 10 : AUTOMATION OF WATER SUPPLY SYSTEM

10.1 Water Meters

10.1.1 Introduction

A water meter is a scientific instrument for accurate measurement of quantity of water distributed to the consumers. It also fulfils the need to know accurately the water produced and distributed.

It differs from flow meter in respect of the following points:

1. It is a quantity meter and not a flow rate meter.
2. Water meter is always specified in two accuracies, i.e., lower range and upper range accuracies, whereas a flow meter is specified in a single range accuracy.
3. The upper range and lower range accuracies are 2% and 5% of the actual quantity respectively for the water meter, whereas it is variable for flow meter as per the customer's requirement.

Water meters having sizes from 15 mm to 40 mm as per BIS 779:1994 are considered to be domestic water meters and sizes from 40 mm and above as per BIS 2373:1981 and ISO 4064 Part-II (2014) are considered to be bulk water meters.

Water meters help in apparent loss reduction accounting, volume of water used, and the evaluation of the effectiveness of efficiency and conservation measures. Water meters can serve its purpose only when working properly and providing an accurate reading. Mechanical water meters lose sensitivity with time due to wear and tear of moving parts, hence, proper periodic maintenance and/or replacement is required to achieve the objective. On the other hand, electromagnetic/ultrasonic water meter accuracy is sustained over product life (12–15 years) to the meter.

Water meters are generally classified based on the different mechanisms used by the water meter to measure the volume of water consumed by the end user. There are several types of water meter technologies available in the market for domestic water meter and bulk water meter. Traditionally, mechanical Class B multi jet and Woltman meters were used, however, with advancements in technology, water boards are opting for electromagnetic/ultrasonic AMR water meters. Due to the various advantages they offer like reduction of cycle time for billing, accurate measurement over meter life, no air measurement, low maintenance, and better customer service. Water meters are broadly classified into (i) Domestic meters and (ii) Bulk meters based on consumption by the user. (Table 10.1).

The details of water meters is discussed in Chapter 13: Water Meters of Part A of the Manual.

10.1.2 Sizing of Water Meters

Sizing of water meter is done keeping in view the guidelines given in Indian standard IS 2401 (withdrawn) and ISO 4064 Part-II (2014) – Test Report Format. In general, main considerations are as follows:

1. Water meter has to be selected according to the flow to be measured and not necessarily to suit a certain size of water main.
2. The maximum flow of meter connection shall not exceed the maximum flow rating.

3. The nominal flow of meter connection shall not be greater than the nominal flow rating. The minimum flow to be measured shall be within the minimum starting flow of the meter.
4. Low head loss, long operating flow range, less bulky, and robust meter shall be preferred.

Table 10.1: Classification of Water Meters Based on

Operating Principle					Constructional Features	Consumer Category		Metrological Characteristics
Electromagnetic/ Ultrasonic Smart Meter	**Semi Positive or Piston or Volumetric**	**Inferential or Velocity or Turbine**				**Domestic Meter as per IS 779**	**Bulk Meter as per IS 2373**	Classes A to D A and B as per ISO BIS 4064, 779
		Vane Wheel or Fan Type		**Woltman or Helical Type**				
Dynamic ratio Q3/Q1 is R250 to R1000 as per ISO 4064	Available with Dynamic ratio Q3/Q1 is R50 to R160 as per ISO 4064	**Single Jet –** Available with Dynamic ratio Q3/Q1 is R50 to R160 as per ISO 4064	**Multi Jet –** Available with Dynamic ratio Q3/Q1 is R50 to R160 as per ISO 4064	Available from 50 mm to 500 mm as per BIS and 50 mm to 800 mm as per ISO	Wet dial meter Dry dial meter LCD display Mechanically coupled Meter	• Available up to size 50 mm • Screwed connection	• Available from size 50 mm and above • Flanged connections	
Available from 15 mm to 300 mm as per ISO 4064 (MID Approved) **Advantages of Smart / Static Meters** 1. Dynamic Ratio Q3/Q1 up to R1000	**Advantages** 1. Most sensitive 2. Less sensitive to flow disturbances **Disadvantages** 1. Water must be	Available from 15 mm to 50 mm as per IS 779 and 15 mm to 100 mm as per ISO 4064 **Advantages** Simple and less complicated The cheapest	Available from 15 mm to 300 mm as per ISO **Advantages** Less sensitive to flow disturbances Can sustain hostile flow	**Advantages** 1. Suitable for higher flows 2. Less pressure loss 3. Robust Construction 4. External and internal regulators **Disadvantages**	Magnetically coupled meter Straight reading cyclometer Multi pointer meter (Analogue type) Combination of Cyclometer and pointer **Advantages of mechanical coupled**	• Body with Brass of Bronze or Plastic • Available in Class 'A' and 'B' in IS	• Body: cast or steel • Not available in classes in IS	

Operating Principle					Constructional Features	Consumer Category		Metrological Characteristics
2. Low flow measurement 3. No Moving Part 4. No Air Measurement 5. Inbuilt AMR Facility 6. Inbuilt Alarms, data logging facility **7.** Accuracy of the meters sustain for a life of the meter	free from solid dirt particles 2. Difficult to maintain 3. Difficult to calibrate 4. Failure of rotating part causes failure of water flow through the Meter	Less loss of pressure **Disadvantages** 1. Sensitive to flow 2. Requires specialised calibration as external regulator is not available 3. Not sustained in hostile flow conditions	conditions External regulator facilitates easy calibration Easy maintenance **Disadvantages** Costlier than that of single jet More pressure loss	1. Approach conditioning piping is required 2. Not available in metrological classes in BIS. Limited to higher flows.	1. Not affected by external magnetic field. **Disadvantages** 1. Bush leak problems 2. Air escape hole create problem during submergence. 3. Available in class 'A' only			
8. Installation can be					**Advantages of**			

Operating Principle					Constructional Features	Consumer Category		Metrological Characteristics
done in any orientation **Disadvantages** 1. More costly than Mechanical meters.					**Magnetically Coupled** 1. Available in Class 'A' as well as Class 'B' 2. More sensitive 3. No condensation of water in resister **Disadvantages** 1. Temperable with external magnetic field. 2. In intermittent supply high temperature of water may damage the properties of the magnet. **Advantages of LCD Display Static Meters**			

Operating Principle					Constructional Features	Consumer Category		Metrological Characteristics
					1. Available in Ratio R250 to R1000			
					2. Suitable for wide range of flows (very low to high flows) 3. Less sensitive to flow disturbances 4. Can be installed in any orientation 5. Life of meter 10 to 15 yrs. 6. Low maintenance required. 7. U0D0 – Meter works accurately with zero upstream and downstream length for installation			

10.1.3 Installation of Water Meters

In order to ensure proper operation of the meters, guidelines are provided in IS 779 and ISO 4064-2014 for their installation as per the drawing given in it. At the same time, following guidelines should be borne in mind while installing the meters.

1. The water meter being a delicate instrument shall be handled with great care. Rough handling including jerks or fall is likely to damage it and affects its accuracy.
2. The meter shall be installed at a spot where it is readily accessible.
   To avoid damages and over run of the meter due to intermittent water supply system, it is always advisable to install the meter U Shape connection (as per IS779 installation diagram). Also, the minimum straight length condition, as per the drawing, shall be observed.
3. The meter shall preferably be housed in a chamber with a lid for protection; it should never be buried underground, neither installed in the open exposed condition nor to be installed under a water tap, so that water may not directly fall on the meter. It should be installed inside inspection pits, built out of bricks or concrete or meter box and covered with lid. It should never be suspended.
4. The meter shall be installed in horizontal direction or can be installed in vertical direction (for static meters) if required, and the flow of water should be in the direction shown by the arrow marked on meter body.
5. Before connecting the meter to the water pipe, it should be thoroughly cleaned by installing in the place of the water meter a pipe of suitable length and diameter and letting the passage of a fair amount of water flow through the pipe work to avoid formation of air pockets. It is advisable that the level of the pipeline where the meter is proposed to be installed should be checked by a spirit level.
6. Before installing the meter in the pipeline, check the coupling set and insert the washers. Then tighten the coupling nuts onto the pipes and install the meter between the coupling nuts. To prevent the meter from rotating during operation, it should be fixed with suitable non-metallic clamps. Care should be taken to ensure that the washer does not obstruct the inflow and outflow of water.
7. The protective lid should normally be kept closed and should be opened only for meter reading purpose.
8. The meter shall not run with free discharge to atmosphere. Some resistance should be given in the downside of the meter if static pressure on the main exceeds 10 m head.
9. A meter shall be located where it is not liable to get severe shock of water hammer, which might break the system of the meter.
10. Because of the small clearance in the working parts of the meters, they are not suitable for measuring water containing sand or similar foreign particles; in such cases, a filter or dirt box with sufficient effective area must be placed on the upstream side of the meter. It should be noted that the normal strainer inside a meter is not a filter and does not prevent the ingress of small particles such as sand.
11. Where intermittent supply is likely to be encountered, the mechanical meter may be provided with a suitable air valve before the meter in order to reduce inaccuracy and to protect the meter from being damaged.

10.1.4 Testing and Calibration of Water Meters

1. The testing and calibration of a water meter is essential before putting it into use as it is a statutory requirement. It is also essential to test it periodically (for mechanical meters, every three years; for static smart meters, every seven years), in order to ascertain its performance as during the course of meter working it is likely that its accuracy of measurement may deteriorate beyond acceptable limits.
2. A meter suspected to be malfunctioning is also tested for its accuracy of measurement. The testing is done as per IS6784-1996 (reaffirmed 2002)/ISO4064 part III. A faulty meter if found to be repairable, is repaired, calibrated and tested for its accuracy before installation.

The metering accuracy testing is carried out at Q1, Q2, Q3, and Q4 separately.

Where:

Q1: Minimum flow rate at which the meter is required to give indication within the MPE tolerance. It is as mentioned in IS779 and is determined in terms of numerical value of meter designation in case of ISO 4064. Q1 value is derived from the ratio, i.e., Q1 = Q3 / ratio.

Q2: The transitional flow rate at which the MPE of the water meter changes in value. Q2 is 1.6 times of Q1.

Q3: Permanent flow rate as mentioned in ISO 4064 -2014 for each size of the meter.

Q4: The Overload flow rate at which the meter is required to operate in a satisfactory manner for short periods of time without deterioration. Q4 is 1.25 times of Q3.

Dynamic Ratio – Q3 / Q1

The accuracy of water meter is divided into two zones, i.e., (1) Lower measurable limit in which ±5% accuracy from minimum flow to transitional flow (exclusive) and (2) Upper measurable limit in which ±2% accuracy from transitional flow (inclusive) to maximum flow.

3. The procedure for conducting the above test is as follows (as per ISO 4064): Water meter is fixed on a test bench horizontally or vertically or in any other position for which it is designed and with the direction of flow as indicated by arrow on its body. By adjusting the position of regulating valve on upstream side, the rate of flow is adjusted. At the desired rate of flow, the difference in pressure gauge readings fitted on upstream and downstream side of water meter is noted. The flow is now stopped with regulating valve, measuring chamber is emptied, and zero water levels on manometer attached to measuring chamber is correctly adjusted. Initial reading of the water meter from its recording dial is noted. Now the flow at the set rate is passed through the water meter and the discharge is collected in the measuring chamber. After passing the desired quantity of water through the meter, the flow is once again stopped. The discharge, as recorded by measuring chamber, is noted. The final reading of water meter is noted. The difference between the initial and final readings of water meter gives the discharge figure recorded by water meter. Now the discharge recorded by measuring tank is treated as ideal. The discharge recorded by water meter is compared with this ideal discharge. If the quantity recorded by water meter is more than the ideal, the meter is called running fast or vice versa. The difference in the quantity recorded by meter from ideal quantity is considered as error. This error is expressed in percentage.

   If the limits of error for the meter exceed the specified Maximum Permissible Error (MPE) in the Standard, the meter is readjusted by the regulator if it is available in the mechanical meter. In a mechanical meter a change in position of the regulating screw will displace the error curve (calibration curve) in parallel to former position. With the closing of the regulating orifice the curve will shift upward while opening the same will lower the curve. If the curve does not get into acceptable limit, the meter is not used. Some of the organisations are accepting accuracy limit for repaired water meter double the value of new water meters at respective zones, i.e., for upper zone accuracy is +4% and for lower zone accuracy is +10%.

10.1.5 Water meter Classification:

The water meter metering classification is divided according to the water meter transitional flow rate (Q2) and the minimum flow rate (Q1), which indicates the sensitivity of the water meter as shown in Table 10.2. The old regulations are classified according to Class A water meter, Class B water meter, Class C water meter, and Class D water meter, and Class D is the highest level. (RS Components, Northants, n.d.). The water meter classification according to ISO 4064-1, 2014 Standard is shown in Table 10.2.

At present, Class A water meter has basically withdrawn from the mainstream market, and Class B water meter is the most commonly used water meter in the market. The Class C water meter has been more popular in the market because of its high measurement accuracy and ability to read at low flow. Class D water meter has higher requirements for manufacturing process and equipment and at present mainly offered by an electromagnetic/ultrasonic smart water meter.

At low flow (which is ±5% from minimum flow rate) (Q1) to transitional flow rate (Q2) exclusive boundary

At high flow is ±2% from transitional flow rate (Q2) to overload flow rate (Q4).

Q1 – Lowest Flow rate Q2 – transitional flow rate
Q3 – Permanent flow or nominal flow rate Q4 – highest flow rate

Table 10.2: Water meter Classification- According to ISO 4064-1, 2014 Standard

According to ISO 4064 (2014) Standard								
Size		Ratio	Q_4 Overload flow	Q_3 Nominal Flow	Q_2 transitional flow	Q_1 Min flow	Min reading	Max reading
DN (mm)	Inch		m^3/hr		L/h		m^3	
15	1/2"	80	3.125	2.5	50.000	31.250	0.001	999999
		160			25.000	15.625		
		250			16.000	10.000		
		400			10.000	6.250		
		500			8.000	5.000		
		630			6.35	3.968		
		800			5.000	3.125		
20	3/4"	80	5.00	4.00	80.000	50.000	0.001	999999
		160			40.000	25.000		
		250			25.600	16.000		
		400			16.000	10.000		
		500			12.800	8.000		
		630			10.16	6.349		

According to ISO 4064 (2014) Standard

Size		Ratio	Q_4 Overload flow	Q_3 Nominal Flow	Q_2 transitional flow	Q_1 Min flow	Min reading	Max reading
DN (mm)	Inch		m^3/hr		L/h		m^3	
		800			8.000	5.000		
25	1"	80	7.875	6.3	126.000	78.750	0.001	999999
		160			63.000	39.375		
		250			40.320	25.200		
		400			25.200	15.750		
		500			20.160	12.600		
		630			16.00	10.000		
		800			12.600	7.875		
32	1 1/4"	80	12.5	10	200.000	125.000	0.001	999999
		160			100.000	62.500		
		250			64.000	40.000		
		400			40.000	25.000		
		500			32.000	20.000		
		630			25.40	15.873		
		800			20.000	12.500		
40	1 1/2"	80	20	16	320.000	200.000	0.001	999999
		160			160.000	100.000		
		250			102.400	64.000		
		400			64.000	40.000		
		500			51.200	32.000		
		630			40.63	25.397		
		800			32.000	20.000		
50	2"	80	25	20	400.000	250.000	0.001	999999
		160			200.000	125.000		
		250			128.000	80.000		
		400			80.000	50.000		
		500			64.000	40.000		
		630			50.79	31.746		
		800			40.000	25.000		

10.1.6 Repairs, Maintenance and Trouble Shooting of Mechanical Water Meters

Mechanical water meters' metrological performance normally deteriorates over a period. The fact that a meter shows no outward signs of damage and has a counter that appears to be incrementing, does not mean that the meter is operating satisfactorily. Figure 10.1 shows Types of Maintenance.

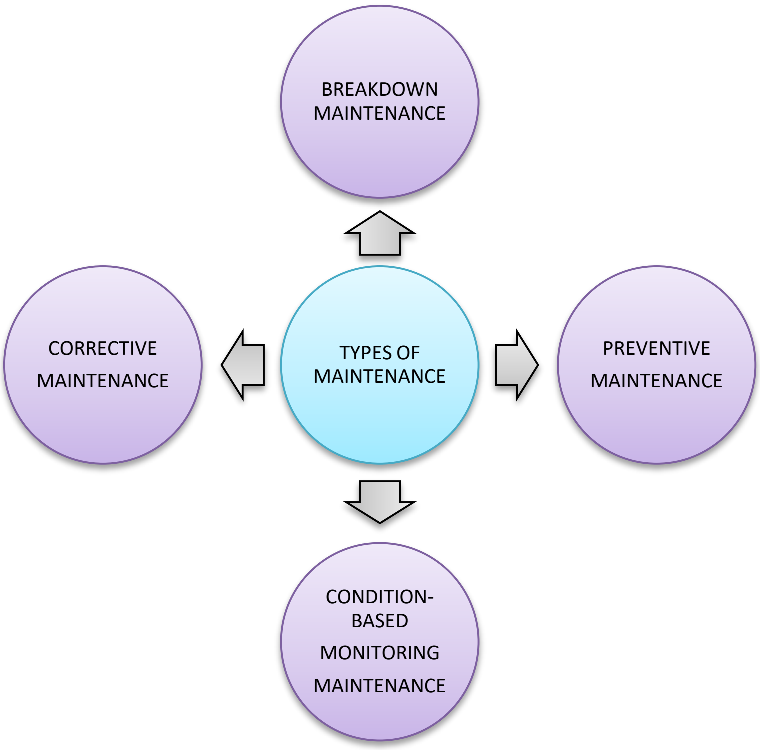


Figure 10.1: Types of Maintenance

Preventive maintenance:

1. Proper handling, storage, and transportation of water meters.
2. To clean the dirt box or strainer wherever installed (once in year or in case consumer complains on pressure loss).
3. To replace the gaskets, if any.
4. To clean the chamber in which the meter is installed and keep free from flooding, and seepage.
5. To remove the meter for further internal repair/replacement if it does not show correct reading pattern.

Breakdown maintenance:

Replacement of broken glass, lid and fallen wiper wherever provided-

These are the only basic breakdowns observed during periodical inspection. If a meter is found not working, then it shall be removed immediately and sent to meter service workshop. In meter workshops, normally the following steps are performed to carry out the repairs.

1. Disassembling of water meters including strainer, measuring unit, regulator, registering device, etc.
2. Clean all disassembled spare parts in detergent solution in warm water.
3. Inspect the cleaned parts and replace worn parts and gaskets, if any.
4. Inspect the meter body spur threads and cover threads.
5. Inspect the sealing surface on meter body and paint the meter body, if necessary.
6. Inspect the vane wheel shaft pinion, bearing and pivot.

7. Inspect the vane wheel chamber.
8. Reassemble the water meter properly after reconditioning.
9. Calibrate and test the repaired water meter for leakage and accuracy as per IS 6784.
10. Make entry in the life register of that water meter for keeping history record.

Table 10.3: Trouble Shooting of Water Meters

S. No.	Trouble	Cause	Remedy
1.	Meter reads in reverse direction	Might have been installed in reverse direction	Check the arrow on the meter body and install the meter properly, if necessary
2.	Meter not recording	Impeller to register link broken	Remove the meter for servicing and repairs
3.	Continuously moving pointer/digit rotates but no change in indicator	Pointer and drum link missing Drum defect	Remove the meter for servicing and repairs
4.	Dial/glass foggy	Climatic condition	Wait for climate change if it is rainy
5.	Meter suspected to be slow or fast	Inlet flow disturbance, missing internally defective, deteriorated magnets in case of magnetic meter	Clean the external filter/dirt box where provided and the in- built strainer Ensure full open condition of upstream valve. If doubt persists, remove meter for testing, servicing and repair
6.	Bush/gland leakage	Gland deformity	Remove meter for testing and servicing
7.	Regulator, head, body leakage	Regular washer damaged, loose screw	Remove the meter and repair
8.	Physical damage to meter including broken seal	Improper installation	Remove meter for testing, servicing and repair, physical protection arrangement be made
9.	No water available past the water meter even though inlet side is charged	Semi positive/positive displacement meter with jammed piston	Meter is acting as a stop valve. Remove it for inspection, servicing, and repair

In case of smaller size water meters, it is advisable to check cost benefit ratio before getting them repaired.

10.1.7 Repair, Maintenance and Troubleshooting of Static Water Meters

Static meters do not have any moving parts. In case of any failure, an alarm will be displayed on the LCD screen.

Table 10.4: Trouble Shooting of Static Water Meters

S. No.	Trouble	Cause	Remedy
1.	Meter reads in reverse direction	Wrong installation	Check the flow arrow in the meter body and display.
2.	Meter not recording	Bypass of meter	Check water supply for bypass.
3.	Low battery	Component failure	Replace the meter
4.	Physical damage to Meter including broken seal	Improper installation/theft	Remove meter for testing, servicing and repair, physical protection arrangement be made

10.1.8 Prevention of Tampering of Water Meters

In order to prevent tampering, the following precautions should be taken.

1. Water meters, shall be installed properly in the chamber with lock and key or in the Cast Iron covers with lock and key in order to avoid tampering.
2. Water meters must be sealed properly.
3. Water meters shall not allow reversible flow; it should register flow in forward directions only.
4. Water meter dials should be easily readable without confusion.
5. The lid, glass of water meters must be made up of tough materials as per IS 779 and shall be replaced timely.
6. The wiper or dial as far as possible is avoided.
7. In case of magnetically coupled meters, the proper material to shield magnets must be provided in order to avoid the tampering of such meter by outside magnets in the vicinity of meter.
8. Periodical inspection/checking at site is essential to ensure the proper working of meter.
9. Special sealing arrangements may be necessary and provided for bulk meters whereby unauthorised removal of the meter from the connection can be detected.

In spite of above, to tackle the problems of tampering, suitable penalty provisions/clauses shall be there in the rules or the water supply agreement with the consumer. This will also discourage the consumer tendencies of neglecting water meter safety.

10.1.9 Trend in Replacement of Water Meters

In general, if a water meter goes out of order due to any physical damage or non- operation of registration device and is beyond economical repair, it should be replaced with immediate effect. In Indian context, the performance of water meter depends upon:

1. The quality of water meter produced by manufacturer, and it differs from manufacturer to manufacturer;
2. The design of pipeline and fittings in line with meter;
3. The workmanship and care when handling and installing the meter;
4. The pattern of water passing through the meter;
5. The type of supply of water whether it is continuous or intermittent;

6. The meter maintenance and testing;
7. The proper selection of meter.

The performance of a water meter must be monitored continuously with suitable historical information. Any abnormality noticed needs immediate action. Timely removed faulty meter, and especially mechanical type meter, prevents cascading and cumulative damages.

Looking at the amount of transactions involved, bulk meters/commercial meters shall be given priority in replacements. Based on the experience gained over period of time, a well-planned programme for periodical meter testing, servicing, repairs and replacement wherever necessary shall be designed.

10.1.10Automatic Water Metering Systems

A water meter is a cash register of a water supply authority. Consumption based water rates require periodic reading of meters except in remote or automated meter reading of meters. Except in remote or automated meter reading, these readings are usually done by meter readers visiting consumers' premises, one by one, and noting down the indicator reading by the meter. These readings are recorded manually in books or on cards and later keyed in manually to a customer accounting or billing system. For meters with AMR facility, readers use handheld data entry terminals (HDETs) to record meter readings. Data from these devices is transferred electronically to a billing system. In other cases, key entry has been replaced by mark-sense card readers or optical scanners.

The environment of meter reading in case of non-AMR mechanical meters usually is not favourable to the meter reader as most of the water meters are installed in underground chamber; these chambers are filled in many cases with water, reptiles, or insects. Often, access to these meters is also obstructed when these meters are installed in the consumers' premises. Sometimes manual work is involved when opening chamber covers. Some consumers connect their electrical earth terminal to water utility pipe which endangers the safety of the meter reader. If during the meter reading visit the consumer premises are not accessible, the meter reader will have to visit it again which increases the cost of meter reading.

The solution to above difficulties is to install automatic system to read meters and process the results by computer. Because of development in integrated circuit technology and low powered radio transceivers, this system, to some extent, is simplified.

The data can be captured by the meter readers from the meter in one of the following ways:

1. Manual entry into meter books;
2. Manual entry into portable handheld entry terminals or recorders;
3. Direct electronic entry from meter registers either into portable data terminals or display units from which readings are transcribed in the field;
4. Telemetry link through radio or telephone.

Remote register meters

This system consists of a coiled spring mechanism wound by the register gears in the meter. A small generator is attached to the spring which trips and upwinds when the meter reaches a certain consumption increment. The spinning of generator sends an electrical pulse to the remote display unit installed outside. This system is known as electro-mechanical remote registering. The place of this system is being taken by electronically encoded remote registering. In this type, small printed circuit boards (PCB) are installed between the counter wheels of meter register; wiper blades attached to the counter wheels contact discrete positions on the PCBs corresponding to meter reading digits. A small microprocessor determines the positions of the wiper blades on PCB and converts in serially coded output. Similarly non-contact type optical-encoded sensing technology is also being used.

In order to collect the data from the site, HDET is used. This unit consists of a programmable microprocessor-based unit, with memory, keypad, display unit, and battery power supply. It has an interface part so that necessary meter reading route instructions can be downloaded to the unit from a host computer, and the meter readings themselves uploaded. The meter reader follows the HDET's instructions.

In a remote electronic meter reading system the output from the encoded register meter is captured through a probe attached to HDET. For reading a meter the probe is connected to a receptacle on the outside of consumer's premises.

Presently, some of the systems of automatic meter reading are as follows:

1. Radio

In this system, a radio frequency transmitter is installed in the meter. A receiver is located at a fixed or movable location like a vehicle. Communication between transmitters and receivers takes place at a predetermined time or on demand.

Technological advancement in meter reading such as automated meter reading systems can lead to a better solution to address many issues of the traditional manual meter reading system like need for human resources, efficiency, accuracy, delayed work, unavailability of customer during metering visit by employee, etc. Some of the accrued advantages of automatic water metering are as follows:

i) improvement in efficiency of meter reading;
ii) reduced operating cost;
iii) physical access problems;
iv) estimated billing not necessary;
v) tampering of meter can be detected;
vi) no reading errors.

2. GSM based AMRs

The GSM technology provides services like Short Message Service (SMS) and General Packet Radio Service (GPRS) for retrieving readings from individual houses back to the service provider wirelessly. The GSM network is an efficient, reliable, and secure communication standard that is being used because of its low cost, simple setup, wide operating distance, and less human intervention.

10.2 Flow Meters Introduction

10.2.1 Introduction

Various methods are available for metering flow rate and total flow. Each method has its own specific characteristics, which are directed towards individual installation requirements. In water industry flow rate meter is termed as flow meter and total flow meter is termed as water meter.

A wide range of standard terms are used to describe the essential performance characteristics of instruments and sensors. Some of these terms are as follows.

1. **Accuracy**
   It is defined as the difference between the reading of an instrument and the true value of the measured variable expressed as a percentage of either full scale or true value of the measured variable, i.e., either in terms of full scale or flow rate of the flow meter.

   As far as possible, the accuracy should be selected in terms of percentage of flow rate as it remains constant within the rangeability irrespective of variation in flow rate.
2. **Range**
   The difference between the maximum and minimum values of the physical output over which an instrument is designed to operate normally.
3. **Rangeability/Turndown ratio**
   Describes the relationship between the range and the minimum quantity that can be measured.
4. **Linearity**
   The degree to which the calibration curve of a device matches a straight line.
5. **Resolution**
   The error associated with the ability to resolve output signal to the smallest measurable unit.
6. **Repeatability**
   The quantity which characterises the ability of a measuring instrument to give identical indications or responses for repeated applications of the same value of the quantity measured under stated conditions of use.

10.2.2 Types of Flow Meter

In water works, normally, the following types of flow meters are used. They can be classified in to:

A. Differential Pressure/Head Flow Meter

1. Orifice Flow Meter
2. Venturi Meter
3. Pitot Tube
4. Annubar (Average pitot tube)

B. Linear Flow Meter

1. Turbine Wheel Flow Meter
   - Full bore type
   - Insertion type
2. Variable Area Flow Meter (Rotameter)

3. Vortex Flow Meter
   - Full bore type
   - Insertion type

4. Magnetic Flow Meter
   - Full bore or Inline type
   - Insertion type

5. Ultrasonic Flow Meter
   - Doppler type
   - Transit time type

10.2.3 Advantages and Disadvantages of Flow Meters

A. Differential Pressure/Head Flow Meter

1. Orifice Flow Meter

a) Advantages

i) It can be used for most fluids with some exceptions
ii) No moving parts
iii) Flow rate, indication, and integration are easily obtained
iv) It can be fitted in any configuration of pipeline
v) Suitable for any pipe diameter
vi) Signal can be transmitted long distances
vii) Good accuracy
viii) Suitable for extreme temperature and pressure
ix) Calculation possibilities for unusual situations

b) Disadvantages

i) Rangeability 4:1
ii) Energy cost in terms of head loss
iii) Ideal conditions are required for good accuracy
iv) Suitable for particular range of Reynolds number
v) Accuracy in terms of span
vi) Minimum slope for tapping piping has to be maintained, i.e., 1:10
vii) Very long conditioning section required
viii) Intensive maintenance required
ix) Edge sharpness of the orifice must be assured
x) It requires isolation of pipeline during installation

2. Venturi Meter

a) Advantages

As mentioned under orifice meter, less pressure loss and hence less energy cost.

b) Disadvantages

Same as under Sr. Nos. i, iii, iv, v, vi and x of orifice flow meter, in addition to high capital cost.

3. **Pitot Tube**

a) **Advantages**

As mentioned under orifice flow meter, except at Sr. No. vii, it does not require isolation of pipeline for installation and, comparatively, capital cost of the flow meter is less. Head loss is also less.

b) **Disadvantages**

As mentioned under Sr. Nos. i, iii, v, vi, vii of the orifice flow meter, in addition to inferiority in accuracy as it being point velocity measurement.

4. **Annubar (Average Pitot Tube)**

a) **Advantages**

As mentioned under pitot tube, in addition to higher accuracy.

b) **Disadvantages**

As mentioned under pitot tube, except inferiority in accuracy, i.e., accuracy improves due to averaging of multi-ported pressures.

B. Linear Flow Meter

1. **Turbine Wheel Flow Meter**

I. Turbine Wheel Flow Meter (Full bore or Inline)

a) **Advantages**

i. Excellent accuracy, linearity, and repeatability
ii. Usable at extreme temperature and pressure

b) **Disadvantages**

i. Suitable for only for low viscosity
ii. Moving parts and hence wear
iii. Sensitive to contamination
iv. Flow profile sensitive and needs conditioning section
v. Affected by overloading, danger of over speeding
vi. Sensitive to vibration
vii. Isolation of pipeline is required for installation.

II. Turbine wheel flow meter (Insertion type)

a) **Advantages**

i. Isolation of pipeline is not required
ii. Low cost

b) **Disadvantages**

i. Inferior accuracy because of point velocity measurement
ii. Suspended impurities can clog it. In addition to above, the disadvantages mentioned under turbine wheel flow meter (full bore) are also applicable.

2. **Variable Area Flow Meter (Rotameter)**

a) Advantages

i. Inexpensive
ii. No power supply required for local indication
iii. No conditioning section
iv. Easy maintenance

b) Disadvantages

i. It requires vertical installation
ii. Affected by density and temperature of the fluid
iii. Affected by vibration and pulsation

3. Vortex Flow Meter

I. Full bore or Inline type

a) Advantages

i. No moving parts
ii. Robust construction
iii. Unaffected by temperature, pressure, and density changes

b) Disadvantages

i. Conditioning of long approached section
ii. Span limitation due to viscosity
iii. Shedding rate is nonlinear between 2000 and 10000 Reynolds's number
iv. Available up to 400 mm size due to constraints of sensitivity
v. Isolation of pipeline is required for installation

II. Insertion Vortex Flow Meter

a) Advantages

i. Isolation of pipeline for installation is not required
ii. Less costly than that of full bore
iii. In addition to above the advantages mentioned under full bore vortex, flow meter is also applicable.

b) Disadvantages

i. Inferior accuracy due to point velocity measurement in addition to above the disadvantages mentioned under full bore vortex meter are applicable except at Sr. No. V.

4. Magnetic Flow Meter

III. Full bore (Inline) Flow Meter

a) Advantages

i. Unobstructed f low passage
ii. No moving parts
iii. No additional pressure drop
iv. Unaffected by changes in temperature, density, viscosity, electrical conductivity
v. Flow range setting can be optimised
vi. Suitable for water containing suspended solids
vii. Short conditioning section is required as it is insensitive to flow profile

viii. Measures flow both the directions
ix. Minimum maintenance
x. Good linearity
xi. Smaller diameter flow meter can be used on bigger diameter pipe with the help of reducers having angle not more than 160.

b) Disadvantages

i. Air or gas inclusion causes error
ii. Minimum required conductivity of fluid 0.5 m S/ cm.
iii. Isolation of pipeline is required for installation
iv. Vacuum creation may detach inner liner

IV. Insertion Magnetic Flow Meter

a) Advantages

i. Less costly than that of full bore
ii. No isolation of pipeline for installation
iii. Advantages mentioned under Sr. Nos. ii, iv, v, vi, viii, ix, x, xi of full bore magnetic flow meter are applicable.

b) Disadvantages

i. Inferior accuracy due to point velocity measurement
ii. Long conditioning section is required
iii. Sensitive to vibration
iv. Periodic cleaning of electrode is required

5. Ultrasonic Flow Meter

V. Doppler type Ultrasonic Flow meter

a) Advantages

i. Unobstructed flow passage
ii. No moving parts
iii. No pressure drop
iv. Measures flow in both directions
v. Installations of individual elements in existing pipelines possible
vi. Minimum maintenance
vii. Economical for large diameter pipe
viii. Suitable for turbid water

b) Disadvantages

i. Not suitable for clear water
ii. Accuracy is inferior
iii. It requires long conditioning section
iv. Ultrasonic meters are usually complicated to setup and calibration initially

a. Transit Time (Time of Flight) Ultrasonic Flow meter

a) Advantages

i. Advantages mentioned under Sr. nos. i, ii, iii, iv, v, vi, vii of Doppler type are applicable
ii. Accuracy is improved in multipath

iii. Accuracy is superior in insertion (wetted type) than that of clamp type.

b) **Disadvantages**

i. It requires long conditioning section
ii. Not suitable for turbid water or carrying air/gas bubbles.

10.2.4 Installation of Flow Meter

Every user expects a problem-free installation of the meter and thereafter only accurate readings. Regular monitoring is desirable in order to avoid failures.

The meter is installed in the pipeline using flanged or threaded connections giving due consideration for conditioning sections. The stress-free installation is carried out in the pipeline. It is essential to install the flow meter co-axially to the pipeline without protruding any packing or gasket into the water flow stream.

In the case of ultrasonic meters, the probes are welded on the pipeline which requires care to see that no projection is protruding in the pipeline. In this case, onsite calibration is essential. Wherever converters are used with primary elements, it should be observed that the connection between them should be protected against lightning strikes and any other interference.

Installation into an existing pipeline requires shutting down the water supply. This necessitates short installation time. Installations shall be carried out as per manufacturers' recommendations. In such instances, bypass to the meter must be provided for regular maintenance.
In the case of differential pressure type flow meters, the impulse piping requires special care in respect of slope and protection. Similarly, long disturbance free straight sections should be provided for uniformity. Installation should be vibration- free as moving parts in the flow meter will get worn out in addition to the effect on overall accuracy of the flow meter.

Installation in 'U' shape is essential for intermittent water supply. Flow meters should be provided with battery backup in order to retain integrator reading during failure of electric supply.

10.2.5 Maintenance of Flow Meter

Most modern flow meters have a self-monitoring facility provided with which the maintenance staff monitors the health of the equipment. A number of instruments are enunciating the error conditions.

As long as orifice, Pitot tube, Venturi and Annubar flow meters are concerned they require regular purging of impulse piping. Similarly, the transducers require periodical checking of zero and range setting. For the orifice it is essential to check sharpness of the edge as in the case of its deterioration or damage the flow meter reading may vary up to 20%.

Ultrasonic and magnetic flow meters being self-monitoring, give information regarding deviation in accuracy or failure of probe or electrode. Whenever cleaning of probes or electrodes is required, those should be cleaned as per manufacturers' recommendation.

Turbine meters should be checked for bearing wear periodically (again how is periodically defined throughout this chapter and the O&M – proper guidance needs to be provided and added to this chapter) as presence of air in the liquid may damage the bearing because of over speeding.

Deposits are to be expected in any flow meter. These deposits affect the accuracy of the measurement, Vortex meter, Magnetic flow meter, Ultrasonic flow meter, may show erroneous reading in the presence of deposits. In an intermittent water supply the corrosion rate of the pipe increases due to chlorine and air. The formation of incrustation and subsequent descaling affect flow meter working especially differential pressure type, turbine meters.

- Flow meters typically contain internal Strainer and Non-Return Valve (NRV).
- These units need to be checked periodically to prevent choking of meter due to presence/flow of any foreign materials inside the pipe.
- Water meters need to be sealed to prevent any incidents of tampering. Figure 10.2 shows Pictorial Diagram for Sealing of Mechanical Water Meter.

Simple Procedure for Sealing of Water Meter

1. Tie a sealing wire from the hole of check nut.
2. Tie a sealing wire in opposite side of check nut.
3. Put end wire in head of another end.
4. Lock the cap and note down.
5. Tag the meter sealing number in billing software/manual.

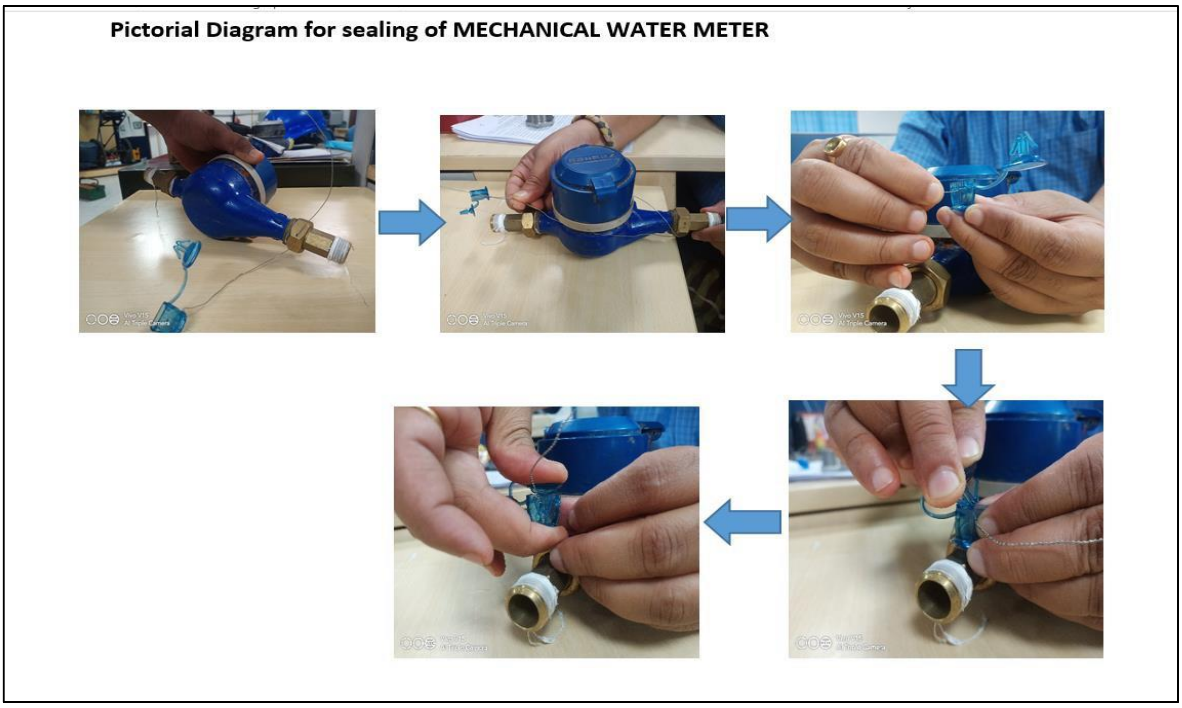


Figure 10.2: Pictorial Diagram for Sealing of Mechanical Water Meter

10.2.6 Calibration of Flow Meters

Flow calibration is essential to:

i) confirm performance of flow meter;

ii) quality control;
iii) comply with statutory or legal requirements;
iv) provide traceability of measurement and confidence in resultant data.

The calibration is normally carried in the flow laboratory with the help of one of the following methods.

i) Gravimetric
ii) Volumetric
iii) Prover
iv) Master or reference meter
v) Tow tank – current meter calibration

There are two philosophies of flow meter calibration. One is that it is better to have a fixed calibration system with all the associated technical back up and with the flow meters being brought to the calibration system, the other favours calibrating in situ leaving the flow meters in their installed condition and using a portable calibrator. The former will generally provide the more accurate calibration, but the latter has the advantage that site specific effects such as proximity to hydraulic disturbances can be taken into account. It is necessary to decide carefully to adopt the option.

There is often no choice but to carry out in site calibration where:

i) Flow cannot be shut off
ii) Site specific conditions have to be accounted for
iii) The meter is so large that removal, transport, and testing costs would be prohibitive.

The major constraint with in situ calibration technique is that the high accuracy laboratory calibration cannot be matched in the field and accuracies of ±2% to ±5% is all that can be achieved and such field tests are called confidence checks rather than absolute calibrations. Such checks are often the precursor to removal of flow meter for laboratory calibration or replacement.

For field test following methods can be used.

i) Clamp on devices
ii) Thermodynamic method
iii) Velocity area methods (insertion meters)
iv) Tracer methods
v) Flow simulators

Normally the manufacturers of the flow meters provide laboratory calibration of the flow meters in their manufacturing facility. Some Government agencies also provide laboratory calibration, viz., Fluid Control Research Institute (FCRI), Palakkad, Kerala, Central Water a Power Research Station (CWPRS), Pune, Maharashtra, and Institute for Design of Electrical Measuring Instruments (IDEMI), Mumbai, and Maharashtra.

Details of various flow meters in respect of following features are given in respective tables.

Average accuracies	:	Table – 10.5
Broad areas of applications	:	Table – 10.6
Performance factors	:	Table – 10.7
Installation constraints	:	Table – 10.8
Fluid property constraints	:	Table – 10.9
Economic factors	:	Table – 10.10
Installation and maintenance	:	Table – 10.11
Common problems encountered	:	Table – 10.12
Applicable standards for flow meters	:	Table – 10.13

Table 10.5: Average Accuracies of Various Flow Meters

S. No.	Type of flow meter	Accuracy %
1.	Square edge orifice	±1S
2.	Venturi	±1S
3.	Pitot	±2S
4.	Annubar	±1S
5.	Turbine	±0.5R
6.	Rotameter	±2S
7.	Vortex	±1R
8.	Magnetic	±0.5R
9.	Doppler	±2S
10.	Transit time	±1R

Legends: S: in terms of full scale
R: in terms of flow rate

Table 10.6: Broad Areas of Application of Flow Meter for Liquid

	z	A	B	C	D
Orifice		0	+	0	0
Venturi		0		0	0
Variable Area		0	0		
Annubar		0		0	0
Turbine		0		0	*
Insertion turbine		0		0	0
Vortex		0			
Insertion Vortex		0		0	0
Electro Magnetic		0	0	0	0
Insertion Electro Magnetic		0		0	0
Doppler		0		+	+
Transit time		0	+	0	0

Legends: 0 is suitable, generally applicable
C: Large liquid flows
+ is worth considering, sometimes applicable ($>1.7 \times 10^4$ L/min.)

* is worth considering, limited availability

D: Large water pipes

Or tends to be expensive. (>500 mm dia.)

A blank indicates unsuitable;

Liquids (temp. >200 °C), not applicable.

A: General liquid application (<50 CP)

B: Low liquid flows (<2 L/min)

Table 10.7: Performance Factors of Flow Meter

S. No.	Type of the flow meter	Linearity %	Repeatability %	Rangeability	Pressure drop at maximum flow	Flow parameter measured
1.	Orifice	0.25% FS to 1%FS	±0.2% FS	3 or 4:1	3–4	R
2.	Venturi	0.25% FS to 1%	±0.2% FS	3 or 4:1	2	R
3.	Variable area	±1% FS to ±5%	±0.5% FS to ±1% FS	1% FS	10:1	3R
4.	Annubar	0.5%A to 1%A	±0.05% A to ±0.2% A	4 to 10:1	1/2	Vm
5.	Turbine	±0.15% A to ±1%	±0.02% A to ±0.5% A	5 to 10:1	3	R
6.	Insertion Turbine	±0.25% A to ±5%	±0.1% A to ±2% A	10 to 40:1	1-2	Vp
7.	Vortex	±1% A	±0.1% A to ±1% A	4 to 40:1	3	R
8.	Insertion Vortex	±2% A	±0.1% A	15 to 30:1	1	Vp
9.	Electro Magnetic	±0.2% A to ±1% A	±0.1% A to ±0.2% FS	10 to 100:1	1	R
10.	Insertion Elec.Mag.	±2.5% A to ±4% A	±0.1% A	10:1	1	Vp
11.	Doppler	No data	±0.2% FS	5 to 25:1	1	Vm, R
12.	Transit time	±0.2 A to ±1% A	±0.2% A to ±1% FS	10 to 300:1	1	R

Legends: A: Flowrate   Vp: Point velocity   NS: Not specified T:
Volume flow   % A: Percentage flowrate   1: Low
Vm: Mean velocity   % FS: Percentage full-scale   5: High

Table 10.8: Installation Constraints for Flow Meter

Type	Orientation	Direction	Quoted range of upstream lengths	Quoted range of minimum downstream	Pipe Diameter mm
Orifice	H, VU, VD, I	U, B	5D/80D	2D/8D	6 to 2600
Venturi	H, VU, VD, I	U	0.5D/29D	4D	>6
Variable area	VU	U	0D	0D	2 to 150
Annubar	H, VU, VD, I	U, B	2D/25D	2D/4D	>25
Turbine	H, VU, VD, I	U, B	5D/20D	3D/10D	5 to 600
Insertion turbine	H, VU, VD, I	U, B	10D/80D	5D/10D	>75
Vortex	H, VU, VD, I	U	1D/40D	5D	12 to 400
Insertion vortex	H, VU, VD, I	U	20D	5D	>200
Electromagnetic	H, VU, VD, I	U, B	0D/10D	0D/5D	2 to 3000
Insertion magnetic	H, VU, VD, I	U, B	25D	5D	>100
Doppler	H, VU, VD, I	U, B	10D	5D	>25
Transit time	H, VU, VD, I	U, B	0D/50D	2D/5D	>4

Legends: H : Horizontal flow
VU : Upward vertical flow
VD : Downward vertical flow
I : Inclined flow
U : Unidirectional flow
B : Bidirectional flow
D : Inner diameter of the pipe

Table 10.9: Fluid Property Constraints for Flow Meter

S. No.	Type	Maximum pressure(bar)	Temperature Range (˚C)	Minimum Reyno1d's number	More than one phase (Gas or liquid).
1.	Orifice	400	<650	3 × 104	P
2.	Venturi	400	<650	105	P
3.	Variable area	700	-80 to + 400	No data	N
4.	Annubar	400	<540	104	N
5.	Turbine	3500	-260 to +530	104	N
6.	Insertion Turbine	70 to 250	-50 to +430	104	N
7.	Vortex	260	-200 to +430	2 × 104	P
8.	Insertion Vortex	70	- 30 to +150	5×10^3	N
9.	Electromagnetic	300	-60 to +220	No limit	S/P
10.	Elect. Insertion	20	+5 to +25	No data	N
11.	Doppler	Pipe pressure	-20 to +80	5×10^3	S
12.	Transit time	200	-200 to +250	5 × 10	N/P

Legends: S: Suitable P: Possible N: Not suitable

Table 10.10: Economic Factors of Flow Meters

Type	Installation cost	Calibration cost	Operation cost	Maintenance cost	Spares cost
Orifice	2–4	1	3	2	1
Venturi	4	1–4	2	3	3

Type	Installation cost	Calibration cost	Operation cost	Maintenance cost	Spares cost
Variable area	1–3	2	2	1	1
Annubar	2	3	2	2	2
Turbine	3	4	3	4	4
Insertion Turbine	2	3	2	2	3
Vortex	3	3	3	3	3
Insertion Vortex	2	3	2	3	3
Electromagnetic	3	3	1	3	3
Elect. Insertion	2	3	2	3	2
Doppler	1–3	1	1	3	2
Transit time (time of flight)	1–3	3	1	3	2

Legends: 1: Low 5: High

Table 10.11: Installation and Maintenance of Flow Meters

Type	Installation	Pipeline ahead of meter	Maintenance during operation	Self-monitoring	Service
Turbine meter	Flanged connections electrical installation	Conditioning section	Maintenance free, monitor, possible foreign lubrication	Not possible	-
Vortex meter	Flanged connections or water installation, electrical	Conditioning section installation	Maintenance free	Error monitoring	Electronic monitor functions and test values
Differential pressure meters	Primary in flanges, impulse piping, convertor power	Long conditioning sections	Regular monitoring	Not possible	Direct measurement at primary
Variable area meter	Flanged or threaded connections	No restrictions	Maintenance free	Constant appearance	-
Electromagnetic flow meter	Flanged connections, electrical connections	No conditioning section	Maintenance free	Monitoring with error announcements	Electronic control functions and test simulator
Ultrasonic meter	Flanged connections or welding nipples,	Long conditioning section	Maintenance free	Signals for signal loss	-

	electrical installation				

Table 10.12: Common Problems Encountered in Flow Meter Performance

S. No.	Problems	Causes	Flow Meter	Remedial Action
1.	Erratic reading	Operated below lower range having limited rangeability of flow meter	Differential pressure type	Replace flow meter
		Operated below lower range having limited rangeability of flow meter	Linear flow meter	Change range setting
		Less static pressure	D.P. type	Remove air trap
		Clogged impulse	D.P. type	Clear the choke up
		Air trapped in impulse	D.P. type	Remove air trap
		Frequent air trap in impulse piping	D.P. type	Change impulse piping slope to minimum 1: 10, If still the problem persists change the flow meter.
		Damaged impulse piping	D.P. type	Rectify impulse piping
2.	Unsteady reading: (oscillating)	L ratio more than 0.65	D.P. type	Redesign orifice
		Pulsating flow	D.P. and Linear type	Condition the flow
3.	Inaccurate reading	Pipeline internally incrusted	D.P. and Linear type	Clean the internal surface of pipeline
		Scaling is formed at tapping points	D.P. type	Clean the tapping points
		Orifice edge gets blunt	D.P. type	Replace orifice plate
		Flow meter downstream is opened within the range of 50 times diameter pipe length	D.P. type	Extend the downstream pipeline beyond 50 diameter length
		Unsymmetrical formation of vena contract due to large diameter of throat in relation to static	D.P. (orifice type)	Redesign the orifice
		Mismatch between flow meter and pipeline	D.P. and Linear type	Remove the mismatch
		Absence of sufficient conditioned approach pipeline	D.P. and Linear type	Provide sufficient conditional approach pipeline
		Foreign particles such as pieces of concrete, bricks, debris etc. are	D.P. (Orifice)	Remove them

S. No.	Problems	Causes	Flow Meter	Remedial Action
		gathered at upstream of orifice		
		Flanged coupling used with flow meter leaking	D.P. and Linear type	Rectify the leakage
		Pipeline may not be cylindrical within the range of 0.3% of the diameter of the pipe	D.P. and Linear type	Replace the pipe length of 2 times dia. immediate upstream of the flow meter
		Pipeline partially filled	D.P. and Linear type	Install valve downstream of the flow meter for throttling

Table 10.13: Applicable Standards for Flow Meters

BS: 7405: 1991	Selection and application of flow meters for the measurement of fluid flow in enclosed conduits
BS: 1042	Methods for the measurement of Fluid flow in pipes – Orifice plates, Nozzles and Venturi Tubes
BS: 5792:1980	Specification for electromagnetic flow meters
BS EN ISO: 6817-1997	Measurement of conductive liquid flow in closed conduits – Method using electromagnetic flow meters
ISO Recommendation — R541 1967(E)	Measurement of fluid flow by means of orifice plates and nozzles
ISO 9104-91/BS 7526: 1991	Measurement of fluid flow in closed conduits – Method of evaluating the performance of electromagnetic flow meter for liquid
BS: 6199: 1991/ISO9 368/1990	Measurement of liquid flow in closed conduits using weighing and volumetric methods
Superseeded by : IS 14615 : Part 1:2018	Measurement of Fluid Flow by Means of Pressure Differential Devices Inserted In Circular Cross-Section Conduits Running Full Part 1 : General Principles and Requirements
IS 2951: 1965, reaffirmed 2022	Recommendations for estimation of flow of liquids in closed conduits – Part I: Head loss in straight pipes due to frictional resistance
IS 14615 Part I: 2018	Measurement of fluid flow by means of pressure Differential devices - Part I: Orifice plates, nozzles and venturi tubes inserted in circular
IS 9115 – 1979, reaffirmed 2022	Method for estimation of incompressible fluid flow in closed conduits by Bend meters

10.3 Instrumentation

10.3.1 Level Measurement

Instrumentation facilitates co-ordination of various water parameters, which are essential for optimisation of water supply and treatment plant. One of the most important parameters amongst them is water level measurement, which is carried out at various locations: water reservoir, inlet chamber, open channel, alum feeding tank, lime tank, filter beds, air vessel, sump well, etc. Level instrumentation includes a range of level measurement equipment including switches, transducers, and radars. These instruments play a vital role in water tanks maintain levels and indicate the time-to-time tank levels.

Schedule maintenance is important for the level measuring devices since these devices are constantly working under wet and damp conditions.

Level measurement is accomplished in water works in two ways.

A. Direct Method
B. Inferential Method

Their Advantages, Disadvantages as well as uses are given below in brief.

A. Direct Method

Hook Type Level Indicator	Sight Glass	Float Type Indicator
Advantages		
i. Low cost ii. Simple	i. Inexpensive ii. Corrosion resistive iii. Simple	i. The level can be read at a convenient place ii. Operates over large temperature range iii. Very accurate
Disadvantages		
i. Only local reading ii. Human error may be encountered in reading	i. Only local reading ii. Accuracy and readability depends on the cleanliness of glass and fluid iii. It is fragile	i. They are tailored to tank geometry ii. Requires a certain amount of mechanical equipment
Uses		
i. Inlet channel level	i. Filter bed level ii. Reservoir level iii. Head loss in the filter	i. Filter bed ii. Final water reservoir iii. Sump well iv. Lime tank

B. Inferential Method

Hydrostatic Pressure Gauge Type and Pressure Bulb Type	Displacer Level Type	Electrical Method (Capacitance Type)	Ultrasonic
Advantages			
i. Easy maintenance ii. Simple to adjust iii. With pressure, bulb type remote reading possible iv. Reasonably accurate	i. Excellent accuracy ii. Possible at remote places	i. Good accuracy ii. Possible at remote places iii. Very sensitive iv. Suitable for highly corrosive media	i. Good accuracy ii. Possible at remote places iii. Suitable for liquid as well as bulk products
Disadvantages			
i. The instrument must be installed at base reference level for gauge type ii. Pressure bulb type relatively costly	i. Limited range ii. High cost iii. Requires stilling chamber iv. Requires a significant amount of mechanical equipment	i. Affected by dirt and other contaminants ii. Affected by temperature	i. Affected by foam ii. Not suitable for high temperature and pressure
Uses			
i. Delivery head of the pump (pressure gauge type) ii. Clear or raw water reservoir iii. Sump level	i. Clear water reservoir ii. Raw water reservoir	i. Raw water reservoir ii. Clear water reservoir	i. Raw water as well as clear water level, i.e. inlet channel sump level, etc. ii. Lime tank iii. Sludge level

10.3.1.1 Maintenance of Level Measuring Instruments

a) Sight Glasses

- After closing top and bottom valves remove the glass and clean with soap water using brush. Clean with fresh water. Assemble the parts again in proper order.

b) Float Operated Instrument

- Guide cable wound round a pulley should be lubricated. Other moving parts should also be lubricated.
- Zero setting should be checked. Float should be checked from corrosion point of view.

c) Hydrostatic Pressure Instruments (Pressure Gauge Type)

- Check for zero setting after disconnecting from the system and purging out.
- Check for the leakages from the connection after reconnecting it.

d) Pressure Bulb Type

- Check for zero setting. Check for air leakages from the bulb by applying soap water.
- Check coupling from corrosion point of view.
- Clean the bulb with fresh water.
- Check for the correctness of the signal by moving the bulb in the water.
- Clean the instrument and check for zero and range setting.

10.3.1.2 Electrical or Ultrasonic Instrument

Level sensors have now become popular to determine the level of water and different type of transmitters are available based on application. The popular transmitters are radar and ultrasonic level transmitters. Many radar level instrument configurations have self-diagnosing capabilities able to determine if the sensor parts are getting coated with dirt or build-up. A loss of signal strength is an indicator of fouling and can warn of accumulations long before they affect the device’s accuracy.

In order to operate properly, an ultrasonic sensor needs a clear path from the transducer face to the surface it is monitoring. If there is some kind of solid buildup or condensation occurs on the face of the transducer, the level indicators would not work properly. Hence, periodic visual inspection is necessary.

10.3.2 Pressure Measurement

In water supply network, pressure parameter plays a very important role in order to get sufficient water to the consumers. Measuring pressure at different locations across DMA helps in understanding flow of water, leakages across water distribution network.

10.3.2.1 Instruments for Pressure Measurement

This pressure or differential pressure measurement is accomplished with the help of following methods in water works.

A. **Manometers:** A manometer is an instrument used to measure and indicate pressure.

There are two types of manometers, analogue and digital.

B. **Elastic Pressure Transducer:** convert the pressure into mechanical displacement which is later converted into an electrical form using a secondary transducer.

C. **Electrical Pressure Transducer:** It uses a sensor capable of converting the pressure acting on it into electrical signals. These electrical signals are then relayed to controllers or Programmable Logic Controllers (PLCs) where they are then processed and recorded.

10.3.2.2 Advantages and Disadvantages of Pressure Measurement Instruments

The advantages and disadvantages of the instrument of pressure measurement normally used in waterworks are given below.

A. Manometers

U Tube Manometers	Well Type Manometers	Inclined Manometers
Advantages i. Simplest ii. Low cost	i. Zero reference setting is possible ii. Low cost	i. More sensitive ii. Low cost
Disadvantage i. No fixed reference ii. Large and bulky iii. Need for levelling iv. No over range protection	i. Accuracy inferior to U tube manometer ii. Large and bulky iii. Need for levelling iv. No over range protection	i. Large and bulky ii. Need for levelling iii. No over range protection
Uses i. For measurement of differential pressure in D.P. type flow meter and calibration of D.P. type transducers	i. For calibration of D.P. type flow meters and measurement of differential pressure in D.P. type flow meter	i. For measurement of very small pressure differences

B. Elastic Pressure Transducer: Bourdon tube type pressure gauge:

a) Advantages

(i) Low Cost
(ii) Simple construction
(iii) Time tested in water automation applications
(iv) Availability in a wide range
(v) Adaptability to electronic instruments
(vi) High accuracy in relation to cost

b) Disadvantages

(i) Low spring gradient below 3 kg/cm^2
(ii) Susceptibility to shock and vibration
(iii) Susceptibility to hysteresis
(iv) Accuracy in terms of full scale deflection

c) Uses

(i) Pump delivery and suction

(ii) Water supply distribution network

(iii) Air receivers

(iv) Chlorinators

(v) Pump cooling water

C. Electrical Pressure Transducer

In this category, the following types are:

1. Strain gauge pressure transducer
2. Potentiometric pressure transducer
3. Capacitive pressure transducer
4. Variable reluctance pressure transducer
5. Piezo electric pressure transducer

The advantages and disadvantages of electrical pressure transducers commonly used in water works are as follows:

Strain gauge pressure transducer	Potentiometric Pressure Transducer	Capacitive Pressure Transducer	Variable Reluctance Pressure Transducer	Piezo electric pressure transducer
Advantages	**Advantages**	**Advantages**	**Advantages**	**Advantages**
a) No moving parts b) have small dimension c) easy to handle	a) Widely used in Industry as these are simpler and less expensive b) Easy compatibility with the requirement	a) Short response time b) Vibration proof c) Extremely sensitive d) It can measure static e) as well as dynamic changes	a) Excellent linearly b) Good repeatability c) Low hysteresis d) High sensitivity	a) Have small dimensions b) have large measuring range, c) easy to handle, install and use. d) High-frequency response e) Robust f) Performance and calibration is stable over time
Disadvantages	**Disadvantages**	**Disadvantages**	**Disadvantages**	**Disadvantages**
a) Non-linear b) Needs regular calibrations	a) Finite resolution b) Wear out early c) Noise signal is generated	a) Sensitivity changes with temperature	a) Relatively large size b) More nos. of components c) More maintenance	a) Cannot be used for truly static measurements. b) Consume more power than some other types of pressure sensor. c) Sensors are

				sensitive to vibration or acceleration
Uses	**Uses**	**Uses**	**Uses**	**Uses**
a) tailored for force, torque, pressure and displacement measurements b) Has its limitations in terms of temperature, fatigue, the amount of strain, and the measurement environment. These limitations must be examined before a strain gauge is used. c) Applications range from medical devices, smart phones, commercial scales, tank and vessel weighing, web-tension and bathroom scales.	a) Where less accuracy is required	b) Distribution network c) In process instrumentation	a) Distribution network b) In process instrumentation	a) Can only be used for dynamic pressure measurement. b) Widely used in biomedical applications, automotive industry and household appliances

10.3.2.3 Calibration of Pressure Measuring Instruments

Pressure instrument calibration is the process of adjusting the instrument's output signal to match a known range of pressure. All instruments tend to drift from their last setting. This is because springs stretch, electronic components undergo slight changes on the atomic level and other working parts sag, bend or lose their elasticity.

The calibration procedure includes zero, span, and linearity adjustments. The pressure is varied with the help of pneumatic calibrator so as to give desired pressures to the instrument. The settings are carried out on the instrument for zero and span adjustment on the basis of applied pressures. For carrying out linearity setting various pressures between zero and maximum range of the instruments are applied and adjusted the output of the measuring instrument with the help of controls provided in the instrument.

In the case of pressure gauges, the calibration is carried out by means of dead weight tester. In absence of pneumatic calibrator, the air can be supplied to the instrument with proper pressure regulator and pressure is measured with the help of manometer so as to calibrate the instrument.

The calibration should be checked every 3, 6, or 12 months depending upon the use and accuracy expected. Maintenance of pressure instruments is essential for their proper working and accurate reading. It also improves the life and reliability of the instruments.

10.3.3 Preventive Maintenance

The manufacturer of the instrument gives the instructions in the manual supplied along with the instruments. These instructions explain how to maintain the instrument. Generally, these consist of following categories.

1. **Visual Inspection**
   Any damage to piping or wiring of the instrument observed should be immediately rectified. It avoids entry of foreign bodies into the system and further damage to the instrument.
2. **Venting or Blow Down**
   Liquid lines are generally clogged subsequently if those are not vented periodically. Similarly, air or gas in the liquid columns gives wrong readings. In order to avoid such incidents, it is essential to blow down the instrument piping periodically on the basis of experience gained in the field.
3. **Cleaning and Lubrication**
   Instruments with mechanical linkages undergo wear and misalignment. Dirt may clog the linkages, causing the mechanism to become less flexible. If these kinds of faults are not attended, the instrument may break down subsequently. This clogging can be removed by cleaning and working of the instrument can be improved by lubrication as per manufacturer's recommendations. Dust can be removed from the panels as well as from the instruments with the help of air blower. If auto test facility is provided on the instrument by the manufacturer the same can be used to check the performance of the instrument daily. If any kind of fault occurs, in such instrument, the same is identified and displayed by the instrument itself. Table 10.14 shows a typical trouble-shooting chart for pressure and level measuring instrument (electronic transmitter type).

Table 10.14: A Typical Trouble Shooting Chart for Pressure and Level Measuring Instrument (Electronic Transmitter Type)

Fault	Possible Causes	Corrective Action
Low output or zero output or high or erratic output	Power Supply	Check output of power supply
		Check for short and multiple
		Check polarity of connections
		Check loop impedance
	Pressure	Check the pressure connection
		Check for leakage or blockage
		Check for entrapped air or gas in
	Transmitter	Check for shorts in sensor leads
		Check connector to transmitter
		Check for amplifier assembly by replacing it with spare one
	Sensing element	Check sensing element for its working

Fault	Possible Causes	Corrective Action
		by gently tapping it.
Tapping by hand gently the sensor does not respond	Mechanical	Check mechanical linkage
		Check for dirt finding
		Excessive wear, misalignment
		For dirt clean and lubricate as per manufactures recommendations
		Realign Mechanical parts if
		For wear replace the worn-out
	Electrical	Replace electrical/electronic subassemblies and perform calibration

10.3.4 Maintenance of Electric Pressure Transmitters

Complete maintenance of a pressure transmitter involves three distinct operations: configuration, calibration, and adjustment. The configuration tasks can be accomplished with a communicator which would communicate with the transmitter and verify its configuration data. On the other hand, adjustment and calibration require equipment that can accurately source pressure and measure current.

Pressure transmitter can have several possible adjustment procedures such as:

- **Rearranging:** sets the lower and upper range points at required pressures, similar to adjusting zero and span on an analogue transmitter.
- **Analogue Output Trim:** adjusts the transmitter's analogue output to match external standards. This essentially adjusts the transmitter's digital-to-analogue converter.
- **Zero Trim:** adjusts the input sensor to compensate for pressure offsets, typically due to installation and orientation.
- **Sensor Trim:** adjusts the factory sensor. This adjusts the analogue-to-digital converter to compensate for sensor errors.
- Pressure transmitters should be mandatory calibrated every once in a year from a reputed accredited NABL lab.

10.4 Automation

10.4.1 Introduction

In small and medium plants, the supervision and co-ordination of various activities can be carried out by the operator manually. However, for large plants, it becomes cumbersome to supervise, operate, co-ordinate, and control it. It is preferable to use PLC-based control system to control these systems.

The process of monitoring the parameter, comparing it with the set values, manipulating the signals and sending the instructions to concerned equipment for taking action is known as automation. Automation entails the replacement or elimination of intermediate components of a system or steps in a process, especially those involving human intervention or decision making, by technologically more advance ones.

The backbone of automation in water supply system consists of: a) water distribution network with electrically (not in all situations) actuated valves (butterfly valves) that controls the flow of water to the households, area-wise and streetwise; b) At the pump side, the system monitors all the electrical parameters of the pump and also controls the pump speed (Variable Frequency Drive) taking the inputs from different control valves at every distribution level; c) The water level sensors will be designed to monitor the availability of water in the ground level storage points; d) The system identifies the leaks based on pressure information and informs the position of leak accurately so that the water gets conserved and also helps to attend the leakage in time; and e) Water quality parameters like, pH, turbidity, and free residual chlorine can be monitored. Other water quality parameters like, temperature, conductivity, dissolved oxygen can be considered in the system design.

10.4.2 Automation of Tubewells

10.4.2.1 General

The remote tube well monitoring and control system enables real-time data collection from the tube well on various parameters and key performance indicators. This knowledge can be used to drive analytics, uncovering tube well performance insights and improvement opportunities, ultimately enabling operational staff to make informed and systematic decisions and thus, reduce operational costs of the entire plant.

Advantages of tube well automation:

a) Complete remote monitoring of water lifted from tube well, pump working hours, water distributed, and electricity consumed.
b) It also helps in monitoring the parameters like water quality, valve status as well as electrical parameters of drives including status of pumps.
c) Also, data regarding water quality in each season, day to day consumption, and pressure and flow measurements at every section of transmission line, levels at each Elevated Service Reservoir (ESR) can be obtained in one platform. Thus, it will help in analysing the performance of the scheme and the areas in which planning is required for optimum service.

10.4.2.2 Establishing System Automation Process

An online remote monitoring system is to be designed to operate, record the working hours of tube well's pumps and motors, duration of operation, water level and discharge, water quality and electricity consumption.

A control room is to be established from where operation and monitoring of whole system can be done. The pumps installed on the tube wells can be automated with features of on/off in accordance with the level of the elevated storage tank. It can be done via remote control panel and soft starter. Also, remote monitoring devices with data loggers can be incorporated which would enable users to monitor pumps and to determine the faults and factors leading up to it. Flow, pressure, absorbed power, and vibrations can all be monitored to create a condition-based monitoring profile eliminating inspection intervals.

Actuators can be mounted on the valves on the inlet pipe of the ESR and also on the supply valves for remote application.

Pressure transmitters, flow transmitters with GPRS are to be installed at different sections of transmission right from water lifting to distribution. For this, pressure probes are inserted in the pipeline at different sections. Drop in pressure at any section of transmission would indicate leakages thus helping in immediate action for necessary repairs thus reducing water losses.

Level transmitters can be fixed at the ESRs to monitor the real time water consumption and for decision making in equitable water distribution. The water quality can be monitored through turbidity, pH, and chlorine analysers installed in the ESR with control panels and data transmission to control room through GPRS.

S. No.	Problems in automation	Remedial measures
1	Unrealistic expectations for Automated system: Automation has many benefits in terms of operation of the system. But that doesn't mean automation of whole system will assure improved efficiency.	Proper strategy and planning should be put into action for optimum utilisation of automation system. Manual operations should not be ignored completely.
2	Using the wrong tool: With many options of tools available for application of automation, the output will not be effective if proper tool has not been adopted.	The tools adopted should comply with the requirement of the system which is to be automated. The tool should give required output, should be affordable, and should be easy to use.
3	Automating non required functions and ignoring useful ones: Automation planning starts by randomly automating functions in the system. This leaves with low automation coverage and too many useless automated functions. Moreover, with this approach, risk of not covering the important scenarios and having gaps in system increases.	Finding out which functions exactly has to be automated for optimum utilisation.
4	Lack of proper training and capacity building in automation: Automation gives a false sense of security. With automated functions running repeatedly, it's leads to reduced human intervention and responsibility for the results. This leads to devastating results	Proper trained staff to be deployed in automated system. Extensive training to be given to them so that they know their roles in the process and have enough technical skills to support the process.
5	Data security: The data can be transmitted through a variety of different communications platforms which mainly fall under either hardwire or wireless category. Options for wireless data transmission include satellite, radio, cellular, and Wi-Fi.	To select reliable and secure communication so as to avoid any loss of control. For this, proper proprietary communication protocols should be designed.
6	Electricity dependent system: Remote Transmission units require uninterrupted energy source so as to avoid loss of data regarding flow, water quality parameters. Also, energy is required for actuator mounted valves.	Uninterrupted power supply should be ensured. Other source of energy supply should be explored like battery operated or solar operated units.

10.4.3 Maintenance Key Performance Indicator (KPI) for equipment

Sl No	Key Performance Indicator	Unit of Measurement
1	Availability	%
2	No. of Breakdowns per month	Nos./month
3	Mean time to repair (MTTR)	Hours
4	Mean time between breakdowns (MTBF)	Hours

10.4.4 Condition-based maintenance (CBM)

Condition-based monitoring maintenance is the most successful form of maintenance. It is based on the actual condition of the machine. CBM is a maintenance strategy that monitors the real-time condition of an asset to determine what maintenance needs to be performed. CBM creates a safer workplace by reducing the likelihood of equipment failure.

Importance of CBM

Condition-based monitoring helps maintenance teams make more informed decisions about performance optimisation and maintenance needs. It follows the strategy that maintenance be performed only when certain thresholds are reached, or the indicators show signs of decreasing performance or upcoming failure.

10.4.5 CBM Steps:

CBM consists of three steps:

1. Capturing sensor data
2. Communicating data
3. Performing maintenance work

1. **Capturing sensor data**

   Condition monitoring sensors track the primary machine maintenance indicators. These sensors check parameters like vibration, temperature, and pressure while equipment is in operation. This facilitates detection of the earliest signals of the failure- mode indicators through sensor. Common condition-monitoring sensors:

   - Vibration and temperatures sensor – Measure vibration and temperatures
   - Pressure Transmitter – Measure the pressure of liquids
   - Ultrasonic Sensors – Monitor the flow of fluid in a pipe line
   - Fluid Condition Sensors – Observe the condition of a fluid such as oil
   - Ammeters – Gauge the current running through a circuit
   - Electromagnetic flow sensor – Monitor the flow of fluid in a pipe line

Figure 10.3: Trained Technicians Can View Data Captured by Sensors to Better Understand

2. **Communicating Data**

   Once a sensor has found that a monitored parameter is out of its normal operating range, it must communicate that information to a human employee who can provide a remedy. Notifications can take many forms. A programmable logic controller (PLC) that runs a machine may notify a technician that service is required in a variety of ways like, for example, turning on a stack light. A human-machine interface (HMI) or SCADA system may turn on a warning light, sound an alarm, display a message, or send a text or email notification. Computerized maintenance management system (CMMS) software may auto-generate a work order.

3. **Performing Maintenance Job**

   When a monitored condition creates an alarm or notification, the maintenance team is dispatched to resolve the problem. SOPs and Checklist are then included on maintenance work orders generated by system, enabling technicians to respond faster and perform repairs with higher quality and consistency. Maintenance personnel also document their work in the system once work is complete. Figure 10.3 Trained maintenance technicians can view data captured by sensors to better understand.

10.4.6 Advantages of CBM

- Early detection of machine problem
- Increases asset lifecycle and ROI
- Lowered chance of catastrophic failure
- Reduced asset downtime.

- Reduced number of unplanned failures
- Improved equipment availability

10.4.7 Disadvantages of CBM

- High sensor costs
- Unpredictable peak times
- Difficulty in choosing sensors
- Reliability of sensors
- Required expertise

10.4.8 Vibration Sensor

A vibration sensor is an electronic device that measures the amount and frequency of vibration in a given system, machine, or piece of equipment**.** Vibration sensors detect the vibration of objects through its mechanical structure and converts the vibration parameter into electrical signals.

10.5 Telemetry and SCADA Systems

10.5.1 Telemetry

The development in electronics and telecommunications has made telemetry systems very reliable and cost effective for use in water quality monitoring. A telemetry system is composed of three subsystems: a) a data acquisition system: composed of the data collection platform which consists of all hardware equipment like sensors, logger, power supply and the transmitter that can collect, store, encode and transmits the data; b) a signal transmission system that can transmit data to the receiver end; and c) a data acquisition, analysis, and dissemination system which can collect the data and manage it.

Due to the wide range of telemetry equipment and monitoring site characteristics, most telemetry system would require custom designs and best engineering judgement in order to obtain the best system performance.

Preventive maintenance includes regular and thorough cleaning of equipment. Also, the transmitters are to be connected to a simulator, and then checked for a known signal and the display is verified. In case of satellite communication system, a satellite antenna must be pointed directly at the orbital location of the satellite in order to obtain the best signal. It must be checked that the antenna is correctly pointed according to the latitude and longitude of the monitoring site. For good signals, it should be seen that her visual path is free from any kind of obstruction. If there is a master computer, check that it can carry out all its required functions, i.e., monitoring of radio performance, status and alarms, etc.

Since this system requires continuous power supply for its working, dedicated uninterrupted energy input options like batteries and uninterruptable power supplies, should be considered.

10.5.2 SCADA Systems

Supervisory Control and Data Acquisition (SCADA) is a computer-aided system that collects, stores, and analyses the data on all aspects of O&M. It gives a better understanding of what is happening in terms of water quantity or water quality which is sourced and supplied.

SCADA maintenance can range from installing operating system updates to adding new users and field instrumentation. SCADA system consists of a) Field instruments: sensors and actuators b) Remote stations: Remote Terminal Unit (RTU) and PLCs; c) Communication network; and d) Central monitoring station.

Maintenance is the key factor for creating a sustainable SCADA system and is comprised of the following:

a) All the components in the SCADA network should be check regularly for its functionality using simulators. The main operating parameters which include voltages, currents, frequencies, inputs, outputs, levels, noise, etc., of every piece of equipment should be tested.
b) The central computer monitoring equipment at the site should be checked to ensure that there are no system problems.
c) Identify the root cause in the system by examining the components. The components of the system should be examined in order to make the appropriate configuration changes or modifications.
d) Regular physical inspection of all RTU sites must be done to check the inventory. The RTU site should be clean and the equipment must be free from dust and pests.
e) The field equipment like sensors and actuators must be cleaned regularly.
f) Alternate power supply should be explored for uninterrupted power input.
g) The communication network should be secured by implementing all the latest protocol and security standards.
h) Stock of essential spare parts to be kept in case of replacement.
i) Any changes to the system should be fully documented and updated.
j) Backup of the data should be kept.
k) The errors in the software must be addressed immediately.
l) The personnel handling the system must be thoroughly trained about all the components of the system.

10.5.2.1 Limitations of SCADA

Before installing a SCADA, the utility staff should visit facilities with SCADA and discuss with the utility managers and then decide the scope of SCADA to be provided in their utility. The objective of SCADA should be to make the job of operator easier, more efficient, and safer to make their facilities performance more reliable and cost effective. There is no doubt that SCADA enables better capacity utilisation and help in improved service levels at low operating cost. The following limitations are to be kept in view before embarking on an ambitious programme of providing SCADA. SCADA designing calls for careful planning and requires a phased implementation, particularly dependent on appropriate training of utility staff and their willingness to adopt the new technology.

Availability of power is very essential to efficient functioning of the system. Wherever possible the RTU for flow meter or pressure sensor is provided power from electricity mains via a battery that acts as a buffer in case of mains failure. There may be metering locations for flow and pressure sensors without any source of power close by. In such cases solar power may be one alternative. Initially installations at such locations may operate well but they are always subject to poor after sales service by vendors, vandalism, and theft.

10.5.3 Information Technology (IT) and IT Enabled Services (ITES)

IT services are used to automate water supply process and to save time and money. IT maintenance refers to the processes required to maintain the IT service throughout its life cycle. To do this, all updates to the software used in the process must be reflected in the system to maintain the performance of the service. A technical support team of software engineers should be formed to modify the software system to add new features or fix bugs. Training should also be included in the maintenance plan.

ITES includes customer interaction services including call centre facilities with adequate telecommunications infrastructure, trained consultants, and access to the necessary databases, Internet, and other online information infrastructure to provide information and support to customers. Therefore, personnel working with the system must be properly trained. Special training programmes must be developed to provide all the technical know-how. Consideration should also be given to providing hands-on training so that personnel are well acquainted with the system they are operating.

10.5.4 Internet of Things (IOT) and Artificial Intelligence (AI)

The Internet of Things (IoT) describes the network of physical objects - “things” that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the internet.

IoT systems have security issues from edge to cloud. IoT devices should be properly secured with multilevel authentication. The devices are developed in view of easement in use, but they must be regularly updated so as to protect it from hacking.

All IoT devices process and communicate data. They need apps, services, and protocols for communication and many IoT vulnerabilities originate from insecure interfaces. They are related to web, application API, cloud, and mobile interfaces and can compromise the device and its data. Hence for this, it is to be secured with the following:

a. Device authentication. It is used to secure access to a connected device and data it generates, for authorisation purpose.
b. Digital certificates. They enable a digital entity (IoT device, computer, etc.) to transfer data securely to authorised parties. It allows us to identify and verify each IoT device uniquely.
c. Use of latest communication protocols, security standards.

Artificial Intelligence (AI) has been one of the key technologies that help transform solving various issues which are generally time consuming to solve using human resources. However, as AI technology progresses and solutions are developed, more variables also appear concerning how things are done and if the current resources would suffice to cater to the ever-changing needs of people. AI has been presented as a tool to make life easier.

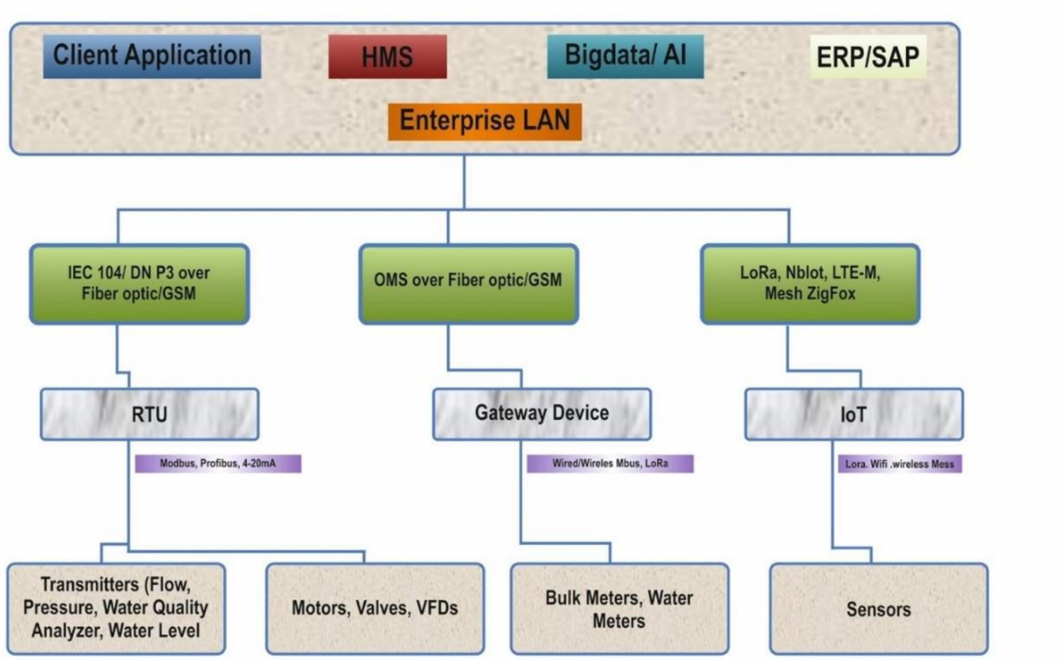


Figure 10.4: Smart Water Management System – SCADA Based

And it is accessible by anyone who has access to a computer. The more people know about AI, and the more trust is built around it, the more they're going to use it. Proper training in AI is to be adopted for further development in the field of automation. Figure 10.4 shows smart water management system SCADA based.

CHAPTER 11 : WATER AUDIT, MONITORING AND CONTROL OF NRW

11.1 Introduction

The gap between potable water availability (WTP production, ground water extraction) and requirement (consumer demand) is increasing day by day. At one end, sourcing water is becoming difficult and expensive; at other end, water distribution losses are significantly high in any typical city or town in India.

When treated water is lost, water collection, treatment, and distribution costs increase, water sales decrease, and substantial capital programmes are often promoted to meet the ever-increasing demand. Therefore, it has become essential to implement a fully integrated water loss management plan in an urban water supply project to make it sustainable and secure throughout its design life.

Water audit is the first step in this direction followed by Water Loss Reduction Plan. Water audit provides fair estimation of water losses for different water supply areas depending on level of audit work. Accordingly, the areas with higher percentage of losses, can be identified for carrying out water loss control activities like leakage detection, network investigation, pressure management, etc. It is very critical to understand the method and critical steps of this process in order to execute it in an efficient manner else, it may not provide desirable outcomes like water loss reduction and improved network efficiency.

11.1.1 Water Audit

Water audit of a water supply system can be defined as the assessment of the total water produced by the water supply utility and the actual quantity of water distributed to the consumer taps throughout the area of service, thus leading to an estimation of the losses termed as non-revenue water (NRW) along with its components. NRW components are broadly classified in three categories: Real Loss also called as Physical Loss, Apparent Loss also called as Non-physical/Commercial Loss, and Unbilled Consumption. More details on these terms are mentioned in subsequent sections.

Water utility may include additional categories for audit study like raw water transmission and water treatment loss optionally, termed as Transmission Main/Bulk Water System Monitoring but the primary focus is on getting clearer and faster understanding on potable water distribution system losses. The objective of water audit is to assess water consumption by different stakeholders such as households, institutions, and commercial establishments, etc. and overall system losses at entire City level or DMA level. Whereas, the objective of NRW is to assess the difference between water supplied in the system and total consumption. The difference between the total supply into a DMA and total consumption in a DMA is NRW at DMA level.

Water audit shall be conducted annually as per IS 17482 (2020). Whereas, NRW assessment can be done once daily or fortnightly or monthly depending on the frequency of measurement of household consumption. The frequencies of measurement of water consumption using various communication technologies are discussed in Chapter 14: Automation of Water Supply Systems in Part A of this manual.

Conditions to fulfil before initiating water audit:

i. The water utility should have a clear updated as-built drawings of the system and should know location and physical attributes like diameter, material, installation year of all inlets and outlets for the study area and inter-zonal crossing pipes by studying the GIS map.
ii. The water utility should have a flow measurement plan. In case of a utility with no/partial bulk flow meters, temporary flow measurement techniques can be used to collect flow data.
iii. The water utility should have consumption and other required data collection strategy. In case of a utility with no/partial consumer meter billing data history, meter sampling techniques can be used to collect sample consumption of accurate volumes.

11.1.1.1 Types of Water Audit

Water audit can be done for entire utility or for an Operational Zone (OZ) or District Metering Area (DMA).

A. Top-Down Water Audit

An audit for entire utility is mostly a desktop study with minimal site interventions, also called a top-down water audit provides input for planning overall improvements in the system. This approach requires minimal site measurements, and it can be done for both intermittent and continuous water supply systems.

B. Bottom-Up Water Audit

Audit for an OZ or DMA is more detailed, accurate and frequent study to get water losses per hour that helps in understanding the extent of Real Vs Apparent losses also called a bottom-up water audit. This approach requires permanent measurements and analysis systems. It is implemented at Operation Zone/DMA level that is supplying 24×7 water (or in transition towards 24×7) where hourly flow and pressure data is captured and analysed along with GIS data, hydraulic model, and consumption information to get insights on areas that needs interventions to reduce water loss. This approach is performance oriented and focused on limited area instead of utility-wide measurement. It provides clear visibility on water loss situation of the area and benefits achieved in terms of the loss reduction efforts. 24×7 water supply will be hard to maintain unless there is continuous monitoring of the area.

For ease of understanding, the top-down water audit is also termed as utility-wide water audit and bottom-up water audit as continuous monitoring of OZ/DMA. Various components of water balance table are explained in Section 11.3.

C. Transmission Main/Bulk Water System Monitoring

Transmission Main/Bulk Water System Monitoring is another useful audit that is done for bulk water supply system of utility to keep track of treatment and transmission losses. It is best suited for Indian utilities that have enormous distribution tapings on transmission mains causing unequitable distribution and inefficient bulk water operations. The transmission main loss tracking will provide clear visibility on current level of losses and unknown tapings and will enable utility to reduce these anomalies and prompt actions on future leaks and unauthorised taping works. This continuous audit is possible for any water utility that is monitoring of bulk water supply system through Supervisory Control and Data Acquisition (SCADA) or Internet of Things (IoT) based systems by deploying Transmission Main Monitoring and Analysis software to aggregate data from all sources and provide water loss reports for various sectors of bulk water system.

11.1.1.2 Objectives of Water Audit

I. Top Down Water Audit: The objective of top-down water audit is to assess the following

a. Average annual water volume produced, supplied, and billed for a utility;
b. Estimate annual water loss both real (physical) and apparent (commercial/non-physical);
c. To identify and prioritise components (real or apparent) and/or water supply areas that need immediate attention for water loss control;
d. To effectively plan strategy to reduce losses to an acceptable minimum over a limited timeframe;
e. To derive volume gains to meet additional demands with water made available from reduced losses, thereby saving on additional production and distribution costs;
f. To project revenue gain from the sale of water saved;
g. To capture utility's Water Loss KPIs for planning better future operations leading to consumer satisfaction.

II. The objective of bottom-up water audit is to assess the following:

a. Hourly water volume supplied and consumed for an OZ/DMA;
b. Hourly water losses in the system and tracking of minimum night flow of the system;
c. Continuous monitoring of inlet, average and critical pressure of the system;
d. Segregation of real and apparent losses;
e. Continuous monitoring of leakage volume and pre-localisation of water loss for site intervention and reduction of losses;
f. Continuous tracking of Water Loss KPIs for early warnings and timely network improvement planning to maintain the continuous water supply system.

11.1.2 Water Audit Period and Frequency

11.1.2.1 Utility-wide (Top-down) Water Audit

The ideal audit study period (for which the flow, consumption and other data is collected) for utility-wide (top-down audit) water audit is one year. If the expense of repeating temporary flow measurement is very high, and if it takes significant time and effort to complete this work, it may undermine the subsequent benefits in terms of water loss control. In such case, utility should evaluate the situation carefully, and find smart methods to collect data automatically using field data loggers and transmitters, implementation of SCADA and IOT based systems, Water Network Analysis Software deployment, etc., to automate the process. In absence of these systems, the audit frequency can be reduced to once in two or three years. Whenever there is a water network improvement project or continuous water supply project, the utility-wide water audit should be initiated, and study results should be used for planning purpose.

11.1.2.2 Continuous Monitoring of OZ/DMA (Bottom-up audit)

A more detailed analysis is required for continuous water supply areas. Continuous monitoring of OZ (bottom-up audit) is regular hourly observation and daily analysis. For management and reporting purpose, weekly/monthly reports should be auto- generated by software for improvement planning in continuous water supply area.

11.1.3 Water Loss Reduction

Water Loss Reduction is not always a key component for major water network rehabilitation projects in India so far. Network performance gain is mostly achieved by replacing water networks only. But there are other effective methods to improve the system. A more focused approach is needed for continuous monitoring and timely intervention at smaller scale and at a granular level for sustaining service standards in long term. Key components of this approach are:

a) **Performance Visibility**: For tracking performance and efficiency of network interventions, certain Key Performance Indicators (KPIs) like NRW %, Water Loss per Connection, Real Loss %, Apparent Loss %, etc., should be tracked and monitored continuously.

b) **Targeted Performance Improvement**: Annual Water Loss Reduction Plan can be made only for areas that need intervention. Field investigations and leak detection activities should be carried out for localised areas where water loss is significant. The strategy of water loss reduction should be decided based on Water Audit findings and factoring local conditions. It is mostly the visible and invisible leakages that cause water loss, some areas may have much higher pressures compared to other areas, and a pressure control strategy may be more suitable to curtail water loss due to leakages along with leakage detection. Some areas may have more unauthorised consumption and a social campaign for water wastage control may be more suitable than other methods. Yearly review of past year's action plan implementation should help in evaluating the strategies that worked in local conditions and should result in better planning for subsequent years.

11.1.4 Benefits of Water Audit and Water Loss Reduction Plan

Water audits and Water Loss Reduction Plan can achieve substantial benefits:

a. Reduced Leaks

Repairing the leak will save money for the utility, including reduced power costs to deliver water and reduced chemical costs to treat water.

b. Financial Improvement

It can increase revenues from customers who have been undercharged, lower the total cost of wholesale supplies, and reduce treatment and pumping costs.

c. Improved reliability of supply system

Consumers tend to store water and drain it off to again store fresh water when the supply is not reliable. Considerable time and water is lost in this process. Hence, improving the reliability of the water supply system will encourage the consumer to reduce the wastage of water and use their time in a productive way.

d. Increased Knowledge of the Distribution System

During a water audit, distribution personnel become familiar with the distribution system, including the location of main and valves. This familiarity helps the utility to respond to emergencies such as main breaks.

e. **More Efficient Use of Existing Supplies**

Reducing water losses helps in stretching existing supplies to meet increased needs. This could help defer the construction of new water facilities, such as new source, reservoir, or treatment plants.

f. **Safeguarding Public Health and Property**

Improved maintenance of a water distribution system helps to reduce the likelihood of property damage and safeguards public health and safety.

g. **Improved Public Relation**

The public appreciates maintenance of the water supply system. Field teams doing the water audit and leak detection, or repair and maintenance work provide visual assurance that the system is being maintained.

h. **Reduced Legal Liability**

By protecting public property and health and providing detailed information about the distribution system, water audit and leaks detection help to protect the utility from expensive lawsuits.

i. **Reduced disruption**

Improving the water supply network will reduce the breakdown of pipes and, hence, reducing the possibility of delivering substandard water quality. It will also reduce the wastage of treated water which is caused due to disruption/breakage of pipeline.

11.1.5 Water Audit and Water Loss Control Programme

A utility may develop and follow its own Water Loss Control Programme. It is a three- step programme (see Figure 11.1). The critical first step is the water audit.

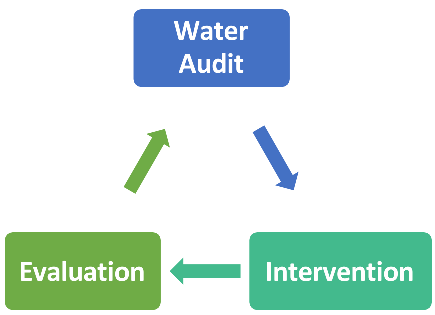


Figure 11.1: Components of a Water Loss Control Programme

While water audit identifies and quantifies water uses and losses from a water system, the intervention process dwells upon the findings of a water audit to reduce or eliminate water losses. The evaluation step determines the success of chosen intervention actions.

A dedicated NRW Call may be created to execute this programme regularly. Actions to be taken by a water utility under the above-mentioned three-step programme are outlined below:

1. **Step 1: Water Audit** at Utility or OZ level
2. **Step 2 Intervention Phase:** It includes strategic actions focused on reducing a component of NRW like:

- Leakage detection and monitoring, i.e., Real Loss Reduction
- Improvement in billing and collection efficiency, i.e., Apparent Loss Reduction

3. **Step 3 Evaluation Phase:** Continuous monitoring and analysis phase to answer questions such as:
   - Whether goals of interventions were met?
   - Areas where more information is needed?
   - How often an Audit Intervention and evaluation process should be repeated?
   - How can performance be improved?
   - Assessment of NRW after completion.

11.1.6 Water Balance

The outcome of water audit is a water balance table for entire utility area or zone/sub- zone wise. Explanation of terms used in water balance is as follows:

- **Non-Revenue Water (NRW):** It is water volume that is not billed, and no payment is received to the utility which is calculated using the water balance (Table 11.1). NRW is measured in the percentage of total clear water supplied to the system termed as system input volume.

Table 11.1: Various Components of Water Balance (IWA modified)

<table>
<tr><td rowspan="8">System Input Volume</td><td rowspan="6">Authorised Consumption</td><td rowspan="4">Billed Authorised Consumption</td><td>Billed Water Exported</td><td rowspan="4">Revenue Water</td></tr>
<tr><td>Billed Metered Consumption</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td>Leakage or Seepage from private underground sumps*</td></tr>
<tr><td rowspan="2">Unbilled Authorised Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="4">Non-Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">Apparent Losses</td><td>Unauthorised Consumption</td></tr>
<tr><td>Customer Meter Inaccuracy and Data Handling Errors</td></tr>
</table>

	Water Losses	Real Losses	Leakage in Transmission and Distribution Mains	
			Storage/ Sumps Leaks and Overflows	
			Service Connection Leaks up to Meters	

** The ULB's engineer should observe consumption of all households through monthly bills and wherever it is found abnormally higher than the average per capita supply (135 LPCD or 150 LPCD based on the city class x no. of person in billed household) or other required institutional or commercial consumptions, the survey team should be deputed to these households to observe the reduction in water level in consumer's sump for atleast 3-5 hours, and knowing the quantity of the sump water loss in litre shall be noted. Further, while doing this exercise, the inflow and outflow from the sump should be ensured to be stopped. Such consumers shall be advised to replace or repair the sumps to make them watertight. When the system is stabilised for 24x7 pressurised water supply these sumps can be bypassed.*

- **System Input Volume:** The volume of treated water input to that part of the water supply system to which the water balance calculation relates. It may come from a utility's own sources and treatment facilities or external bulk suppliers. It is important to note that water losses at raw water transmission schemes and losses during the treatment process are not part of the annual water balance calculations. In case the utility has no distribution input meters, or they are not used, and the key meters are the raw water input meters, the system input has to be based on the raw water meters but must be adjusted by treatment plant water use. In either case, the measured volume must be corrected for known systematic bulk meter errors.
- **Authorised Consumption** refers to water utilised by known water system users. Authorised consumption is a known quantity that is equal to the sum of invoiced authorised consumption and unbilled authorised consumption, and water provided to other water systems is also included. This also includes water exported across operational boundaries. Authorised consumption may include items such as firefighting and training, flushing of mains and sewers, street cleaning, watering of municipal gardens, public fountains, frost protection, building water, etc. These may be billed or unbilled, metered or unmetered.
- **Water Losses:** Volumetric difference between system input volume and authorised consumption is considered a water loss for the system. Water loss can be considered as a total volume for the whole system or for partial systems such as transmission or distribution schemes or individual zones. Water losses consist of real (physical) losses and apparent (commercial) losses.
- **Billed Authorised Consumption:** This represents component of authorised consumption that is billed and produce revenue (also known as revenue water or billed volume). This is equal to billed metered consumption plus billed unmetered consumption.

In case the water is being exported out of study area, the volume is added to the calculation as billed water exported.

- **Unbilled Authorised Consumption:** This represents component of authorised consumption that is legitimate but not billed and therefore do not produce revenue. This is equal to unbilled metered consumption plus unbilled unmetered consumption.
- **Apparent losses**, also known as **commercial losses**, arise when water that should be included as revenue-generating water appears as a loss due to unlawful actions or calculation errors. Unauthorised consumption (theft or illegal use), inconsistencies/ inaccuracies in customer metering, and systematic data handling problems/ errors in the meter reading and billing processes are examples of apparent losses. Apparent losses are the sum of:
    - Systematic data handling errors;
    - Inaccuracies in customer metering;
    - Unauthorised consumption.
- **Real Losses**, also known as **physical losses**, are actual water losses from the system that include leakage from transmission and distribution mains, leakage and overflows from storage tanks, and leakage from service connections up to and including the meter up to the point of customer use/meter.
- **Billed Water Exported:** Sometimes, the water is transferred across operational boundaries or outside the utility study area for water balance. This volume component, if present, is considered billed water exported.
- **Billed Metered Consumption:** This represents all metered consumption that is billed. This includes all groups of customers, such as domestic, commercial, industrial, institutional, etc.
- **Billed Unmetered Consumption:** This includes all billed consumption that is calculated based on estimates or norms but is not metered. This might be a very small component in fully metered systems (for example, billing based on estimates for the period a customer meter is out of order) but can be the key consumption component in systems without universal metering.
- **Unbilled Metered Consumption:** It is the metered consumption that is for any reason unbilled. For example, this might include metered consumption by the utility itself or water provided to institutions free of charge.
- **Unbilled Unmetered Consumption:** It represents any kind of authorised consumption that is neither billed nor metered. This component typically includes items such as firefighting, flushing of mains and sewers, street cleaning, frost protection, etc. In a well-run utility, it is a small component that is very often substantially overestimated.
- **Unauthorised Consumption:** It is unauthorised use of water that may include illegal water withdrawal (for example, for construction purposes), illegal connections, bypasses to consumption meters, or meter tampering and under- reading of customer meters because of meter reader corruption. This is considered part of apparent loss (water that is only “apparently” lost but causes a loss in revenue collection).
- **Customer Metering Inaccuracies and Data Handling Errors:** This is another part of apparent loss caused by customer meter inaccuracies and data handling errors in the meter reading and billing system.
- **Leakage on Transmission and/or Distribution Mains:** It is the water lost due to leaks and breaks on transmission and distribution pipelines. These might either be small leaks

that are not visible at the surface (e.g., leaking joints) or large breaks that were reported and repaired but did leak for a certain period before that and contributed, therefore, to the annual volume of real (physical) losses.

- **Leakage and Overflows at Utility's Storage Tanks:** This represents water lost from leaking storage tank structures or overflows of such tanks caused, for example, by operational or technical problems.
- **Leakage on Service Connections up to the point of Customer Metering:** This represents water lost due to leaks and breaks of service connections from (and including) the tapping point until the point of customer use. In metered systems, this is the customer meter; in unmetered situations, this is the first point of use (stop tap/tap) within the property. Leakage on service connections might sometimes be visible but will predominately be small leaks that do not surface and run for long periods (often years).
- **Revenue Water:** It is often called billed volume, that includes those components of authorised consumption that are billed and produce revenue (also known as billed authorised consumption). This is equal to billed metered consumption plus billed unmetered consumption.
- **Non-Revenue Water:** It is the difference between system input volume and Revenue Water often represented in percentage.

NRW % = 100 × (System Input Volume – Revenue Water) / System Input Volume

Note: NRW is sometimes also referred to as unaccounted-for water (UFW), but these are not synonymous because NRW includes unbilled authorised consumption (Table 11.1) like firefighting, identified leaks, etc., whereas UFW excludes it.

As an example, some utilities may include volumes from known leaks in "accounted- for" water categories and excluded it from UFW, thus underestimating actual leakage volumes, which is a loss to the water utility. NRW includes it and hence provides clearer picture of water loss.

11.2 Planning and Preparation for Water Audit

Planning and preparation for the audit work should include listing of location and operational status of existing flow meters and pressure loggers, availability of water supply network maps, count, and status of existing and planned OZs/DMA in study area and validation of Zonal/DMA meters if present. Plan may also include portable flow measurements if necessary. Past flow meter readings may be documented for reference purposes. Initial preparation or survey may be required for acquisition of all consumer and consumption volume data, known water loss locations and land use statuses (authorised/unauthorised areas) and public service water supply records available with utility. For utilities with limited consumption and billing data, include planning of meter sampling and estimation work to fill the gaps in utility data. Also review the requisite resources including trained manpower, tools, plans, plumbers, fitters, etc. to carry out Audit work successfully.

Level of water audit study should be decided based on various factors like size of utility, status of isolation, ease of bulk flow data collection, ease of consumption and other data collection. A typical Indian utility may conduct water audits at various levels:

1. **Utility-wide Audit Study (Top-down):** The utility water network may receive potable water supply from one or more WTP and/or few distribution tubewells spread across the utility area. Utility-wide water audit will require flow measurement at all these inlet points, but no flow data is required at inter-zonal level. This is basic and quick audit study suitable

for small utilities. If the utility is serving a bigger network and population (say 1 lakh and above), it may become hard to get good insights about different parts/zones. Sometimes, Raw Water System Losses and WTP losses are included in this study if not already monitored continuously.

2. **Transmission Main/Bulk Supply System Continuous Monitoring/Audit:** Utilities mostly have Transmission Mains supplying water from Water Source to Supply nodes like UGR, ESR or distribution supply points. For monitoring, permanent flowmeter, data logger and transmitter setup is required at all potable water source outlets and at the inlet of supply nodes like ESR etc. Hourly data should be captured and analysed regularly to monitor water loss in the system. It will be cumbersome to collect this data and analyse manually. Utility should use Water Network Analytics Software for automated data collection, cleaning, analysis and reporting purpose. A water network GIS database and Hydraulic Model will also be helpful for more detailed analysis. Usual issues for implementation of this system are lack of centralised verified data on Transmission Main pipes and inter connections and unauthorised tapings supplying water directly to distribution network. The benefits of Transmission Main Continuous Monitoring are clear visibility on transmission losses and unauthorised tapings, early information on system performance issues, monitoring and control of unauthorised tapings. The system may also be extended to capture raw water transmission losses, WTP losses and Distribution Main losses if required and found suitable by utility. **For utilities having tank water balance issues and unauthorised tapings on transmission mains, these monitoring/audits will provide clear visibility of transmission system issues over time.**

3. **Continuous Monitoring/Audit of OZ/DMA:** A water supply zone/sub-zone may have further division by multiple ESR Command Areas. An ESR command area may have one or more Operation Zones (OZ) and sometimes divided in many DMAs. For Operation Zone Continuous Monitoring/Audit, permanent flowmeter, data logger and transmitter setup is required at inlets and outlets of the network along with key location pressure logger and transmitter installation (critical, average and inlet/outlet points). Ideally all consumers should be metered with monthly consumption readings, or at least sample meters should be installed across the OZ. The data should be captured continuously and analysed regularly. It will be cumbersome to collect this data and analyse manually. Utility should use Water Network Analytics Software for automated data collection, cleaning, analysis and reporting purpose. A water network GIS database and Hydraulic Model will also be helpful for more detailed analysis. As it is much more detailed and continuous study that will require initial capital expenditure, hence it is important to prioritise the Supply Zone where this should be initiated first in order to maximise the benefits. Usual issues that utility may face are lack of isolation of OZ/DMA, flowmeter/pressure logger data capture issues, consumption data capture issues, lack of updated network maps and unavailability of Hydraulic Model data from previous design studies. Utility should try to do this study on pilot basis first, in order to understand and resolve the issues/improve the plan before Zone wide implementation. The benefits of continuous monitoring are service level tracking and regular insights for service improvement, early warnings regarding water supply issues, data availability for better planning for future expansion as well as for taking informed decisions during Operation and Maintenance. **For an Intermittent to Continuous Water Supply System Improvement Project, these monitoring/audits are very important.** Table 11.2 summarises which utility should go for what level of water audit.

Table 11.2: Summary of which utility should go for What Level of water Audit

Utility	Level 1	Level 2	Level 3
Small Utility looking for overall NRW situation	Yes		
Big Utility looking for overall NRW situation	Yes	Yes	
Utility with 24×7 Projects in various parts of the supply area		Yes	Yes
Utility planning major water supply improvement project for various water supply zones	Yes		
Utility running 24×7 water supply for various OZ/DMAs		Yes	Yes

Once the level of Water Audit is decided, various key activities like map data collection strategy, bulk flow data collection strategy, consumption and other data collection strategy should be planned before executing the Audit works. Following sub sections provide the details in this regard.

11.2.1 Verification and Updating of Maps

It is desirable to have maps of all water transmission and distribution lines ahead of water audit works. However, no utility has 100% data up-to-date all the time. In this case, minimum required data is:

i. WTP Location and Command Area Boundary Map
ii. All Transmission Lines Map feeding to all zones/sub-zones
iii. Zone/Sub-zone Boundary Maps
iv. Inter-zonal crossing pipelines demarcation on Zone Maps
v. ESR location and bypass pipe location if any
vi. All Tubewell locations that are feeding to Potable Water System
vii. All Existing and Proposed Permanent Flow Meter Locations
viii. All Existing and Proposed Pressure Logger Locations
ix. All Existing and Proposed OZ/DMA Maps

These maps should ideally be collected before starting the audit work for efficient planning of measurement works. A distribution map is required but not mandatory for zonal water audit. Basic details like ESR OZ (or DMA) wise boundary, network length and consumer count should be made available.

Consumer and billing data availability should be verified from billing department ahead of audit work. If it is planned to carry out consumer survey, then ideally it should be done ahead or along with audit work. If it is done along with audit work then it should be combined with other audit components like meter testing, meter sampling, average pressure assessment and consumer connection pipe information collection.

Utility-wide water audit is not a big Capex project and should be treated more as an overall study of the system with few site visits and data collection only for gap filling purposes. If there are a lot of street excavation, sizable amount of permanent bulk meter installation, or water network validation and investigation during audit period itself, the purpose of audit study, which is to provide insights quickly for further Capex and Opex works, may not be fulfilled.

11.2.2 Bulk Flow Measurement Planning

Best case is when the water utility is already having bulk flow meters installed to collect total system input volumes and zone wise system input volumes. In case the flow meters are not installed or partially installed, it is necessary to carefully plan bulk flow measurement strategy.

The installation of permanent Bulk Flow Meter is a big CapEx work and is usually combined with SCADA implementation. However, if the utility needs vital system performance inputs, then it is logical to prioritise installation of those flow meters first that will help in audit work (first priority is to system input flow meters followed by zonal water input flowmeters). Ahead of complete SCADA implementation (or in case no SCADA is planned) installation work should be done along with automated data transmission system. This will help in continuous data capture without manual intervention, making future audit work easier.

Audit work should ideally be taken up after permanent flow meters are installed for at least system input volume data collection. But it may not be possible for utilities looking for water network improvement planning in the very near future. In such case, temporary flow measurement is the only option and priority-wise, bulk flow meter installation may be taken up as early as possible after first water audit is done.

It is expected that bulk meters will be required at the following locations for water audit, however, utility should carefully review the water network and plan the measurement strategy accordingly:

- All major system supply points;
- All tube wells that supply the system (water supply tanks or consumers) directly;
- Major transfer mains which are expressly required for audit;
- All water export points that are carrying water from system but delivering it to consumers outside the study area.

For sizing, placement, and selection of flow meter, please refer to Chapter 13: Water Meters, Part A of this manual.

The pressure logger placed with a flow meter provides additional data that can be interpreted to get additional insights about the system. It is not necessary but desirable to install pressure loggers along with permanent flow meters.

11.2.3 Consumption Data Collection Planning

The consumption data capture is one of the biggest challenges in India as most of the cities have either no consumer meters, or meter readings are not captured regularly leading to average volume-based billing for most of the consumers.

Best case is when the utility has monthly consumption data for almost all the consumers. But if it is not the case, sample consumption data capture can be planned.

Sometimes the utility is already planning 100% metering and volumetric billing in near future, that is a positive step towards getting better consumption estimates, but it is important to plan metering activity in right manner to get maximum benefit. If 100% metering/replacement is planned for entire utility, it is recommended that the utility follows the prioritisation as mentioned point wise below.

Water audit team will get required minimum data as soon as work up to point number 2 is complete as mentioned below. Work mentioned in point 1 and 2 can also be carried out or bundled in water audit study if there is no meter installation project planned by the utility.

1. If there are water supply zones in the city, the priority should be to install new meters and replace/repair existing meters of non-residential consumers for a particular zone. Once sizable work is complete for one zone, the next zone should be engaged. Priority for the zone should be set based on non-residential demand figures available with utility billing department or by non-residential consumer survey.
2. Sample consumer meters should be installed for residential consumers before initiating 100% metering project. Ideally AMR meters should be chosen for these locations to minimise manual reading and to provide the ability to gather data more frequently and at a more granular level.
3. If there is already a DMA implementation plan for a city, 100% residential metering project should be implemented along with other construction work DMA by DMA. Other construction works include average and critical pressure point logger installation, boundary valve and end-cap installation and inlet/outlet bulk flow meter installation. If there are existing meters installed for limited consumers, it should be tested and replaced if needed along with 100% metering project of DMA. This will provide the best return of investment on consumer meter and billing system setup expenditure as not only billing data is available, but DMA- wise, water loss can also be tracked. If there is no DMA planning, then OZs should be used to prioritise the implementation. Particular OZs that have higher volume supplied and with least complaints and higher service quality should be selected first for implementation. Once sizable work is completed for one OZ/set of prioritised Ozs, next Ozs should be engaged.

Consumer meter sampling can be done keeping following points in mind:

a. All zones should be covered during meter sampling. A consumer database should be used to extrapolate it to get total consumption. If the data is not present, consumer survey may be carried out ahead or along with water audit.
b. Meter sampling is done for regular volume consumers like residential areas. Irregular volume consumers like institutions, industries, etc., cannot be generalised, sampled, and extrapolated for total consumption. Permanent consumer metering is the way to handle irregular consumers, preferably AMR type to reduce manual data collection errors.
c. GIS map is the best way to plan and check the spread of sampling. Latitude and Longitude should be captured while sample meter is installed.
d. Normally 1%–5% sample size is enough for audit purposes, however, utility should assess and decide this range based on local conditions.

For existing consumer meters that are working and read regularly for billing purpose, meter testing should be planned. Following points should be kept in mind while planning this activity.

a. Meter testing should include all sizes of meters present in the network. Further categorisation can be done based on installation/repair dates, manufacturer, water quality parameters, etc., if available. The test results should be categorised and correlated with billing data base to get the extent and range of meter error.
b. Average slow or fast percentage of test recording of meters is known as correction factor.

This average metered consumption multiplied by the correction factor is known as water used by consumer.

c. Sometimes it is not feasible to test all meters in labs, in this case onsite testing can be done by installing new or calibrated meter in series of existing meter. Detailed testing results may not be availed in this case, but the coverage of testing can be increased easily this way.
d. GIS map is the best way to plan and check the spread of testing. Latitude and Longitude should be captured for tested consumer meter locations.
e. Normally 5%–10% of testing is enough for audit purposes, however, utility should assess and decide this range based on local conditions.

11.3 Water Audit Strategy

11.3.1 Utility-Wide (Top-down) Water Audit

The utility-wide (top-down) water audit strategy is explained below. A flow chart is also attached as **Annexure 11.3**.

The standard approach for an Indian town/city should be to start with utility level data collection that is to get total system input volume (Stage 1) and authorised consumption (Stage 2) to estimate total water loss, and then segregate apparent and real losses (Stage 3). The information should be gathered from existing records, data, and other relevant information available with the utility and then fill the gaps by temporary measurements wherever necessary using non-destructive methods. Sample consumption and pressure data should be collected if there are areas with no monitoring of consumption and pressure. In such case, consumer survey provides information to estimate total consumption and should be carried out ahead (or along with) the audit study.

11.3.1.1 Stage 1: System Input Volume Assessment

Before starting the audit, water supply system boundary should be identified. Information should be collected for potable water volume produced. Utility may consider including additional calculation for raw water produced vs delivered at water treatment plant (WTP) and treatment loss estimation. However, for system input volume calculation, treated water volume should be considered.

While gathering data for the study, it is common practice to ask for the latest available data and longer duration records for better validation. It is also required to include the assumptions and considerations in the audit report. The purpose here is to provide the best estimates of water volumes with available data and temporary measurements without causing much delay and destruction.

Volumetric data should be captured and compiled from all utility water sources based on flow meter data preferably with an existing Flow Meter calibrated within last 12 months. If there is no flow meter installed at these locations, then a temporary flow meter calibrated within last 12 months can be installed to capture regular flows. Hours of measurement will depend on flow pattern variation. Most of the supply points may have 24-hour cyclic pattern, repeating itself daily with minor changes during the seasonal variation that can be captured by multiple measurements during study period. However, one must be careful to avoid days with unusual flow conditions due to ongoing construction or maintenance work. If the flow is irregular and varies every day in an unplanned manner, the temporary measurements may not be that useful for water audit and may result in erroneous calculation. Utility should prioritise installation of permanent flow meters at such locations. If pump technical details are available, then volume estimates can also be derived from its discharge and pressure measurement. Pump operation logbooks can be used to estimate yearly volumes in that case. However, it is a less accurate method compared to permanent flow measurement.

Sometimes pipes are old and buried deep, thus making it impossible to take temporary measurements. If it is not possible to measure actual discharge, utility may be consulted to gather any previous records available or other possible considerations on a case-by-case basis to get an assumption on missing data. These assumptions should be clearly written in audit report. If most of the system inlet pipes fall under this category, the water audit quality will be very poor and may not be able to provide reliable inputs for future water loss monitoring and reduction plans. In such cases, permanent measurements of flow and pressure at system inlet points should be prioritised ahead of any detailed planning of water system improvements.

Once volumetric data is captured at all system inlet points, any water import or export points. System input volume is derived by the formula as mentioned below:

System Input Volume = Total Production of Water + Water Imported – Water Exported

11.3.1.2 Stage 2: Authorised Consumption Assessment

Quantification of billed authorised consumption is done by collecting billing records from customer billing system. Depending on how billing is done, it is categorised under metered or unmetered volume.

Sample meter testing should be done for metered consumption accuracy estimation. It is recommended to test 5%–10% of existing meters across entire study area and only for meters that are used for regular metered billing. Onsite testing by installing new/calibrated meter can be done if it is not feasible to send meters to meter testing lab.

Sample meter installation (or meter sampling) should be carried out to assess unmetered consumption. It is recommended to carry out meter sampling for 1%–5% of reference residential consumers across entire study area.

For audit purpose, it is recommended to install sample consumer meters and get reference consumption data. There might be huge variations in daily consumption of different non-residential consumers that may cause significant deviation in audit calculation. So, meter sampling may or may not provide enough data for general water consumption assessment of these non-residential consumers. Hence for non- residential consumers, if metered consumption is not available, it is recommended to install meters to 100% non-residential consumers as soon as possible. Automated meter reading (AMR) meters can be considered if data and human errors need to be minimised.

Once billed data is *collected* and meter testing, meter sampling and consumer survey (if required) is done; following formula can be used for billed consumption calculation.

Billed Metered Consumption = Sum of Billed Consumer's Metered Volume

Billed Unmetered Volume = Average Sample Meter Consumption × Average Billed Consumer Count

Sometimes, a quantum of water is exported outside the system, e.g., to industries in ULB area, but still billed by utility. This can be categorised as billed water exported and calculated as below.

Billed Water Exported = Sum of Billed Consumer's Volume Exported Outside Utility Water System

Calculation of billed authorised consumption is done by formula as mentioned below:

Billed Authorised Consumption = Billed Metered Consumption + Billed Unmetered Consumption + Billed Water Exported

Quantification of unbilled authorised consumption is done by assessing various consumption volumes that are not billed but used for designated purposes like public stand posts, public building, public gardens, water fountains, swimming pool, construction sites, firefighting, street cleaning, supply to schools, etc.

Quantification unbilled unmetered consumption is done based on a combination of existing measurement, assumptions, and consideration in discussion with utility. If a particular category has significant count (say public stand posts), sample meters can be installed at selective locations and consumption volume can be estimated based on average unit consumption measurement. Calculation of unbilled authorised consumption is done by formula as mentioned below:

Unbilled Authorised Consumption = Unbilled Metered Consumption + Unbilled Unmetered Consumption

Calculation of Authorised Consumption is done by formula as mentioned below:

Authorised Consumption = Billed Authorised Consumption + Unbilled Authorised Consumption

11.3.1.3 Stage 3: Water Loss Assessment

Calculation of total water loss is possible after authorised consumption is assessed. It is done by using following formula:

Total Water Loss = System Input Volume – Authorised Consumption

Water Loss is further segregated between apparent loss and real loss.

Calculation of apparent loss volume is done by assessing three components: data handling errors, customer meter inaccuracies, and unauthorised consumption. If consumer and billing data is available for a long-term period of time, say, three years or more, it can be analysed by data scientists to discover possible data errors. Customer meter inaccuracies are usually estimated by meter testing of a sample of existing installed meters. Unauthorised consumption is derived from utility consultation, site visits, known issue lists and appropriate assumptions.

Calculation of real loss volume is done by formula as mentioned below:

Current Annual Real Loss (CARL) = Annual Total Water Loss – Annual Apparent Loss

For further subdivision of real losses, it is required to carry out additional measurements for transmission and distribution lines and is covered in subsequent sections. Most of the time, the hurdle is to get clear segregation on areas and water lines, which is very difficult in most of the cities/towns in India. This exercise will be fruitful only if validation and updates on network maps are carried out regularly. Refer to Chapter 7: Distribution System, Part B of the manual.

Calculation of NRW is done by formula as mentioned below:

NRW (%) = 100 × (System Input Volume – Billed Authorised Consumption)/System Input Volume

Water loss per connection is a good Key Performance Indicator (KPI). Calculation is done by dividing water loss by total number of consumer connections.

Water Loss Per Connection = Total Water Loss / Total Number of Consumer Connection.

The formula is good for higher connection density (say more than 20 connection/km of distribution mains. For lower densities, water loss per km of distribution is more suitable KPI.)

The real and apparent loss can be utilised to calculate financial losses as per following:

Total Financial Loss to the Utility = Current Annual Real Loss × Variable Production Cost + Current Annual Apparent Loss × Average Consumption Billing Rate.

This calculation indicates total financial loss to the utility due to NRW and is a good parameter to assess possibility of performance-based projects for NRW reduction.

11.3.2 Continuous Monitoring of OZ/DMA (Bottom-up Water Audit)

For utilities with 24×7 water supply areas, it is recommended to additionally carry out continuous monitoring of water loss components (bottom-up water audit) for 24×7 supply areas. As this audit is usually carried out by automatic sensor data capture and analysis software; the strategy is to get the water loss components (as above) and KPIs but at a smaller granular level.

Additional KPIs can be calculated for an area with continuous water supply. As mentioned below:

Unavoidable Annual Real Loss (UARL) = ((18 × Lm) + (0.8 × Nc) + (25 × Nc × Lc)) × P

Where Lm is Length of Mains (km), Nc is number of service connections, Lc is average length of service connection and P is average pressure (m H_2O).

Infrastructure Leakage Index (ILI) = CARL / UARL

Other KPIs can also be calculated as required by the utility or regulatory authority. For more details, International Water Association’s (IWA’s) publications may be referred.

Use of communication technologies for monitoring NRW in OZ/DMA are discussed in Chapter 14: Automation of Water Supply Systems in Part A of this manual.

11.4 Extended Water Audit with Additional Measurements

Water audit study can be extended to include additional components as below.

a. Raw water transmission mains
b. WTPs
c. Potable water transmission mains
d. Potable water distribution mains

This exercise is faster when utility have permanent flow meters installed at inlet and outlet of these systems already. Temporary measurements can be done if required to fill the measurement gaps where no flow meter is installed. The total loss indicates mostly leakages apart from equipment and reading errors. This audit should ideally be done on daily basis with hourly data of measurement. This will ensure timely detection and measures for water loss control. If the level of automation is not sufficient to get hourly data, then monthly data should be collected to get estimated water loss per month.

Water loss estimation can be done using portable flow measurement techniques like clamp on type ultrasonic flow meters or insertion probe type electromagnetic flowmeters. Pump logbooks along with individual pump flow-rate measurements can also be used for quick estimates in cases where flow rates are fairly constant. These all methods are less accurate but provide faster assessment. For more detailed study, installation of permanent flow meter is the only option.
Potable water transmission mains audit provides transmission main losses in the system. Common issues with it are unauthorised tapings and service reservoir bypasses. It is not possible to segregate transmission and distribution losses without measuring flow in each and every distribution taping (feeder junction). If the count of such tapings is too high or if there are unknown tapings, it is not practical to install flow meters at each taping. Better strategy is to close all tapings and supply water to these areas via distribution systems. An intermediate strategy could be to close maximum tapings leaving only the ones vital to the distribution and put flow meters on these tapings.

Potable water distribution mains audit provides distribution main losses in the system. Common issues with it are segregating the mains from Operation Zones/DMA network. The distribution system is traditionally designed as grids cross connected to have benefits like balanced network, equitable pressure and less water quality issues due to less stagnation. The drawback of such system is that flow measurement points are enormously high. It must be a fare balance between investment in flow measurement exercise and overall benefits in terms of water loss reduction.

11.5 Documentation and Resolution of Problems Faced in Past Audit Study

Common problems faced in the audit study are listed here that may vary from utility to utility.

- Proper network and other water components detail are not available in proper maps. Some maps are available, which are not updated with proper indication of appurtenances.
- Normally much attention is not paid by the Water authorities to the water audit of the water supply schemes.
- The results of audit findings are not made public and is considered a problem in itself, not the diagnosis of underlying problems.
- Barring a few major cities, separate Water audit units are not available with the authority.

Wherever these units are available the water audit staff is not motivated enough to carry out the work. Skilled staff and private companies are limited in this field.
- By and large, water authorities are not equipped with the necessary equipment.
- Proper budgetary provision is not available for carrying out continuous and effective water audit.
- Lack of co-ordination between the water audit unit and operational and maintenance staff.
- No emphasis is given on Information Education and Communication (IEC) activities for conservation of water.
- Lack of reliable data of existing water supply system.

If there were hurdles or problems faced during the study, it should be documented, and possible solutions should be listed down for future audit study. It is not unusual to have assumptions and considerations for various components of water balance to overcome the actual difficulty in data collection, utility must evaluate if the purpose of Water Audit which is to get insights on water loss reduction plan is fulfilled or not. If there are too many assumptions or theoretical/design consideration instead of practical data, the whole purpose of the exercise is defeated.

11.6 Analysis and Intervention of Water Audit Findings

The water balance will provide various components of losses in the system. Utility should review and analyse various components of water loss and plan subsequent actions for water loss reduction. Utility-wide audit study should help in assessing whether the utility should focus on real losses or apparent losses or unauthorised consumption. Zone-wise audit study should help in prioritising the area of action:

1. Areas that need immediate leak detection and repair to reduce real losses;
2. Areas that need social campaign and network investigation to reduce unauthorised consumption;
3. Areas/consumers that should be prioritised for meter placement or replacement planning;
4. Areas that need levels of losses to be closely and continuously monitored;
5. Areas that appear to need no further work at the current time.

Post water audit, the water loss reduction planning should be done. The frequency of this plan may be kept yearly. All of these actions are discussed in subsequent sections. It should be noted that all actions cannot be taken simultaneously for entire utility and should be staggered across multiple years. Yearly review of actions taken in the previous cycle and improvisation for next cycle is the most important part of this strategy. The focus should be to act on reduction of highest component of water loss within limited time period within predefined budget and if possible, focused on limited area that is prioritised based on audit findings.

11.7 Action Plan for Water Auditing/Continuous Monitoring of Water Loss

For a utility trying to control water loss, it is necessary to include a strategy for continuous data capture and analysis along with major Capex projects. Following Table 11.3 provides recommendation based on key issues faced by Indian water utilities.

Table 11.3: Recommendation based on Key Issues faced by Indian Water Utilities

Utility Issues	Water Audit/Water Loss Monitoring Recommendation	Execution Strategy
OZ improvement or 24×7 project/DMA creation	Continuous OZ/DMA Monitoring and Analysis	Throughout Water Supply Improvement or 24×7 Water Supply Project Maintenance Period
General Utility Water Loss Performance Assessment	Periodic Water Audits	Along with major system wide improvement project and post project execution / Yearly Audits
High Transmission/Storage Losses	Continuous Transmission Main Monitoring and Analysis	Along with SCADA Project/Flow metering Project
High Distribution Losses	Sectorisation to isolate OZ/DMAs, followed by continuous monitoring	Along with NRW reduction project

Sectorisation of the Water Network: If the utility has clear sectorisation of transmission mains (flow meters at each inlet, taping and outlet) and OZ/DMA isolation, the NRW monitoring, and reduction strategy can be implemented at a smaller scale, e.g., an Operation Zone/DMA. This way utility may start small, in a cost-effective way and learn from it before expanding the strategy to a zonal level or utility level.

Software for Continuous Water Loss Monitoring: SCADA and various flow, pressure, and level sensors generate huge amount of data that is impractical to be analysed just by human efforts or excel sheets. For a utility, it is possible to implement a continuous monitoring and analysis software at a transmission grid level or a smaller scale like OZ/DMA. The analytical software may guide the utility towards leakiest OZ/DMA or a transmission sector that may have a new unauthorised taping. This way utility may focus its NRW reduction efforts on specific sectors optimising overall resource utilisation.

11.8 Action Plan for NRW Reduction

Action plan for NRW reduction is divided in sub-components as explained below.

11.8.1 Apparent Loss Reduction

Apparent losses relate to water that is consumed but not paid for. Apparent losses are usually caused by water theft/illegal connections, problems and errors in metering, data handling, and billing or revenue meter under-registration. While the first two causes are directly related to water utility management and may be reduced by improving company procedures, water meter inaccuracies are considered to be the most significant and hardest to quantify. Water meter errors are amplified in networks subjected to water scarcity, where users adopt private storage tanks to cope with the intermittent water supply.

11.8.1.1 Losses in Meters

Losses in meters happen due to the following reasons:

a) Customer meter leaks: Leaks can be caused by loose spud nuts on the meter, broken or damaged couplings, loose packing nuts, damaged or broken meter yokes, damaged or broken angle stops, or broken meters.
b) Improper meter sizing: Customer service connections and meters were typically sized based on the peak flow rates that the meter was expected to encounter. Because peak flows are uncommon, most meters recorded flows at the low end of their design range. Many flow meters are less accurate at the low end of their range, with very low flows not being captured at all. The current consensus focuses on the flow range most commonly encountered rather than rare peak flows.
   On the other hand, meters that are undersized for the flow profile they will transmit much higher flows of water than they are designed to accommodate, resulting in a rapid loss of accuracy. Utility managers should monitor their billing data for unexpectedly high consumption for the existing sized meter and test these meters more frequently. Meters that have been proven to be undersized should be replaced with a larger model.
   The high, average, and low consumption values can be used to determine whether a water meter is appropriately sized for the actual water consumption pattern. If most of the flow through a customer meter occurs at the high or low end of the meter's specified range, the meter is most likely improper for the application.
c) Correct installation: If fully functional water meters are not installed properly, they may be inaccurate. All meter manufacturers provide specifications and installation guidance for their water meters, and water utilities should follow this guidance. Water meters should be installed horizontally, with adequate spacing and appurtenances (strainers) as needed. A water meter should be installed in a location away from weather extremes and other stresses.
d) Non-functional Meters: Non-functional meter is defined as any water meter showing no or less consumption. These meters are identified based on less than average consumption in the same month in the year immediately preceding, provided that said meter had been determined to be defective upon testing in the lab by the operator or the battery of the water meter is dead. Either way, the utility managers should monitor their billing data for such unexpected changes, and appropriate action should be taken in time as this leads to loss of revenue as the consumer is billed on average consumption in place of actual consumption. Hence, the meters are required to be periodically tested and replaced if required.
e) Slow/Ageing Meters: Ageing meters tend to deteriorate by many factors discussed above and lead to inefficient measurement of the flow. Hence, the meters are required to be periodically tested and replaced if required. As per studies conducted in many countries regarding NRW, it has been found that water meters tend to go slow with its age. It is recommended during water auditing some meters, 10 years and more than 10 years of age should be tested for its accuracy to work out factor of losses.
f) Multiple connections in a building: With multiple connections in a building the consumption gets reduced abnormally as compared to a single connection. Water rates are on consumptions slab basis the revenue gets reduced abnormally.
g) Calibration of Meters is required if an old meter is used for measurement. Usually, a calibration certificate is valid for one year duration.

Minimising customer meter under-registration requires substantial technical expertise, managerial skills, and upfront funding. Customer meter management should be undertaken holistically, best described by the term "Integrated Meter Management."

Case Study Maynilad Water Services: Integrated Meter Management

In the past, the responsibilities for metering-related activities were scattered throughout the organisation of Maynilad Water Services Inc. As a result, metering efforts and resources (e.g., data loggers, service vehicles, and meters) were often uncoordinated and insufficient. With the establishment of the Integrated Meter Management (IMM) department and its integration in the Central NRW Division, Maynilad now has a one-stop-shop for all metering issues. The IMM department is a young team of highly specialised engineers responsible for all metering related issues—from the smallest customer meters to the largest raw water bulk meters.

The lack of good quality meter testing facilities, especially when it comes to larger diameter meters, and the lack of experience in how to best utilise such facilities is one of the problems. This makes it easy for manufacturers to supply meters from second- class quality manufacturing batches with little risk that the utility would ever find out.

Another common problem is the reluctance to invest in high quality but more costly meters for large customers. Normally, the top accounts of a utility generate such a large portion of their revenues that any investment in more advanced meters can be economically justified. The payback time is often just a matter of months. Yet, many water utilities opt to maintain and calibrate old meters over and over again instead of taking appropriate action and installing new meters. To improve the situation, a utility may follow stringent standards like MID and ISO 4064 for metering project.

11.8.1.2 Illegal Connections

While meter under-registration is more of a technical problem, water theft is a political and social issue. Reducing this part of commercial losses is neither technically difficult nor costly, but it requires making difficult and unpleasant managerial decisions that may be politically unpopular. The reason is that illegal connections are nearly always wrongly associated with only the urban poor and informal settlements. However, water theft by high-income households and commercial users, sometimes even large corporations, often accounts for sizable volumes of water lost and even higher losses of revenue.

In addition to illegal connections, other forms of water theft include meter tampering and meter bypasses, meter reader corruption, and illegal hydrant use.

Another common problem is "inactive accounts". In cases where a customer's contract has been terminated, the physical service connection, or at least the tapping point on the main, still exists and is easy to re-connect illegally. Stringent inactive account management and verification programme can easily solve this problem.

Consumers may resort to many techniques to make a connection free or reduce their bills, as follows:

a) bypassing the meters and illegal connection to consumer's own connection (bypass);
b) tampering the meters;
c) hidden tap running from the water main;

d) illegal connection to a neighbour's supply running along the wall of the property.

11.8.1.3 Public Standpost

Water utility managers often neglect the water losses/ use from a public stand post, and hence, the water supply to the public stand post remains unaccounted for. It is recommended to shift the population served by stand post to community connections/group connections.

11.8.1.4 Billing and Collection Inefficiency

The billing system is the only source of metered consumption data that can help determine the volume of NRW through an annual water audit. However, most billing systems are not designed to retain the integrity of consumption data. Rather, they are designed to deliver accurate bills to customers and correctly account for the bills. However, there are many day-to-day processes in operating a billing system that has the potential to corrupt the integrity of the consumption data, depending on the design of the particular system.

Issues that can affect consumption volumes include:

- meter reading practices causing manual reading errors;
- handling of reversals of overestimation;
- processes used for dealing with complaints about high bills;
- customer leaks;
- estimation of consumption;
- meter change-outs;
- tracking inactive accounts;
- the processes for the identification and rectification of stuck meters; and
- poor follow-up with consumers who are not paying, i.e., having illegal/leaking connections.

Improvement in Billing and Collection Efficiency

Improving billing and collection activities has an immediate impact on the revenue streams of a service provider that can, in turn, help the service provider in improving services and reduction of NRW. However, while effective billing and collection practices depend on many internal factors (including customer databases, the extent of metered and unmetered service provision, tariff and billing structures, delivery of bills, and facilities for customer payments), the institutional arrangements under which service providers operate and provide services determine whether such practices will remain sustainable in the long term. Efficient billing and collection practices can set incentives for the provider to effectively charge and collect water bills while also fulfilling a commercial orientation to services.

Action to improve billing and collection practices are as follows:

a) Monthly billing system based on a volumetric structure with uniform/telescopic volumetric charges and ensuring bills are sent to the correct person for the right amount.
b) Computerised system of billing and an updated and complete customer database.
c) Use of electronic interface such as mobile app-based meter reading applications for AMR/Non-AMR meters.
d) 100% customer metering and 100% billing based on metering should be followed.
e) The service provider must authorise a single point from which consumers can purchase

their meters or provide the meters themselves so that a standardised meter is being used as authorised by the service provider. Service providers also need to have a meter checking, maintenance, and repair policy in place so that any faults identified by meter readers at the time of meter reading can be reported and addressed. Providers should also have in place metering checks where responsible staff could single out problem cases, especially those of incorrect consumption units recorded (data entered could indicate unrealistic consumption units such as negative units or excessive figures).

f) OZ-wide implementation of AMR for total consumption volume data capture. AMR systems can be either walk-by or drive-by. An endpoint is connected to the meter's encoder register. The endpoint captures water flow and alarm data which is collected by utility personnel by walking or driving by with a data receiver in proximity to the device. After collection, the meter data is transferred to a database where utilities can monitor and analyse usage, troubleshoot issues and bill customers based on actual consumption, rather than predictions that were often required with bi-monthly or quarterly manual reads.

g) Meter reading applications: A lot of data handling errors can be avoided by using meter reading applications. The common technologies used by many water service providers worldwide are handheld devices or mobile/web-based meter reading applications that enable meter readers to record readings easily and reduced manual intervention.

h) These apps are preloaded with a set of records or information based on which the water meter data needs to be collected. The apps also generate alerts for incorrect entries or anomalies, for instance, in case meter readers enter erroneous data or if they do not read the meter but continue to generate readings on average monthly consumption. These apps give meter readers two options for generating bills:

   i. Spot billing, where they could generate bills on the spot and hand them over to the consumer once the meter readings are entered. This helps utilities streamline and implement effective billing systems, improve cash flows, and make the processes more customer-centric.

   ii. Batch billing, where meter readers can collect the required data and, at the end of the day, download the data in their office where the master database gets updated, and bills are generated according to the billing cycle.

i) Outsourcing the billing and collection function.

j) Incentives for meter readers for providing effective services in meter reading.

k) Ensuring regular and on-time payments by including the following actions:

   i. Encourage consumers to connect legally to the network;

   ii. For continuous default and nonpayment or in cases of illegal connections, using sanctions, such as water connection cutoffs;

   iii. Incentive schemes for customers who have huge arrears in their bills;

   iv. Encourage consumers to pay on time for services by simplifying the payment process.

l) Resolving customer grievances: A call centre is a must to ensure that a customer focus on service delivery is maintained. Such centres help service providers to respond to consumer grievances in a speedy, appropriate, and efficient manner by receiving constant feedback about the services that they are providing.

11.8.2 Real Loss Reduction

Real loss reduction includes following key activities mentioned in a simplified way (refer IWA Water Loss Task Force Recommendations):

- Active leakage detection and monitoring to limit unreported leaks
- Efficient and fast repair of leakages that are reported or detected
- Maintaining supply pressures to be within desired optimal range
- Keeping Water Network data up to date and timely replacement as and when required

11.8.2.1 Active Leakage Detection and Monitoring

Active leakage detection and monitoring refers to continuous monitoring of an area of supply, say, OZ, and tracking its total loss, segregating it in real and apparent loss components and carrying out leakage detection work where the real losses have started to increase. Now if there are reported leakages, it is obvious to repair those in the first place. But if the OZ is still high on real losses, it clearly indicates utility is not aware of a massive amount of unreported leakages. This awareness time is directly proportional to water loss. Hence, an active leakage detection and monitoring programme can help in reducing leak awareness time for utility. It is followed by field activities to detect the leakages and can be monitored as average leakage location time. Once a leak is pinpointed, the average repair time should also be tracked for measuring performance.

The major activities in the leak detection work in the distribution system are as below:

- Preliminary data collection and planning
- Pipe location survey
- Assessment of pressure and flows
- Locating the leaks
- Assessment of leakage

A. Preliminary Data Collection and Planning

The water distribution drawings are to be studied and updated. The number of service connections is to be obtained and in the drawings of the roads the exact locations of service connections marked. The district and sub-district boundaries are suitably fixed taking into consideration the number of service connections, length of mains, pressure points in the main. The exact locations of valves, hydrants with their sizes should be noted on the drawings. The above activities will help in planning the conduct of sounding of the system for leaks or for fixing locations for conduct of pressure testing in intermittent water supply system before commencement of leak detection work or for measuring pressure and leak flow in the continuous water supply system.

B. Pipe Location Survey

Electronic pipe locators can be used during survey. These instruments work on the principle of electromagnetic signal propagation. It consists of a battery-operated transmitter and a cordless receiver unit to pick up the signals of pre-set frequency. There are various models to choose from. Valve locators are metal detectors that are available which can be used to locate buried valves.

C. Assessment of Pressure and Flows

Data loggers are used to record the pressure and flows. It is an instrument which stores the raw data electronically so as to be able to transfer it to the computer with a data cable link. Two types of portable data loggers are used either with a single channel or dual channel. Single channel loggers are of the analogue type with built in pressure transducers. A simple push fit connection with the street main enables direct recording of pressure for future retrieval.

Dual channel loggers consist of an analogue-type sensor for pressure and a digital type sensor for recording flow reading. A pulse head for picking up a flow reading and its conversion into an electronic pulse is required with this logger. The data of pressure and flows are stored into the data loggers during the test. Subsequent transfer of the data is made electronically into the computer's magnetic storage for further processing.

In the absence of electronic equipment, the pressures can be ascertained by tapping and providing a pressure gauge. Flows can be assessed by using meters on a bypass line.

D. Locating the Leaks

To zero in on the possible location of leakages, the following methods or combination of methods could be adopted.

Leak Pre-localisation Methods:

a. If continuous monitoring of OZ/DMA is set, it provides primary level of information on area that needs to be investigated.
b. Calibrated hydraulic model, GIS data, leakage data analysis, asset condition assessment, etc., can be used to pre-localise potential high water loss areas.
c. Step test can be carried out in monitored OZ/DMA to find leakiest pockets.

Once the area of investigation is identified, further localisation is done by site investigation as mentioned below.

i. **Walking**

Walking over the main, looking for telltale signs of the presence of water.

ii. **Sounding**

Sounding is the cheapest and an effective method of detecting leaks in a medium-sized water supply system.

Sounding could be categorised into two types: Direct and Indirect.

- Direct sounding is made either on the main or fittings on the main such as sluice or air valves; fire hydrants stop taps, or any other suitable fittings.
- Indirect sounding consists of sounds made on the ground surface directly above the mains to locate the point of maximum sound intensity. This method is a good supplement for confirming the location of leak noise identified through direct sounding.

It is important to have good supply pressure in water lines for this method to be effective. Water escaping from a pressurised pipe emits a sound similar to the sound that can be heard when a seashell is held up to the ear. But it takes a lot of experience to distinguish it from other sounds.

The range of frequency of the sound depends upon many factors such as the nature of the leak, size of the hole through which water is escaping, the pipe material, nature of the ground in which the pipe is laid, etc. The equipment used is:

a) Non-Electronic Equipment

These are also known as listening sticks. They are simple pieces of equipment consisting of a rod of any material with an earpiece.

b) **Electronic**

These are electronic listening sticks consist of a metal rod that is screwed onto a combined microphone and amplifier unit. The sound can be amplified using a volume knob and can be heard through earphones.

There is also a ground microphone consisting of a microphone unit and an amplifier unit; the microphone unit is attached to a handle that enables the unit to be placed on top of the ground, and the signal received is amplified and passed on to the user through headphones. Some equipment has indicators.

There are noise loggers that can record leak noise continuously from permanent or temporary locations that can be analysed by experts or a computer programme to filter, process and identify presence of a new leak in the system.

iii. By the use of gas tracer

A gas tracer is injected into the main and will surface out along with water at the point of the leak. A detector is used to search for the substance that escapes. Boreholes are made at frequent distances. The content of each borehole is sampled in turn using a hand detector to ascertain the presence of gas. This method is costly but can be used in systems that doesn’t have good water supply pressure in line.

iv. By using a Leak Noise Correlator

The leak noise correlator is an instrument consisting of a radio transmitter unit and a correlator unit. Both the units are placed on the test mains at the two ends of the stretch under correlation by attaching their magnetic sensors to the mains. The correlator unit identifies the various frequencies of leak sounds and calculates the distances of the leak points from the correlator unit automatically.

E. Classification and Application of Leak Detection methods

The most common form of categorisation is the leak detection principle applied, i.e., following the traces left by a water leakage – either the noise produced by the leaking water (acoustic), the fact that the lost water quantities are missing downstream (flow- rate), the temperature changes in the vicinity of the leak (thermal) or other principles. The methods are described in this order of classification.

Another possibility of classification is the difference in the application of the sensor technology. Here, four different categories can be identified: (1) methods where the leak sensors are guided through the pipe in a mobile way – so-called pigs; (2) methods where the sensor elements are placed near the pipe in the form of a cable; (3) methods where the sensors are attached at a point on or in the pipe; and (4) methods where no contact with the pipe and also not with the water column is necessary. Table no. 11.4 shows both ways of classification.

Table 11.4: Classification and Areas of application of the different methods

No.	Method	Classification		Areas of application						
		Principle	Sensor type	Temporary leak detection	Preventive maintenance/ Daily Monitoring	Applicability in distribution networks	Applicability in large diameters (which cannot be interrupted, longer length, deeper)	Preliminary Identification of leak	Identifying more accurate location of leak	Pinpointing leak location
1	**By listening rods**	Acoustic	Contact sensor	✓		Yes	Exceptionally with many access points	✓		
2	**By ground microphones**	Acoustic	Contactless sensor	✓		Yes (main use)	To some extent for, pinpointing			✓
3	**Leak noise correlation**	Acoustic	Contact sensor	✓		Yes (main use)	To some extent, with hydrophones		✓	
4	**Noise logging**	Acoustic	Contact sensor	✓	✓	Yes (main use)	To some extent, with hydrophones	✓		
5	**Pushed hydrophones**	Acoustic	Pig	✓		Yes (especially for connections)	Yes, but with different characteristics		✓	✓
6	**Tethered hydrophones**	Acoustic	Pig	✓		In exceptional cases	Yes (almost exclusively)		✓	✓
7	**Free-floating hydrophones**	Acoustic	Pig	✓		No	Yes (exclusively)		✓	
8	**Distributed Acoustic Sensing**	Acoustic	Sensing cable		✓	Possible	Yes (preferentially but not exclusively)		✓	
9	**Volume balance**	Flow-rate	Contact sensor	✓	✓	No (see flow monitoring)	Yes (exclusively)	✓		
10	**District Metered Areas**	Flow-rate	Contact sensor		✓	Yes (exclusively)	No	✓		

No.	Method	Classification		Areas of application						
		Principle	Sensor type	Temporary leak detection	Preventive maintenance/ Daily Monitoring	Applicability in distribution networks	Applicability in large diameters (which cannot be interrupted, longer length, deeper)	Preliminary Identification of leak	Identifying more accurate location of leak	Pinpointing leak location
	(DMAs)									
11	**Flow monitoring**	Flow-rate	Contact sensor		✓	Yes (exclusively)	No	✓		
12	**Hydraulic Model Leak Pre-Localisation**	Calibration	Contact Sensor			Yes		✓		
13	**Step test**	Flow-rate	Contact sensor	✓		Yes (exclusively)	No	✓		
14	**Hydraulic leak localisation pig**	Flow-rate	Pig	✓		Yes (especially for connections)	No		✓	✓
15	**Thermal imaging cameras**	Thermal	Contactless sensor	✓		No	No			✓
16	**Thermal imaging drones**	Thermal	Contactless sensor	✓		Yes	Yes		✓	
17	**Distributed temperature sensing**	Thermal	Sensing cable		✓	Possible	Yes (preferentially but not exclusively)		✓	
18	**Moisture sensing smart-cables**	Moisture	Contactless sensor	✓		No	No			✓

No.	Method	Classification		Areas of application						
		Principle	Sensor type	Temporary leak detection	Preventive maintenance/ Daily Monitoring	Applicability in distribution networks	Applicability in large diameters (which cannot be interrupted, longer length, deeper)	Preliminary Identification of leak	Identifying more accurate location of leak	Pinpointing leak location
19	**Moisture sensing cables**	Moisture	Sensing cable		✓	Yes	Yes		✓	
20	**Ground Penetrating Radar (GPR)**	Electromagnetic	Contactless sensor	✓		Yes	Yes (for pinpointing)			✓
21	**Satellite radar**	Electromagnetic	Contactless sensor	✓		Yes	Yes	✓		
22	**Tracer-gas**	Chemical	Contactless sensor	✓		Yes	To some extend with, bubble creators		✓	✓
23	**Sniffer dogs**	Chemical	Contactless sensor	✓		Yes	Yes		✓	✓
24	**Negative Pressure Wave Method**	Pressure	Contact sensor		✓	Only in combination with other methods	Yes (exclusively)	✓		
25	**Soil probes**	Mixed	Contactless sensor	✓		Yes (main use)	To some extend for pinpointing			✓

11.8.2.2 Leakage Repair Techniques

There are a number of different techniques for repairing pipes that leak. These techniques depend on the severity of leak, type of break in the pipe, the condition of the pipe and the pipe material. Repair techniques are explained in detail in Section 4.4.4.7 of Chapter 4 “Transmission of Water” and Section 7.6.10 of Chapter 7 “Distribution System” in Part B of this manual.

11.8.2.3 Use of Water Efficient Plumbing Fixtures

Water leakages after consumer connection (meter) is not reflected as loss in utility water audits. But practically, there is a huge number of average or no bill consumers for a typical water utility. So, role of efficient plumbing fixtures can’t be ignored. Water- efficient plumbing products should be installed in all public buildings, and other major consumers considering the important role that such products can play in reducing water consumption without compromising personal hygiene and customer satisfaction. Further details can be seen from Chapter 15: Water Efficient Plumbing Fixture in Part A of this manual.

11.8.2.4 Prevention of NRW in Consumer Connection

For domestic connection galvanised iron pipes are mainly used. After a period of time these pipes get choked due to corrosion/tuberculation. For house service connection, non-corrosive pipes can be used. The water supply drawing should have correct layout of the pipes, diameter, material, valves, etc. This would facilitate proper maintenance.

11.8.2.5 Pressure Management

The supply pressure is a key factor connected to water lost through leakages. Low pressures are not desirable from service quality point of view and high pressures will cause high volume of leakages. The situation is more aggravated in undulated terrain. Cross connecting different OZs or transmission systems also adversely affect the pressure ranges, leading to areas with very high and very low pressures. So, there are design and operational issues that should be tackled first, followed by advanced methods like pressure management valves to maintain optimal pressures in the OZs/DMAs.

11.8.2.6 Network Asset Update and Replacement

The network is continuously changing to cope up with ever increasing demands. Utility mostly struggle to keep up with this pace and a lot of network data is mostly missing from central GIS repository, or in worse case, there is no GIS repository at all. If the network data is not available, various network analysis and renewal prioritisation can’t be thought of. And ultimately, an improvement project will have to consider 100% replacement due to lack of existing network information and uncertainly about its condition. This is not sustainable and desirable if the service standards are to be maintained. Hence, the first thing is to fix the basic issue of not routing all network CapEx and OpEx changes to a central repository. Followed by various analysis and prioritisation for optimal renewal of network infrastructure.

11.9 Instrumentation and Software for NRW monitoring and Reduction

This section devotes itself to describing applications of digital tools to reduce physical water losses and increase the energy efficiency of water utilities. Globally, digital applications have been developed for leak detection, pressure management, energy- efficient pumping and energy management.

11.9.1 Digitalisation to Reduce Physical Water losses

Innovative digital techniques are discussed here under:

(i) Remote acoustic instruments
(ii) Data analysis software
(iii) Smart pressure management valves

(i) **Remote Acoustic Instruments**: Remote acoustic instruments can be used with various acoustic tools like noise loggers. This enables utility to continuously track and analyse the data over a long period of time without physical access to the instrument for data exchange.

(ii) **Data Analysis Software:** For utilities with very high levels of NRW, the precision for leak detection should commence after water loss is localised to OZs/DMAs. Analysis software can provide sector wise total loss, hourly losses summary for last day, segregation of real and apparent loss component for 24×7 water supply, consumption anomalies, etc. SCADA and consumption data combined with hydraulic model of the network can also be used for network calibration and leak pre-localisation. Pinpointing leaks are not possible by data analysis tools, but it may guide field teams to the right OZ and prepare leak detection routes based on analytical prioritisation.

(iii) **Smart Pressure Management Valves:** With reference to NRW, the high pressures lead to leaks in old pipelines. With smart pressure management valves, different inlet pressures can be set for day and night based on consumption requirement analysis. That will help in controlling unnecessary pressure rise during night and keep water loss due to leaks under control.

11.10 Advanced Metering Infrastructure (AMI)

Advanced Metering Infrastructure (AMI) is an integrated system of water meters, communication networks and data management systems that enables two-way communication between meter endpoints and utilities. Unlike AMR, AMI doesn't require utility personnel to collect the data. Instead, the system automatically transmits the data directly to the utility at predetermined intervals. Meter data is sent to utilities via a fixed network. The utility can use the data to improve operational efficiencies and sustainability by effectively monitoring water usage and system efficiency, detecting malfunctions and recognising irregularities. With a fixed network, utilities work with specific vendors to get their infrastructure and technologies up and running. And today, existing cellular networks, designed to minimise downtime, can be used to make sure meter data is collected securely and without interruption. A network of smart water meters and intelligent infrastructure that provide continuous and historical data to improve system intelligence, visibility, automation, and control. Smart water solutions are credited with:

- enhancing meter reading efficiency;
- assuring long-term meter accuracy;
- improving customer service processes;
- decreasing NRW;
- streamlining billing processes;
- supporting security to deter tampering.

A common misconception is that smart water solutions are only available for utilities with a certain population size or that dedicated utility resources are required to maintain an AMI network after it is deployed, but neither of these statements are true. Smart water solutions using existing cellular networks are available for utilities of all sizes and locations. There are three steps utilities can take to use AMI leak detection to conserve water: metered leak detection, district metering leak detection and acoustic leak detection. Each method leverages specific aspects of AMI technology to detect leaks in different ways. AMI solutions transform data collected through the system into valuable and actionable intelligence for users across the utility, empowering the entire organisation to address conservation and revenue protection.

Approach 1. Metered Leak Detection

With certain AMI systems, a leak flag is sent whenever continuous flow of a metered account is detected over a specific timeframe. A communication module takes a consumption reading at the top of every hour and records this reading into its memory. When the reading is taken, the module can detect if there has been flow over the previous hour or if there has been no consumption. If there is one week of non-zero consumption (continuous flow), the communication module marks this as a potential leak and includes a leak flag with its next data transmission.

The data passes through the AMI collection engine and ultimately is accumulated in a data repository where leak and other data can be viewed. The user can see consumption values over time to see when the potential leak began, if it is improving or getting worse, and the day it was repaired.

Figure11.2: Typical leaks at a joint

Approach 2. District Metering

Performing district metering is another way utilities can utilise AMI for water conservation. This involves grouping and aggregating stored data in a software application. The process consists of three steps:

1. Identify the meter or meters that feed water into the district (i.e., the master meter).

2. Identify the group of meters in the district and combine the total consumption of these meters on an interval-by-interval basis. Accrue the combined consumption of the district into a virtual meter.
3. Compare the net consumption of the master meter with the metered consumption of the aggregated district on a time-synchronised interval-by- interval basis. Any difference between the net consumption of the master meter and the aggregated consumption of the virtual meter is considered NRW, which can include leaks. The precise time synchronisation of all readings to the top of the hour or some other reference point is a key component of this analysis. In other words, one cannot compare consumption of the master meter today to the aggregated consumption of the virtual meter from a different day. It must consist of an instantaneous comparison of water-in to water-out at the same moment for accurate analysis.

NRW can result from leaks, theft, or mis-metering. However, when a district metering analysis has been performed, much more information is available regarding where to look for leaks throughout the network.

Approach 3. Acoustic Leak Detection

Acoustic leak detection is another way utilities can account for and identify NRW. The combination of acoustic leak sensors, AMI technology and data analysis software enables proactive leak mitigation. Using a communication module with an integrated acoustic leak sensor, water providers can collect and analyse vibration patterns from anywhere in the distribution system, improving their ability to maintain critical water infrastructure. Having a proactive acoustic leak detection system reduces NRW and conserves water resources through early leak warnings. Utilities can lower repair costs by finding and repairing leaks before they become costly main breaks. By pumping and treating less water, utilities extend the lives of their facilities.

Metered leak detection, district metering and acoustic leak detection allow utilities to be more sustainable by reducing the number of leaks in a system and the amount of water that would otherwise have been wasted. Using AMI to detect leaks can maximise water supply availability by detecting new, evolving, and pre-existing leaks automatically. It also can mitigate pipeline accidents and infrastructure leakage with an eye toward improving utility operations, maintenance, and capital improvement decisions. Ultimately, this technology enables utilities to focus on conservation and create a more resourceful future. The utilities in the region can build successful leak detection and prevention programmes by utilising mobile AMR and fixed network AMI systems.

Utilities conduct audits to determine how much water pumped into the distribution system is actually metered. AMI data can make these audits more accurate by helping utilities identify where loss may be occurring. For example, AMI data can identify meters that are not recording properly, either because they are broken or have been bypassed through theft. Unmetered water usage, whether authorised or not, is a key source of NRW loss.

In addition, a major NRW culprit is using the wrong-sized meter in an application, such as when a high-water-use business (e.g., a laundromat) moves into a commercial building originally developed for light industrial use. If the wrong meter is used, it may not record all the water that is used, which results in lost revenue.

Underground leaks in the distribution system are a primary cause of NRW loss but can be difficult to locate. Acoustic loggers integrated into a fixed-network system can cost- effectively identify small, underground leaks before they become big problems.

The loggers send data to the utility over the fixed network, where web-based application software automatically correlates the data and identifies and locates high- probability leaks. This approach simplifies acoustic leak detection, eliminating the need to send crews into the field and providing the means to manage the process from the utility.

Once the units are installed, operators can monitor the system and analyse results at the utility office. No manual or drive-by data collection is required. The system can be deployed stand-alone or added on to the AMI network system, and which operates with minimal operator involvement.

Several smart metering companies have deployed the technology, which use the system to find underground leaks that occur on several lengths of galvanised service lines and cast-iron pipes.

When considering automation of meter reading, utilities should weigh the benefits of a fixed AMI network for a truly smart infrastructure.

Improvements in customer service, conservation efforts, quantification of non-revenue losses, leak discovery, and operations improvements provide long-term, benefits over both drive-by and walk-by systems.

11.11 Assessment of NRW after Completion

After completion of all the improvements a review of the number and nature of complaints received before, during and after the project should be undertaken and may be tabulated as given in Table 11.5.

An independent survey is to be carried out on the consumers after completion of the NRW works and the consumers are to be surveyed to give their opinion on issues of water supply, e.g., defective water supply (the duration of supply, the pressure available, etc.), water leaks, water quality and billing and metering.

The overall assessment of these figures will give the impact of the NRW exercise.

Table 11.5: Analysis of Complaints Received in the Division before and after the NRW works

Timeline	Nature of Complaint			
	Defective Water Supply	Water Leak	Water Quality	Billing and Metering
2 months prior to work				
Month prior to work				
During work				
Month after work				
2 months after work				

The report should also include general data as follow:

a. Name of Division
b. Total No. of connections
c. No. of connections tested
d. Month/Year completed
e. % of Division covered

11.12 Capacity Building

Capacity building can address the shortcomings and help the ULB staff to deal with governance, management, and technology issues. In-house training centre – for continuous staff training and capacity building at all levels and staff with different specialisations (i.e., engineering, plumbing, accounting, consumer relation, etc.) should be developed.

The activities against real and apparent losses require a comprehensive water loss control programme that comprises technical and social aspects of management to locate and reduce these water losses and thus maintain or increase revenue for the maintenance of water utilities.

Water utility managers need specific answers to Who? What? When? Where? Why? How often? and how much? These questions should be discussed for each of the following aspects during capacity building programmes:

- Record keeping
- Audit/balance performance indicators and benchmark analysis
- Economic analysis
- Metering – locating, sizing, initial installation, validation, replacement
- Meter reading or Automatic Meter Reading (AMR)
- Additional system monitoring, including SCADA – Data transfer – billing, data error analysis
- Leakage management programme
- Periodic leak detection sweeps
- DMA, zone flow analysis, and other forms of leak testing
- Leak locating – method and training
- Leak repair
- Repair, rehabilitation, or replacement analysis, design, and execution
- Pressure management

11.13 Periodic Operational Staff Training

Periodic Operational Staff Training can bridge the gap in the skills of individuals in many areas, such as:

(a) leak detection and repair;
(b) quality studies and analysis of water losses;
(c) meter management and effective technical approaches to managing water losses;
(d) monitoring leakage levels;

(e) location of leakage using equipment such as leak noise correlator amplifiers and listening sticks;
(f) leak detection methods are possible under different conditions;
(g) improve awareness;
(h) increase motivation;
(i) transfer skills;
(j) introduce best practices/appropriate technology.

11.14 Case Studies of Water Audit

Case Studies on Water Loss Reduction are given at **Annexure – 11.1** and **11.2**.

CHAPTER 12 : ENERGY AUDIT AND CONSERVATION OF ENERGY

12.1 Introduction

Electrical energy is an expensive commodity and the cost of energy is increasing day by day. Generally, pumping installations consume a huge amount of power; the proportion of energy cost can be as high as 70% to 80% of the overall operational expenditure (OPEX).

The need for conservation of energy, therefore, is of utmost importance. All possible steps need to be identified and adopted, to conserve energy and reduce energy costs so that water tariffs can be kept as low as possible and the gap between the cost of production and supply of water and the price affordable by consumers can be reduced. Conservation of energy is also important and necessary in the national interest. Further, conservation of energy also helps in preventing climate change.

In the above context, the following strategy needs to be adopted in the management of energy in pumping installations, treatment and distribution.

i) Use energy efficient equipment and machinery at the time of planning, design, inception and operations.
ii) Conduct thorough and in-depth energy audit covering analysis and evaluation of all equipment, operations, and system components that have bearings on energy consumption and identify the scope for reduction in energy consumption.
iii) Implement measures for the conservation of energy on priority basis.
iv) Check and ensure that energy saving, as envisaged, is achieved.
v) Repeat the studies at regular intervals and review the performance to identify continuous improvement and maintain optimum performance and energy efficiency.

12.2 Energy Audit

What is energy audit?: It is an assessment and accounting of energy efficiency. It also relates to energy quality. The starting point is the identification of energy-consuming equipment for the knowledge of energy-saving potential.

Energy audit can result in enhancing efficiency, improving quality of power and most importantly reduce the wastage of energy. The energy audit can start with review of electricity bill and end with recommendations for guaranteed means to reduce this bill, after implementation of energy-saving measures identified, based on observations during energy audit.

Energy audit should recommend best energy management practices.

12.2.1 Method of Energy Audit

1. Identify energy consuming equipment and sources of losses.
2. Compile, update energy consumption data.
3. Detail review of energy consumption profile.
4. Recommendations of energy saving measures.
5. Workout investment to be made and calculate payback period.

12.2.2 Types of Energy Audit

A. **Walk Through Energy Audit**
It is a simple review in which auditor investigates energy consumptions.

B. **Specific Energy Audit**
This starts with data collected during walk through audit. This audit provides detail analysis of specific aspect/equipment of project.

C. **Detailed Energy Audit**
This is known as investment grade energy audit. It is detailed analysis of all energy consumption avenues, recommendation of energy saving measures and indication of investment with envisaged payback period.

12.2.3 Energy Audit Report Format Recommendations

1. **Title page**:
Title of energy audit report, Client name, project audited, submission date etc.

2. **Table of contents:**
A clear precise and well-formatted table of contents is an indicator of good report.

3. **Preamble:**
Mention brief description of project, objectives of energy audit, scope of audit, methodology adopted, etc.

4. **Short summary:**
Reader should get a glimpse of report. Illustrative summary is as in Table 12.1.

Table 12.1: Summary of Recommendations

I. Short Term Measures					
S. No.	Recommendations	Estimated Energy Savings, kWh/Year	Annual Cost Savings, in Rs.	Capital Investments, in Rs.	Payback Period
1					
2					
II. Medium Term Measures					
S. No.	Recommendations	Estimated Energy Savings, MWh/Year	Annual Cost Savings, in Rs.	Capital Investments, in Rs.	Payback Period
1					
2					
III. Long Term Measures					
S. No.	Recommendations	Estimated Energy Savings, MWh/Year	Annual Cost Savings, in Rs.	Capital Investments, in Rs.	Payback Period
1					
2					

Conclusion:

i. The annual energy bill of ....installation is Rs. .... Lakhs.
ii. The potential annual amount saving identified by the study is Rs. ....
iii. Overall cost saving is Rs.. ......at the capital investment of Rs. .... and payback period is.. months.

5. **Detailed report:**

This includes sequential compilation of activities and observations of energy audit and recommendations with measures of energy conservation, proposed modifications, investment and payback.

12.2.4 Guidelines for Conducting Energy Audit of Pumping Stations

1. The audit should be done by Bureau of Energy Efficiency (BEE) accredited energy auditor with relevant experience in pumping system.
2. Use latest calibrated instrumentation as given in Table 12.2.

Table 12.2: Illustrative details of Instruments used during the Energy Audit

S. No.	Instrument Used	Parameter Measured	Range	Accuracy
1	Ultrasonic Flow Meter	Water flow through pipes		±1 %
2	Ultrasonic Thickness Gauge	Thickness of Pipes		±0.1 %
3	Portable Power Analyser • Voltage • Current • Power	Electrical Parameters of various loads		±0.5 % ±0.5 % ±0.5 % ±0.5 %
4	Pressure Gauge/Pressure Transducer	Pressure of water		±0.5 %
5	Digital Tachometer	Speed of Motor		±0.5 %

3. Observe all safety precautions.
4. Record combination of working and standby pumps and note design point, corresponding to number of working pumps.
5. Conduct site performance test and measure motor input power.
6. From motor type test report, find out motor efficiency corresponding to actual load, during testing as a percentage of motor full load. Note the power factor.
7. Based on this data, find out pump input power.
8. Calculate water horsepower of pump by actual measurement of discharge and head.
9. Dividing water horsepower by pump input will give pump efficiency.
10. Compare the calculated pump efficiency with designed pump efficiency using manufacturer's performance curves, data sheets, etc. Compare actual values with the design/performance test values, and if any deviation is found, list the factors with the details and suggestions to improve performance.
11. Refer Figure 12.1, Table 12.3, Figure 12.2, and Table 12.4 for illustrative losses in typical Horizontal Split Casing Centrifugal (HSCF) and Vertical Turbine (VT) based pumping installations.

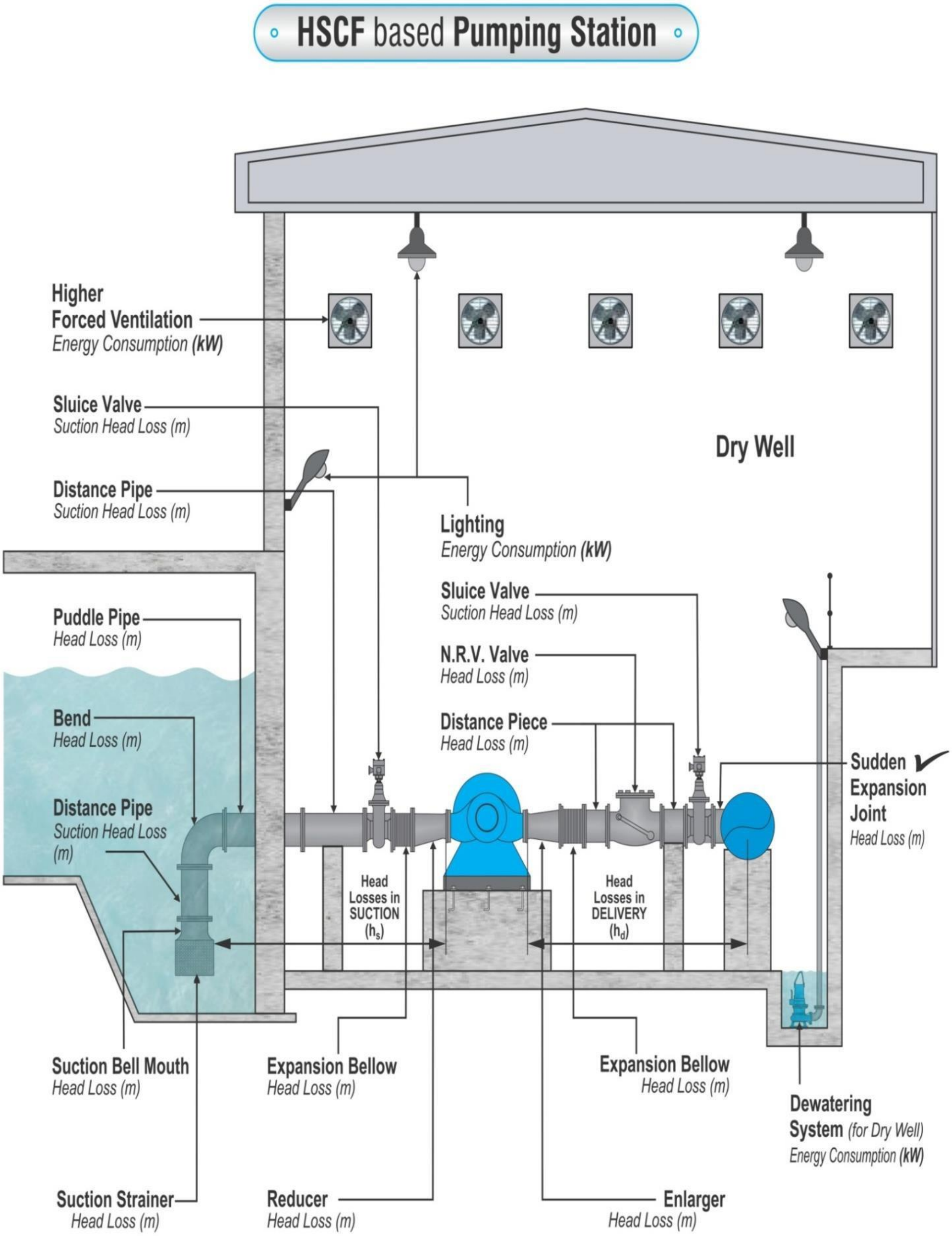
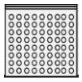
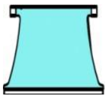
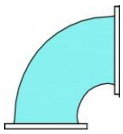
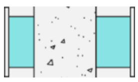
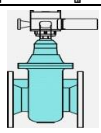
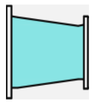
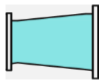
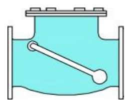
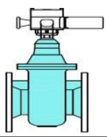
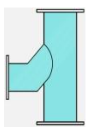
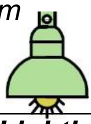
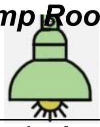
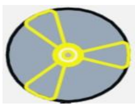


Figure 12.1: Horizontal Split Casing Centrifugal (HSCF) Based Pumping Station

Table 12.3: Energy required for pumping station with HSCF Pumps

S. No.	Project:	****			
1	***Total Capacity***			*D*	
2	***Working Hours per day***			*hr*	
3	***Pump sets Quantity***	***Working***		*Nos*	
4		***Stand-by***		*Nos*	
5	***Pump set's Rating @ Discharge Nozzle***	***Rated (Effective) head***		*m*	
6		***Q Discharge Nozzle/ pump***		*L/s*	
7				*m3/hr*	
8	***Pump Output (p)***	***Waterpower***		*kW*	
9	***Pump Delivery***	***Nozzle Size***		*mm*	
				Type of Pump set	**HSCF**
10.1	***Suction (Head) Losses (hs)***	***Suction Strainer*** 	Loss Factor "K"	***K value*** (Resistance Coefficient)	
			Loss	*m*	
10.2		***Bell Mouth*** 	Loss Factor "K"	***K value*** (Resistance Coefficient)	
			Loss	*m*	
10.3		***Distance piece*** 	Length	*m*	
			Loss	*m*	
10.4		***90⁰ Bend*** 	Loss Factor "K"	***K value*** (Resistance Coefficient)	
			Loss	*m*	
10.5		***Puddle Pipe*** 	Length	*m*	
			Loss	*m*	
10.6		***Distance piece*** 	Length	*m*	
			Loss	*m*	
10.7		***Sluice Valve*** 	Loss Factor "K"	***K value*** (Resistance Coefficient)	
			Loss	*m*	

S. No.	Project:	****			
10.8		***Expansion Bellow*** 	Loss Factor "K"	***K value*** (Resistance Coefficient)	
			Loss	*m*	
10.9		***Reducer*** 	Loss Factor "K"	***K value*** (Resistance Coefficient)	
			Loss	*m*	
10.10		***Total***	*m*		
11.1	***Delivery** (Head) **Losses (hd)***	***Enlarger*** 	Loss Factor "K"	***K value*** (Resistance Coefficient)	
			Loss	*m*	
11.2		***Expansion Bellow*** 	Loss Factor "K"	***K value*** (Resistance Coefficient)	
			Loss	*m*	
11.3		***Distance piece*** 	Length	*m*	
			Loss	*m*	
11.4		***NRV Valve*** 	Loss Factor "K"	***K value*** (Resistance Coefficient)	
			Loss	*m*	
11.5		***Distance piece*** 	Length	*m*	
			Loss	*m*	
11.6		***Sluice Valve*** 	Loss Factor "K"	***K value*** (Resistance Coefficient)	
			Loss	*m*	
11.7		***Sudden Expansion Joint*** 	Loss Factor "K"	***K value*** (Resistance Coefficient)	
			Loss	*m*	
11		***Total***	*m*		

S. No.	Project:	****		
12	***Total head (H)*** **=** *to be developed by pump to overcome ALL Head Losses up to Discharge Nozzle*		*m*	
13	***Pump Efficiency (ηp)***		*%*	
14	***Pump Shaft Input (bkW)***		*kW*	
15	*(Mechanical)* ***Power drawn from*** *(Driver)* ***Motor***		*kW*	
16	***Motor Efficiency (ηm)***		***%***	
17	***Motor Terminal Input*** *(Electrical)* ***Power Consumed*** *(PumpSET)* ***(Pmi)***		*kW*	
18	***Overall*** *(Pump SET)* ***Efficiency (ηO)***		*%*	
19	***TOTAL Electrical Power Consumed by Pumpsets***		*kW / hr*	
			kW-hr / Day	
20	***Energy Consumption*** *in* ***Lighting*** *of Electrical Room* 	*Unit Rating*	*kW*	
		Quantity / W + S	*nos*	
		Working hr / day	*hr*	
		kW / Day	*kW / Day*	
21	***Energy Consumption*** *in* ***Lighting*** *of* ***Under Ground Pump Room (Dry Well)*** 	*Unit Rating*	*kW*	
		Quantity / W + S	*nos*	
		Working hr / day	*hr*	
		kW / Day	*kW / Day*	
22	***Energy Consumption*** *in Auxiliary power consumption of* ***Dewatering Pump*** *(used for dewatering seepage, gland and gasket leakage dewatering of dry well under ground pump room)*	*Unit Rating*	*kW*	
		Quantity / W + S	*nos*	
		Working hr / day	*hr*	
		kW / Day	*kW / Day*	
23	***Energy Consumption*** *in* ***Forced Ventilation (of Under Ground Pump Room (Dry Well)*** 	*Current*	*A*	
		Volt	*V*	
		Power Factor	*Ø*	
		Power	*kW*	
		Quantity of Fans	*nos*	
		kW / Day	*kW / Day*	
24	***Total Auxiliary and Ancillary Power Consumption***		*kW / Day*	
25	***Transformer, Electrical Substation and Miscellaneous Losses***		*kW / Day*	
26	***Pumping Station (PS)***	***P.S. Total Power Consumed***	*kW / Day*	
27		***P.S. Efficiency (Wire to Water)***	*%*	
28		***Specific Power Consumption***	*kW / ML*	

Note: Above layout of HSCF pumping station is illustrative. Generally, end suction pumps will have similar layout. In case of submersible/submerged pumps; except for suction strainer; no other suction piping or suction valves etc will be present. The losses need to be computed depending upon equipment involved in pumping station on case-to-case basis.

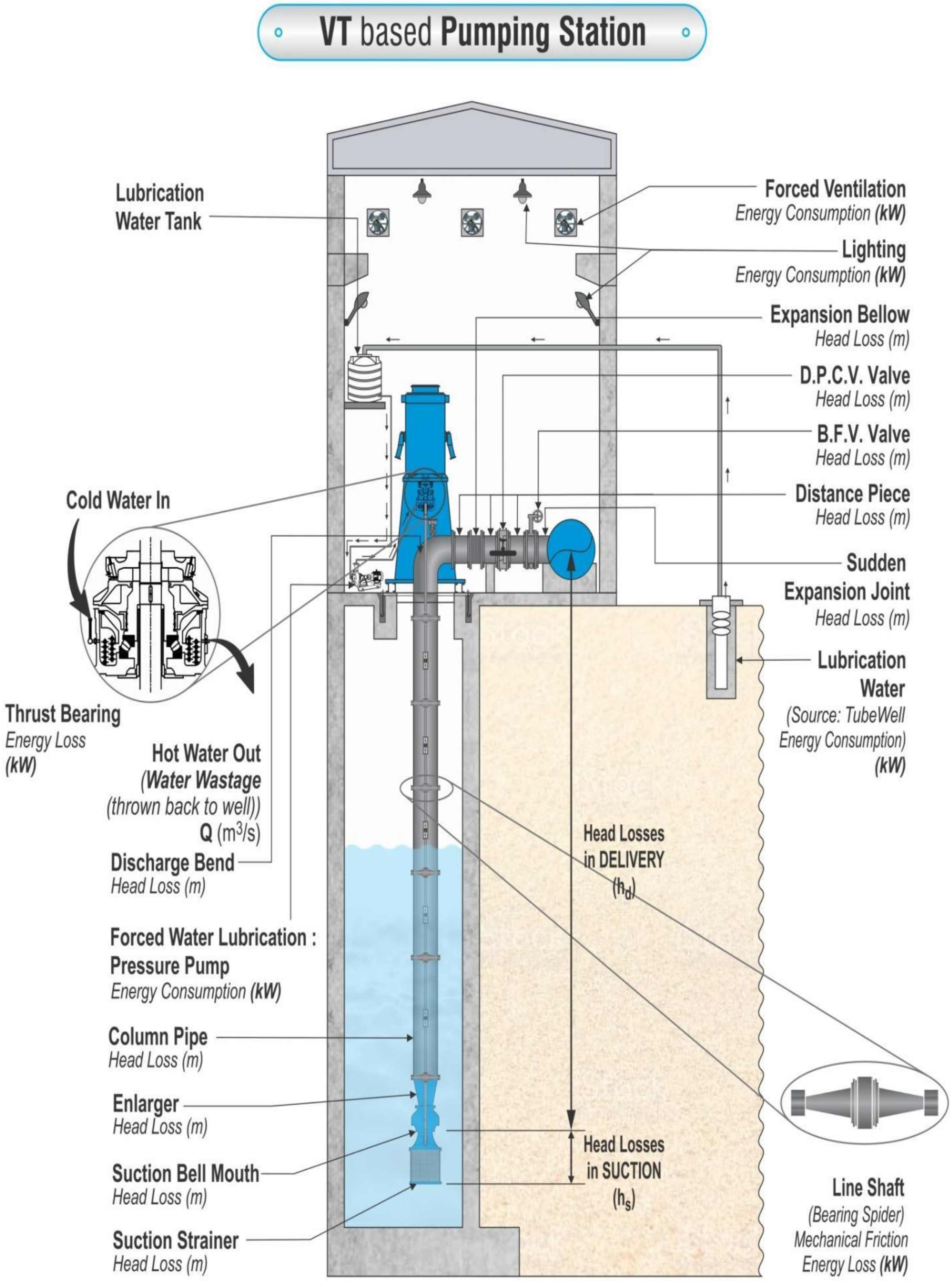
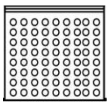
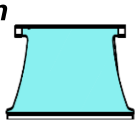
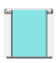
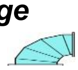
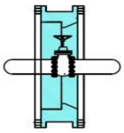
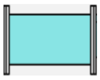
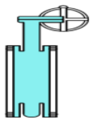
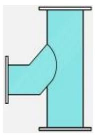
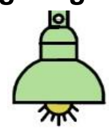
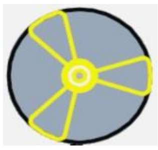


Figure 12.2: Vertical Turbine (VT) Based Pumping Station

Table 12.4: Energy required for pumping station with VT Pumps

S. No.	Project:	***			
1	***Total Capacity***			*MLD*	
2	***Working Hours per day***			*hr*	
3	***Pumpsets Quantity***	***Working***		*Nos*	
		Stand-by		*Nos*	
4	***Pumpset's Rating @ Discharge Nozzle***	***Rated (Effective) head***		*m*	
5		***Q Discharge Nozzle/ pump***		*l/s*	
6				*m^3/hr*	
7	***Thrust Bearing Cooling Water as applicable***	***Q/Qpump***		*%*	
8		***Q/pump***		*m^3/hr*	
9	***Q Bowl***			*m^3/hr*	
10	***Pump Output (p)***	***Waterpower***		*kW*	
11	***Pump Delivery***	***Nozzle Size***		*mm*	
				Type of Pumpsets	**VT**
12.1	***Suction (Head) Losses (hs)***	***Suction Strainer*** 	Loss factor "K"	***K value*** (Resistance Coefficient)	
			Loss	*m*	
12.2		***Bell Mouth*** 	Loss factor "K"	***K value*** (Resistance Coefficient)	
			Loss	*m*	
12		***Total***	*m*		
13.1	***Delivery (Head) Losses (hd)***	***Enlarger*** 	Loss Factor "K"	***K value*** (Resistance Coefficient)	
			Loss	*m*	
13.2		***Column*** 	Loss	*m*	
13.3		***Discharge Bend*** 	Loss	*m*	

13.4		***Distance piece*** 	Length	*m*	
			Loss	*m*	
13.5		***Expansion Bellow*** 	Loss Factor or "K"	***K value*** (Resistance Coefficient)	
			Loss	*m*	
13.6		***Distance piece*** 	Length	*m*	
			Loss	*m*	
13.7		***DPCV Valve*** 	Loss Factor or "K"	***K value*** (Resistance Coefficient)	
			Loss	*m*	
13.8		***Distance piece*** 	Length	*m*	
			Loss	*m*	
13.9		***BFV Valve*** 	Loss Factor or "K"	***K value*** (Resistance Coefficient)	
			Loss	*m*	
13.10		***Sudden Expansion Joint*** 	Loss Factor or "K"	***K value*** (Resistance Coefficient)	
			Loss	*m*	
13		***Total***	*m*		
14	***Bowl Assembly head (H) = Head*** *to be developed by bowl to overcome ALL Head Losses up to Discharge Nozzle*			*m*	
15	***Bowl Efficiency (ηb)***			*%*	
16	***Bowl Assembly Input Power (Pb)***			*kW*	
17	*(Mechanical - Friction)* ***Line Shaft*** *(as applicable)* ***Losses (Pa)***			*kW*	
18	*(Mechanical)* ***Thrust Bearing*** *Losses* ***(Pt)***			*kW*	

19	***Pump Input power (P)***		*kW*	
20	***Pump Efficiency (ηp)***		*%*	
21	*(Mechanical)* ***Power drawn from*** *(Driver)* ***Motor***		*kW*	
22	***Forced Water Lubrication system*** *(IF applicable for Line Shaft lubrication) (Electrical)* ***Power consumption*** *(of forced water pumping system)*	***Power consumed to Source Forced Water***	*kW*	
		Power consumed to Pressurise Forced Water	*kW*	
23	***Motor Rating Offered***		*kW*	
24	***Motor Efficiency (ηm)***		*%*	
25	***Motor Terminal Input*** *(Electrical)* ***Power Consumed*** *(PumpSET)* ***(Pmi)***		*kW*	
26	***Overall*** *(PumpSET)* ***Efficiency (ηO)***		*%*	
27	***TOTAL Electrical Power Consumed (PumpSET + Forced Water Lubrication system)***		*kW / hr*	
			kW-hr / Day	
28	***Energy Consumption*** *in* ***Lighting*** 	*Unit Rating*	*kW*	
		Quantity / W + S	*Nos*	
		Working hr / day	*hr*	
		kW / Day	*kW / Day*	
29	***Energy Consumption*** *in* ***Forced Ventilation*** 	*Current*	*A*	
		Volt	*V*	
		Power Factor	*Ø*	
		Power	*kW*	
		Quantity of Fans	*Nos*	
		kW / Day	*kW / Day*	
30	***Total Auxiliary and Ancillary Power Consumption***		*kW / Day*	
31	***Transformer, Electrical Substation and Miscellaneous Losses***		*kW / Day*	
32	***Pumping Station***	***P.S. Total Power Consumed***	*kW / Day*	
33		***P.S. Efficiency (Wire to Water)***	*%*	
34		***Specific Power Consumption***	*kW / ML*	

Note: Above layout of VT pumping station is illustrative. In case of submerged VT pumps; the line shafts, line shaft bearings, couplings, etc., will not be present. Also, no separate pre-lubrication or external lubrication arrangement will be present. The losses need to be computed depending upon equipment involved in pumping station on case-to-case basis.

12.2.5 Observations for Higher Energy Consumption

Some of the key points are listed below:

1. Illustrative causes of inefficient use of energy.
2. Reduced efficiency of pumps after the operation for few years.
3. Operating point of the pump is far from optimum.
4. Increase in the head loss in a pumping system due to clogging of the strainer, encrustation of column pipes, and pumping mains.
5. In the pumping station, there is an improper/uneconomical diameter of sluice valves, column pipe, etc.
6. Over estimation of frictional losses while calculating pump head. In such a case, the pump runs at the lower head and higher discharge in the system, resulting in increased power depending on the nature of the power curve.
7. Wastage of energy due to the operation of electrical equipment at low power factor.
8. Higher electrical system losses. Refer Figure 12.3, Table 12.5, Table 12.6, Table 12.7 and Table 12.8.

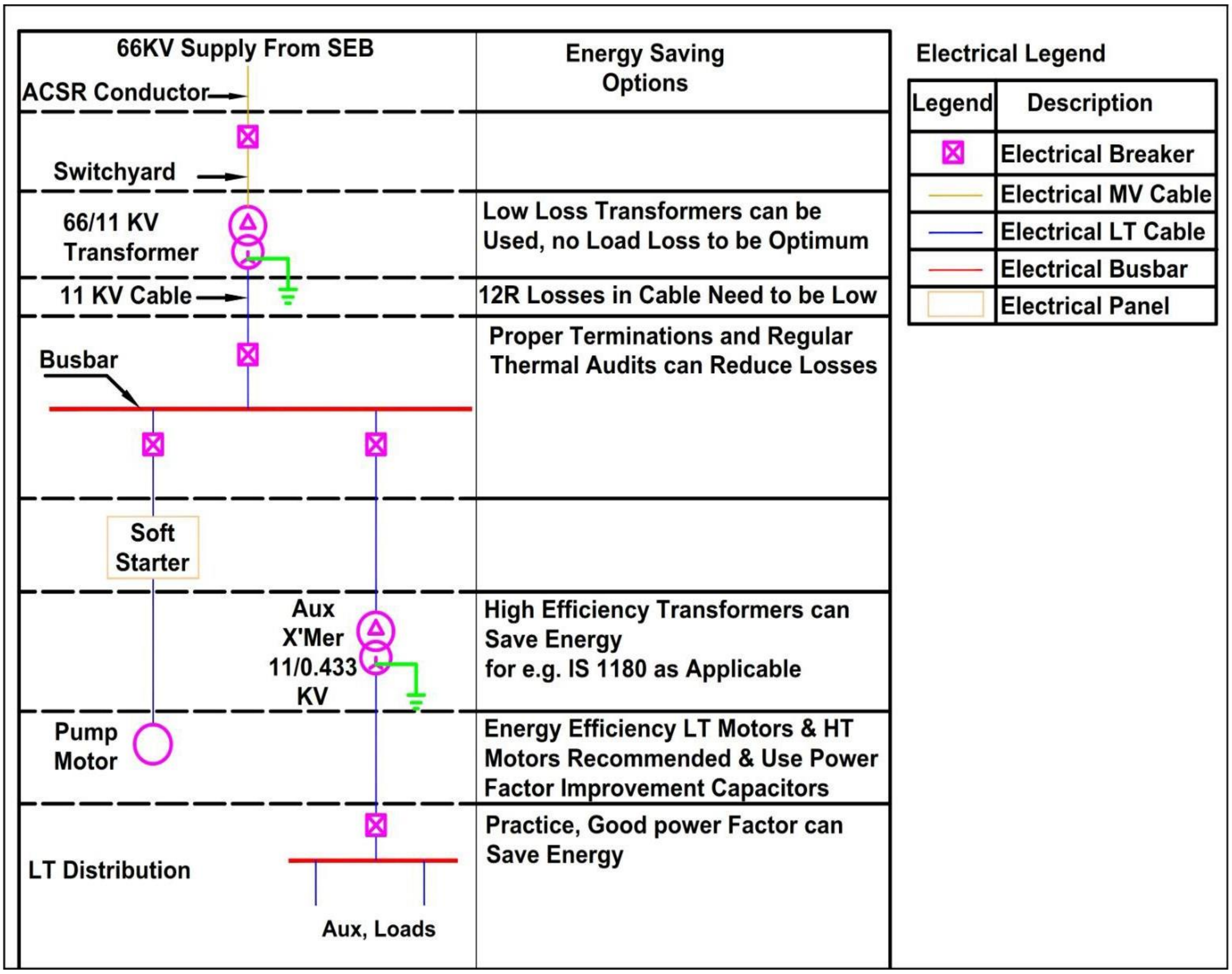


Figure 12.3: Illustrative Large Water Pumping Station

12.2.6 System Distribution Losses

In an electrical system, often the constant no load losses and the variable load losses are to be assessed alongside, over a long reference duration, towards energy loss estimation.

Identifying and calculating the sum of the individual contributing loss components is a challenging issue, requiring extensive experience and knowledge of all the factors impacting the operating efficiencies of each of these components.

For example, the cable losses in any industrial plant will be up to 6% depending on the size and complexity of the distribution system. Note that all of these are current dependent and can be readily mitigated by any technique that reduces facility current load. Various losses in distribution equipment are given in Table 12.5.

In system distribution loss optimisation, the various options available include:

- Relocating transformers and sub-stations near to load centres;
- Re-routing and reconductoring such feeders and lines where the losses/voltage drops are higher;
- Power factor improvement by incorporating capacitors at load end;
- Optimum loading of transformers in the system;
- Opting for lower resistance All Aluminium Alloy Conductors (AAAC) in place of conventional Aluminium Cored Steel Reinforced (ACSR) lines;
- Minimising losses due to weak links in distribution network such as jumpers, loose contacts, old brittle conductors.

Table 12.5: Typical Losses in Electrical Distribution Equipment

S. No	Equipment	% Energy Loss at Full Load Variations	
		Min	Max
1.	Outdoor circuit breaker (15 to 230 KV)	0.002	0.015
2.	Generators	0.019	3.5
3.	Medium voltage switchgears (5 to 15 KV)	0.005	0.02
4.	Current limiting reactors	0.09	0.30
5.	Transformers	0.40	1.90
6.	Load break switches	0.003	0.0 25
7.	Medium voltage starters	0.02	0.15
8.	Bus ways less than 430 V	0.05	0.50
9.	Low voltage switchgear	0.13	0.34
10.	Motor control centres	0.01	0.40
11.	Cables	1.00	4.00
12.	Large rectifiers	3.0	9.0
13.	Static variable speed drives	6.0	15.0
14.	Capacitors (Watts / kVAr)	0.50	6.0

Source: Para. 1.6 of Chapter 1: 'Electrical Systems' in Book-3, 'Energy Efficiency in Electrical Utilities' of BEE (Preparation book for Energy Managers and Auditors).

Table 12.6: Illustrative Losses in Electrical System

S. No.	Load Description	Working	Stand By	Total Quantity	Losses (kW)		Total Losses in kW
					No load Losses	Load Losses	
1	Main stepdown Transformers for Pumping Station						
2	Auxiliary Transformers						
3	Losses in VFD if applicable						
4	Any Other Losses						

Table 12.7: Illustrative Total Power Calculations Summary

S. No.	Load Description	kW	Nos.	Total kW	Total MW
1	Total HT Load of Pump motors				
2	Total LT Load for Pumping Station-				
	Losses in Auxiliary/Ancillary				
3	Total Losses in Electrical (Distribution) system				
	TOTAL				

Table 12.8: Illustrative LT Power Calculations

S. No.	Load Description	kW	Voltage	Working	Stand By	Total Quantity	Efficiency	Total Working Load kW	Total Power in kW
				LT LOADS					
1	Exhaust Fans in								
2	Air Conditioner (1.5 Tonne)								
3	EOT Crane								
4	Battery Charger								
5	Dewatering Pumps								
6	UPS								
8	PLC and SCADA								
9	Discharge Butterfly Valve actuators								
9	Auxiliary Supply for 132 kV Breakers, 11 kV Panel and other misc. panels, etc.								

S. No.	Load Description	kW	Voltage	Working	Stand By	Total Quantity	Efficienc y	Total Working Load kW	Total Power in kW
10	Lighting Load and Area electrification including Pump house, control room, office, etc.								

12.2.7 Remedial Measures

The energy audit report should include guidelines for corrective measures (remedial measures) to be taken against the existing operating practices or methods, etc., resulting in energy wastage.

While suggesting such measures, energy auditor should emphasise energy saving or efficiency improvement for prolonged periods rather than more efficiency for shorter periods.

This is referred as sustainable efficiency, e.g., use wearing ring material of proper grade which will reduce rate of wear and maintain efficiency for longer period. Hence suggested corrective measures in energy audit should be aimed at sustenance of efficiency for prolonged period.

For example, these measures can be replacement of material of impeller or material of wearing rings or maintaining little liberal wearing ring clearance rather than very light clearances.

These measures can be refurbishment also, which is cost-effective measure, e.g., applying energy efficient coating in hydraulic passages to reduce losses etc.

Sometimes system modifications like changing the pipe diameter, etc., or avoiding unnecessary or sharp bends, etc., can result in system energy improvement. Energy auditor can highlight such modifications.

Improvement in electrical system will mean proper sizing of transformers, adding appropriate power factor, improvement in capacitors or using energy efficient motors, etc.

While suggesting all such corrective measures, the energy auditor should work out cost implication of each measure, anticipated energy saving as a result of particular measure and calculate payback period to recover the cost incurred.

12.2.8 Illustrative Energy Conservation Possibilities

1. Use of energy-efficient pumps.
2. Replacement or refurbishment of inefficient pumps.
3. Trimming of impellers.
4. Use of high-efficiency motors.
5. The application of efficiency improvement coatings to pumps can reduce energy requirements.
6. Suggest the points to ensure specific energy consumption (SEC) with the best achievable value.

7. Enlist the scope of improvement with extensive physical checks/observations based on the actual operating parameters and enlist the recommendations for actions to be taken for improvement, as applicable.
8. Consider variable speed drives application only after a detailed analysis of the system and where it is necessary. Improper of application of variable speed drives results into many electromechanical problems.
9. Even if the pumps installed are small, efficiency considerations should not be ignored. The savings per pump may not be high, but many large facilities may have a large population of small pumps. The total power usage of the small pumps in the system often can be greater than that of the larger pumps.

12.2.9 Frequency of Energy Audit

Large Installations	: Every year
Small and Medium Installations	: Every two years

12.2.10 Conclusion of Techno-Commercial Details

Energy auditor should conclude in very clear manner about the avenues of energy saving, suggested corrective measures to be implemented to save energy and the commercial implications or cost required to implement such measures.

12.2.11 References used during Audit

While calculating various frictional or other losses or pump set efficiency (or similar technical parameters), energy auditor should furnish the calculations and formulae used, while referring to source from where such formula was referred to for the purpose of clarity.

12.2.12 Contribution made by the Concerned Persons

During energy audit, auditor might have referred to quite various authorities and/or concerned persons to get system details or information about existing operating practices, etc. Also, auditor might have referred to some experts, reports, books or any other literature, etc. All of these references need to be acknowledged in energy audit report.

12.3 Pumping Systems "Life Cycle Cost" Perspective

Pumps are purchased as individual components but provide a service only when operating as part of the system. The satisfactory performance of a pump depends upon its compatibility with the system in which it operates. Hence pumps should not be seen as independent components, but as a part of the system.

The cost of operating the system depends on many interdependent factors, including how well the system design was optimised, the nature of the installation, and the way in which the system is operated and maintained. The initial purchase price of the pump is a small part of the total life cycle cost for pumps.

This makes it imperative to review the pump selection and operation, keeping in view the total application requirements through the operating life. It is generally observed that out of total expenditure incurred on a pump, only 2.5% to 5% is incurred on capital expenditure in pump purchase, and the balance is done on its operation, maintenance, and energy costs. Since the pumps are expected to run for 15 to 20 years, a review of pump performance on a continuous basis is essential.

The concept of the system's total cost needs to be considered over the entire life.

This is referred to as the concept of "Life Cycle Costing." Here we consider the cost of maintenance and repairs etc. in addition to energy costs.

LCC = I + EC + MRC

LCC = Life Cycle Cost

I = Initial investment cost

EC = Energy cost over life cycle

MRC = Operation, Maintenance and repair costs over the life cycle.

The concept such as improvement in operating efficiency, sustenance of efficiency and better operational practices will carry greater significance and ensure sustained energy saving. This can be endorsed in the systematic energy audit.

12.4 Efficiency and Energy Conservation Tips

12.4.1 Illustrative System Design Criteria for Energy Conservation

The criteria for designing an optimum system are as follow:

1. When a pump duty point is designed, there is a tendency to add margins and round up. As a result, an oversized pump is selected, which will operate away from the designed point and may consume higher power. Higher flow may be required to be regulated through the throttled valve, while wasting energy. A pump should be selected for the actual required flow and corresponding head. Adding unnecessary additional heads or capacity will result in higher energy costs. Do not keep unnecessary margins or do not oversize pumps as it leads to uneconomical operation, and the pump may operate at lower efficiency.
2. Give due importance to pump selection.
3. Select the pump to run at the best efficiency point or very near to the best efficiency point.
4. Consider the operating zone for the pump. This shall depend on levels in the sump, system resistance curves, the number of pumps in parallel operation, etc.
5. Decide the speed of the pump and the number of stages of the pump based on a specific speed criterion.
6. Select the optimum motor rating so that the motor runs near to full load and delivers higher efficiency.
7. Select proper suction and delivery pipe and valve sizes so that the frictional losses are minimum, resulting into better system efficiency.
8. For pumps operating over a wide range of duties, it is advisable to select a pump having optimum peak efficiency and a flatter efficiency curve in the operating range.
9. The energy consumed by the pumping system depends on the design of the pump and the manner in which the system is functional. These factors are Interdependent and need to be carefully matched to the system to ensure optimum energy consumption and economical operation.

10. In case of large variations in demand pattern, the aspect of variable speed can be considered; however, this is a need-based application and requires detailed system review. Care should be taken as, in certain cases, the reduced pump discharge is found to be very near to the minimum flow. Also, considering the combination of high capital cost and benefits due to saving, other options like providing trimmer pumps or 50% or 33% capacity pumps additionally may score over variable speed pumps. Though the option of variable speed is lucrative from an energy-saving point, its total impact on the system needs a critical review and should be adopted where the circumstances warrant.
11. Consider the pump as a component of the system and select the pump after analysing full system requirements, to ensure optimum energy consumption.
12. Despite the extra cost, it is worth considering the use of investment (precision) casting, field proven energy-efficient surface coatings, or polishing to reduce surface roughness, which increase efficiency.

12.4.2 Efficiency Considerations

1. Consider wire to water efficiency of the total system.
2. Energy conservation in the pumping system needs to focus on all components that consume energy and not only pumps and motors. Hence system efficiency and system optimisation are more important rather than pump set efficiency alone. The pump may be of the highest attainable efficiency, but if not matched properly with the system, it will not yield desired results.
3. There is a tendency to quote the highest possible efficiency to have a competitive advantage. However, incremental efficiency over and above a certain limit is achieved at the cost of some other parameters, and ultimately the user suffers rather than getting benefited. Hence, optimum efficiency selection needs to be given more importance rather than the highest possible efficiency selection.
4. Generally, an increase in component life and mechanical reliability can adversely affect maximum attainable efficiency. Hence a detailed economical evaluation should be made considering life cycle cost concept explained in point no.12.3 above.

12.5 Water Treatment Plant

As there are large number of small motors for various drives the unit efficiency is generally low. However, the power loss in a WTP is not considered serious due to the very small load, as compared to the pumping system. Nevertheless, energy conservation in WTP operations is quite important particularly in large plants.

12.5.1 Drives

Flash mixers and clarifier drives, have gear box or belt/ chain drive, and flexible coupling to reduce the speed to the required rate. Proper lubricant in the gear box, and checking its level, and timely topping up/ replacement of the lubricant is necessary to keep it smooth and efficient. Proper alignment of the motor and gear box and secondary unit like blade shaft, impeller mixer, paddle, etc., is important to prevent early bearing damage and consequent energy loss.

12.5.2 Wash Water Pumps

These pumps generally lift water from pure water channel or tank to an overhead tank for use during backwash of filter beds. These pump sets are to be maintained properly and the total head to be maintained as close as possible to that in the nameplate to operate at the best efficiency range. Automatic starting and stopping of these pumps based on the tank level and clear water channel level should be introduced to prevent overflow, and dry run, which are both not desirable. Proper alignment, lubrication of bearings, and observation of noise and vibration to identify any wear-out in advance will help in timely preventive maintenance and consequent energy savings. Use of power factor capacitor of proper rating should be checked and ensured, to reduce the KVA demand charges. As these pumps work for only about four to six hours a day, there is enough time to attend to any repairs without affecting the filter operations. The practice of tapping the rising main for wash water requirement, chlorination, and other secondary uses in the WTP should be discouraged and dedicated pump sets of appropriate rating should be used for these requirements.

12.5.3 Air Blower

The air blower is driven by an electric motor. Normal maintenance of any LT motor is applicable to this motor. In addition, cleaning of Air filters, air passages inside blower, proper orientation of blower to receive free air and checking the valves of all filter beds for any leakages when the valves are shut, and positive closure of non-return valves are some key operation practices to keep the blower efficient both in operation and energy use. Optimisation of air wash time based on observation, seasonal changes in turbidity, etc., should be tried to reduce the duration of air wash without compromising on the quality of washing.

12.5.4 Chlorination

Chlorination pumps not only provide the water for solution of chlorine, but also create a pressure necessary for the chlorinator to suck in the gas for dosing. These are also small pumps and are susceptible to fast ageing due to its continuous operation and high speed, and possible exposure to chlorine fumes.

12.5.5 Use of Renewable Energy

The Water treatment plant offers an excellent opportunity for introducing renewable energy like solar PV panels. The most energy-intensive daily operations of filter bed washing are usually carried out during daytime when the power from solar panels can be used to operate the air blowers, wash water pumps etc. The WTP premises usually has a large, exposed area on roof, wash water tank, filter rooms, chemical rooms, etc., which can be utilised to instal Solar panels and save on payment of energy charges in addition to reducing carbon footprint.

12.6 Operational Practices for Energy Saving

Some of the standard operating practices which can help in energy savings are listed below.

1. During the running of pump, monitor various clearances which govern the efficiency of the pump.
2. After the operation of pumps for a couple of years, the trend analysis done, right from the first day of pump operation can reveal important information, and corrective measures can be taken to ensure optimum energy consumption and prolonged life.
3. During parallel operation, equal load sharing is to be ensured. It is not necessary to operate two pumps in parallel (and throttle both the pumps) when a single pump can meet the reduced load demand.
4. Various minor retrofits reduce the operating cost and enhance the efficiency and service life of pumps.

5. Operate the pump in its safe operating zone.
6. Monitor continuously the energy consumption vibration and noise level data.
7. Carry out investment-grade energy audits.
8. The cost of operating a pumping system depends on many factors which are interrelated. Once the system is designed and implemented, it is absolutely essential to review the actual operation and compare it with the design parameters. This review reveals many opportunities for optimisation with minor modifications to suit the actual system requirements. Such an optimisation study done immediately after implementation ensures satisfactory economical and energy-efficient operation of the pumping system over a prolonged period.
9. Peak demand charges – Opportunities exist for water plant operators to manage demand by deferring certain processes to off-peak periods. For example, backwashing during off-peak periods may help reduce demand, or if water storage is available, filling reservoirs during off-peak periods would be less costly. Another example of excess demand occurs during the period of pump changeover (moving from large pump to smaller pump to meet demand, or vice-versa). If demand charges exist, moving any energy consumption to off-peak periods will result in a lower cost per kilowatt-hour.
10. Power factor – Power factor is the ratio to real power (kW) to apparent power (kVA). Reactive magnetising current (kVAr) is consumed by electrical motors and other devices, resulting in poor power factor. Utilities build their systems to supply the apparent power, but typically only charge for real power. Most utilities have a tariff mechanism to recover costs associated with poor power factor, which include excess capacity (wire, transformers, generators) and associated line losses in the distribution system. Power factor correction capacitors can be added “behind the meter” to offset the reactive current consumption and reduce kVA demand and power factor penalties assessed by the electric supplier. Hence, power factor may benefit by the savings in electric utility bill. Care should be taken in the application of capacitors where harmonic distortion of the voltage wave form exists due to non-linear loads such as variable speed drives or rectifiers.

Some additional good operating practices which can help in energy savings are listed below:

1. The throttling of delivery valves and pipeline valves are to be avoided.
2. The aspect of trimming the impeller or even replacing the impeller needs to be considered to meet the actual demand efficiently.
3. The low system resistance results in higher pump delivery capacity. Such a situation can be rectified by replacing the impeller of better material and designed especially for operating requirements and run with better efficiency.
4. The high operating costs (even for old pumps) can be considerably reduced by deciding on specific objectives and implementing the corrective measures effectively and timely.
5. It is very important to check efficiency and other data regularly in order to access the operational condition of pumps as well as to determine the residual life of important components.
6. Measurements made with the same equipment at regular intervals (say six months) reduce measurement tolerances and reveal relative changes in efficiency. The rotor

dynamic behaviour and clearance assessment can be done.

7. Based on the above information, consumption of spare parts and energy needs can be planned in advance.

12.7 Maintenance Aspects for Energy Conservation

1. Periodically check the pump for replacement/refurbishing important components.
2. Consider the modern techniques available for energy conservation like surface coating, etc., to improve the efficiency of the existing pumps in the system in order to save huge power costs.
3. Use genuine spare parts and consult the manufacturer for any service requirement so as to have the best performance continuously.
4. Conduct site performance tests at regular intervals to notice the effect of continuous running and increased internal clearances. Plan maintenance/overall schedules accordingly.
5. Upgrade material for fast-wearing parts. This will lengthen the time intervals between overhauls.
6. Recondition all metal-to-metal fits. Always restore original clearances.
7. Using the latest instrumentation, consider the assessment of operating conditions and explore the operational trends. Workout residual service life continuously and make concrete proposals for rectification or replacement and energy-efficient operation.
8. Restoring Wearing Ring Clearance: Due to the wear of wearing rings, the clearance between wearing rings increases, causing a considerable reduction in discharge and efficiency. If wearing rings are replaced, the discharge and efficiency improve, resulting into lower specific power consumption. (Figure 12.4)

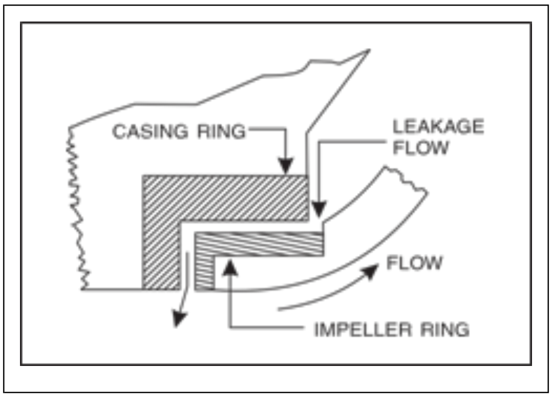


Figure 12.4: A Typical Wearing Ring

Initial leakage through wearing rings is considerably low. Due to operation, wearing rings wear out, causing an increase in clearance which increases leakage loss and results in a consequent reduction in the effective discharge of the pump. The pumps have to be operated for more number of hours, causing an increase in energy cost.

If wearing rings are replaced, the clearances can be brought to the original value, and discharge can be improved substantially, and wastage of energy can be avoided.

It is advisable to replace the wearing rings of the pump periodically based on increased clearances.

a) One of the trends is to provide liberal clearances (optimum clearances) initially. This may result in slightly lower efficiency, but sustenance of efficiency over a prolonged period can be ensured. In some cases, in large pumps, there are examples of seizure of metallic wear rings in pumps due to very low initial clearances and finally, users had to maintain relatively high clearances and operate the pumps. While liberal clearances are maintained, it is ensured that the rate of wear over a period of time is reduced, and sustenance of efficiency over a long period is ensured. This results in a longer mean time between overhauls and pump stoppages.

b) Another alternative is to apply different materials for wearing rings like thermoplastic composite materials, etc., the suitability of materials for applications needs to be thoroughly checked. If the original clearances are restored by means of wearing rings made of an erosion-resistant material, efficiency will increase, and the service life of the pump will be prolonged. The material of construction plays an important role as materials like HDPE reinforced with glass fibre particles, etc., are giving better benefits in actual operation.

12.8 Continuous Monitoring

The energy audit exercise explained in above paragraphs is a continuous exercise so as to record, monitor and take preventive actions to achieve energy efficiency. It is recommended to use Internet of Things (IOT), Automation, Digital Twin, etc., to have a real-time record and monitoring. If the ULB do not have technical resources to carry out the energy audit exercise, they can appoint experienced energy auditor. BEE, a Government of India agency has provided a report on general (indicative) scope of services for the auditor which is given in **Annexure 12.1**.

12.9 Energy Saving Companies (ESCO) Model

Water utilities across India face operating challenges in running the water supply system, both in terms of water production and water transmission. Water utilities supply water from multiple pumping stations in bulk quantities for use in the city water system. After commissioning of pumping station, over a period of time, the pump efficiency reduces against the designed efficiency of 80%–90%. With the reduction in efficiency, the energy consumed by the pumping station increases significantly, at times to the tune of almost 20–30%, thereby putting lot of burden on budget of water utilities on account of electricity bills spent against pumping of water and keeps on increasing.

1. Brief of Technical Services

a) Pump Performance Monitoring Solution (PPMS) for Pumping Stations

Installation of comprehensive pump performance monitoring solution, which measures and monitors the hydraulic and electrical parameters of each pump (including individual pump efficiency), shall give visibility of actual efficiencies of the system. Pump monitoring system at individual pumps on all pumping stations shall ensure its efficient and smooth running for longer run. Ultimately, it may increase the life cycle of the pumps and if properly monitored, shall reduce the energy consumption of individual pump. Its benefits are:

- better visibility of the pumping system for effective decision making;

- continuous performance reporting of relevant parameters of pumps;
- savings in energy by giving priority to individual pumps and;
- brings accountability from operational level to management level.

b) Energy Saving Service Operation (ESCO) Model

Energy Saving Service Operation (ESCO) model is suitable for all existing pumping stations which are presently running on operation and maintenance (O&M) contract with more than four to five years old pumps of good size in operation. ESCO companies shall be responsible for installation of necessary Pump Performance Monitoring System (PPMS) and provide services for energy saving measures, designing efficiency projects, retrofitting, redesigning, installing, and maintaining the pumping systems and monitoring the realised energy savings. It is important that the ESCO company not only provides the technical services to implement an energy efficiency project, but also continuously measure and monitor the various parameters for verifying the project's financial viability.

There shall not be any Capex spending by the water utility on account of energy savings. Electricity saving shall also be shared between the water utility and ESCO service provider. The regular operation and maintenance of the pumping stations is handled by the water utility. Its benefits are:

- more water can be supplied with reduced electricity consumption;
- savings in electricity bills and reduced contract demand; and
- asset life gets extended due to regular refurbishment and proper maintenance.

In ESCO, the bidding is generally on higher percentage (%) sharing of savings with the water utilities by the ESCO agency. In a tendering process, highest commitment of percentage sharing of savings to the energy in terms of baseline of SEC shall win the tender. Therefore, water utilities can decide and fix the tender criteria based on their need.

c) ESCO + O&M Model

The ESCO model can also be clubbed with operation and maintenance (O&M) of pumping stations to make it more rewarding for water utilities. In ESCO + O&M model, over and above ESCO operations, the electrical and mechanical operation and maintenance (O&M) of the entire pumping station including switchyard, pumps, motors, sump, pipelines, control panels, battery banks and all facilities inside the boundary of the pumping station is handled by the ESCO service provider. Payment to the ESCO service provider has two components:

- energy saving sharing;
- fixed annual service charges for handling operation and maintenance.

In both the cases, the notified flow of the pumping station, i.e., the daily water supply quantum as specified by the water utility has to be ensured by the ESCO agency. Benefit of both the models is to get the asset life extended due to regular monitoring, measurement and verification and necessary refurbishments of the assets.

2. Approach and Methodology

(i) **Energy Saving Sharing Operation (ESCO) with O&M of Pumping Station:** ESCO with O&M of pumping station means Energy Saving Company shall do the normal operation and maintenance activity of installed pumps for monitoring and implementation of energy saving scheme along with maintenance of all electro-mechanical equipment like control panels, switchyard, pipeline inside the premises of pumping station, civil infrastructure, security, housekeeping, etc.

(ii) **Baseline Establishment:** Baseline of Specific Energy Consumption (SEC) in terms of kWh/kL or kVAh/kL of each pumping station shall be established by water utility based on historical (typically last 12 months) data of electricity (taken from electricity meter installed by State Distribution Companies and water production (taken from flow meter at common discharge of respective pumping station). This baseline shall be published to ESCO to either maintain or reduce this baseline energy consumption.

(iii) **Implementation or Repair Refurbishment and Replacement Period:** During initial implementation period, the ESCO shall instal PPMS for each pump and take up activity related to improvement of health of complete pumping station. In order to improve efficiency of individual pump, ESCO shall strive to improve SEC of pumping station against the baseline.

(iv) **Compensation/Incentive Calculation Methodology:** Once the SEC of the pumping station has been reduced, the benefit of reduced electricity bill shall be shared between the water utilities and ESCO Agency on a mutually agreed percentage. This is how the ESCO agency receives payback against their investments for improving the station performance.

The calculation method of such an arrangement is illustrated in Table 12.9:

Table 12.9: Calculation Method

S. No.	Description	Unit	Nomenclature
1	Total energy consumption during the month on pumping station as per monthly electricity bill based on actual meter reading, installed at pumping station by electricity discom	kWh or kVAh	A
2	Total water produced during the month under consideration from pumping station as per daily/monthly production statement based on actual flow meter readings	L	B
3	Baseline SEC (Calculated using past 12 months' data from the go-ahead date/as mutually decided for electricity and water)	L	C (constant for contract duration)
4	Achieved SEC (Energy consumption per kL of water produced), calculated monthly	L	D= A/B
5	Recent Power Tariff/unit (kWh/kVAh) Rate (Without Taxes/Electricity Duty/Contract Demand Charges) as per electricity bill	INR (Rs/kWh or kVAh)	E
Compensation amount/ recovery from ESCO service provider (in case if ESCO service provider fail to achieve actual SEC lower than baseline SEC)			

S. No.	Description	Unit	Nomenclature
6	Excess energy consumption	kWh or kVAh	F=(D-C) x B
7	Financial implication and payment due to be recovered from the ESCO service provider for the month at recent power tariff	INR	G=F x E
Saving and incentive amount due to saving achieved in energy consumption			
8	Energy saving in terms of kVAh	kWh or kVAh	H =(C-D) × B
9	Financial saving for the month at prevailing power tariff	INR	I=H × E
10	% share to be retained by water utility from the sharable savings	X %	J
11	% share to be passed on to the ESCO service provider from the sharable savings	Y %	K
12	Payment due to the ESCO service provider on account of the energy saving for the month	INR	L=I × K

3. Cost Benefit Analysis

Water supply scheme in India is being operated and maintained generally by O&M contractors on chargeable basis. The scope of contractor is limited to operate existing infrastructure and maintain in order to meet water supply demand of city/territory. Contractor is mainly awarded for O&M of water delivery systems and not for improvement of installed infrastructure. Generally, maintenance is also limited to minor repairs, and if any major repair or replacement is required, the same is being done by utilities.

- In O&M contracts, clubbed with energy saving (ESCO) model, the bidding/award process can be on annual O&M cost of particular pumping station and sharing on energy saving cost will be fixed in the ratio of X%: Y% between the water utility and ESCO service provider.
- The pumping stations where O&M is already being executed by third party contractor, only energy saving work can be awarded to ESCO where scope of ESCO will be limited to energy saving and sharing. Here bidding process may be on maximum percentage sharing of energy saving in percentage terms.

Over and above the reduction in energy saving in terms of kWh/kl or kVAh/kl, the tendering process and subsequent contract may also include following two components for improvement:

- Power factor;
- Contract demand.

It is left to the discretion of the water utility whether to include these improvements as part of the tendering and contract process and subsequent saving sharing mechanism with the ESCO service provider.

The advantage of this process is that it will attract service agencies who are technically capable to improve efficiency and health of pumping station. The appointed ESCO will be bound to do the improvement to the pumps and infrastructure to save electricity consumption.

There shall not be extra cost on the Water Utility to improve efficiency of pumps and health of pumping station. The ESCO Agency will be responsible to do the improvement to get incentive.

4. Advantage and Disadvantage

i. Advantages:

Following are the key benefits to water utilities against the implementation of energy saving measures in energy saving and sharing model + O&M mode.

a) No cost over maintenance/refurbishment/replacement of pump:

i. No cost incurred by utility towards regular/periodic maintenance of pumps in contractual phase of the project.
ii. Pumps will be refurbished by ESCO to maintain/improve the performance of the pumps.
iii. Replacement if required and if observed to be beyond repair will be done by ESCO at no extra cost to utility.

b) No additional cost for installation of separate flow meter and pressure gauge at pump:

i. No requirement of separate flow meter since the monitoring system will measure the water flow for each pump and will be shown at local display of monitoring equipment and over the web based application.
ii. No requirement of pressure gauge at discharge side of the pump since the monitoring system measure the pressure and is shown at the local display of monitoring equipment.

c) Improved pump efficiency:

i. Savings in electricity bills and reduced contract demand thus improving carbon footprint and ensuring environmental sustainability.
ii. More water can be supplied with reduced electricity consumption.
iii. Asset life gets extended due to regular refurbishment.

d) Data availability without any manual intervention:

i. Individual pump and station flow, individual pump and station energy consumption, daily water supplied, cost of water supplied (kWh/kLor kVAh/kL) thus bringing transparency in system.
ii. Actual pump operation visible against manufacturers designed performance like efficiency, power and head.
iii. No need to maintain hourly/daily manual logbook of pumping stations.
iv. Transparency in monitoring the performance of all pumping stations.

e) Improved system performance and decision making:

i. Monthly performance reporting of pumps and pumping stations to relevant authorities.
ii. Best performing and worst performing stations can be ranked, and appropriate actions taken where required.
iii. Better visibility of the system to the senior management for decision making.

f) Technological enhancement and smart solution deployment over the existing system:

i. Single dashboard to view all important parameters of the pump monitoring.
ii. Various performance reports available over dashboard.
iii. May be showcased to national and international level.
iv. Smart solution deployment.
v. Monitoring of multiple parameters of pump.
vi. Dashboard view for graphical representation of pump performance.

ii. Disadvantage:

The only perceived disadvantage of such an ESCO mechanism is for the ESCO agency if the payments receivable by them is not made by the water utility in time. ESCO agency is responsible for making all the initial investments for improvement and if the water utility does not honour their obligation for due payments, the ESCO agencies cash flow is badly hit.

In view of this, it is advised that the water utility preferably opens an ESCROW account with the ESCO service provider for ensuring regular payment mechanism.

5. Case Study

A case study of three different pumping stations of water supply schemes is given below to give an understanding the improvements achieved.

Component	Udaipur – PHED Rajasthan	Bhopal Municipal Corporation	Ujjain Municipal Corporation
Project details			
Type of scheme	Raw water	Clear water	Raw water + clear water
Water handled	~ 30 MLD	~ 180 MLD	~ 135 MLD
Project scope	ESCO + O&M	ESCO	ESCO
Project started	Feb. 2018	Dec. 2019	June 2020
Number of pumping stations	1	1	7
Number of pumps	4	6	31
Pump ratings (kW)	600 each	730 each	17–560 (different ratings)
Improvements achieved over baseline performance			
Pump efficiency – average of pumps (%)	From 66% to 80%	From 70% to 84%	From 63% to 73%
Electricity savings	18.5% on account	5.5% on account of	10.5% on

Component	Udaipur – PHED Rajasthan	Bhopal Municipal Corporation	Ujjain Municipal Corporation
(%)	of reduction in kWh, contract demand and power factor	reduction in kWh	account of reduction in kWh
Monetary savings from beginning of project (Rs)	Rs 4.49 Cr against bill of Rs 24.23 Cr in 55 months (till Sept. 2022)	Rs. 2.08 Cr against energy charges of Rs 36.34 Cr in 33 months (till Sept. 2022)	Rs. 2.88 Cr against energy charges of Rs 27.43 Cr in 27 months (till Sept 2022)

Over and above the savings, water production is now accurately measured and effectively monitored. The overall projects are a winning proposition for the water utility.

Note: The implementing agency or water utilities may avail the above technical services as one of the cost-effective methods of energy savings schemes and cost benefit. The information is not authenticated by CPHEEO/MoHUA. The selection of these technology service agencies shall be made on competitive tendering keeping in view the techno-economic analysis, actual ground condition, operation cost, condition of pumps and pumping stations, energy savings and cost recovery out of the present expenditure.

12.10 Training

1. Training is one of the most economical options for energy saving.
2. Properly formulated training to address specific objectives can yield fast results.
3. The awareness about training is considerably increasing. The training modules are suitably designed, taking into consideration specific application needs.
4. The interaction between various users in a training programme provides a good opportunity to share the experience and implement various solutions resulting in improved and economical/energy efficient system performance. This also can be used for benchmarking best energy conservation practices.

12.11 Conclusion

1. It is needless to emphasise importance of continuous energy saving and energy conservation.
2. Implementing continuous system optimisation measures and adopting technologically advanced energy saving techniques will ensure energy efficient operation.
3. It would be also important to ensure well-coordinated interaction between the user, equipment manufacturer and system Integrator and even small component manufacturers contributing to system performance to ensure energy conservation.
4. This process of integration would result in substantial achievement in an economical manner. This can result in sustained desired performance over a prolonged period at optimum cost and optimum energy.

CHAPTER 13 : SAFETY PRACTICES

13.1 Introduction

As in any utility or industry, dangers are associated with Water Supply System Operation and Maintenance. There is, therefore, a need for safety practices. Physical injuries, cuts, bruises, and infection are common. However serious injuries necessitating long layoff, loss of limbs, eyesight, death due to accident or electrocution may also occur though not so frequently. Adoption of safe practices and use of safety equipment may largely minimise occupational hazards.

*"Accidents do not happen – **they are caused"**.*

Occupational Health Hazard: An occupational hazard is any workplace that causes risk to employee's health. The management of water utility should give immediate attention to the biological and chemical risks while other risks can be used for near future and ensure that all aspects of health and safety are implemented especially training on occupational health and safety at workplace. There are various aspects to be focused on by water utility as follows.

- **Handling Assets:** Risks to physical assets comprise theft and embezzlement of cash, breakdown and damage from natural disasters, fire, and malicious acts. An organisation's future to manage their risks include over- and under-maintenance, improper operation, improper risk management, and sub-optimised asset management systems.
- **Chlorine:** Gaseous chlorine (yellow-green gas) is poisonous and a pulmonary irritant. It has the capability of causing acute damage to upper and lower respiratory tract. Most chlorine exposures are a result of accidental, industrial, or household incidents.
- **Electric Hazards:** Buried cables, overhead powerlines, and downed electrical wires pose a danger of electrocution if workers contact them during site operation. To minimise this hazard, low voltage equipment, water-tight corrosion resistant connecting cables should be used on site. To eliminate lightning hazard, operational works should be halted during electrical storms.
- **Fire Safety:** The causes of explosion and fires at various facilities.
- **Insurance:** In case of emergencies, water utilities, healthcare facilities, nursing home, public health agencies, and local emergency managers are required to work together to minimise detrimental impacts to public health caused by disruptions in drinking water and wastewater services.
- **Specific Safety Equipment for Water System Workers:** Safety equipment are gadgets that are used for protection of life. Different types of personal protective equipment are (i) face shields; (ii) gloves; (iii) goggles; (iv) gowns; (v) head covers; (vi) masks; (vii) respiratory protection; (viii) shoe covers, etc.

13.2 Enhancing Water Safety in India

Safety is of paramount importance in water supply system management, as it is directly affecting the entire population served by the system. Thus, safety of the workman, safety of the equipment, and safety of the process has been described in the existing manual in an exhaustive way. The World Health Organisation (WHO) has published following publications which will help to enhance the safety aspects of Indian water supply systems.

1. Water Safety in Distribution Systems. World Health Organisation (2014)

2. Quantitative Microbial Risk Assessment: Application for Water Safety Management. World Health Organisation (2016)
3. Water Safety Plan Manual: Step-by-step risk management for drinking water suppliers. World Health Organisation (2009)

Safety Council of India Document on Hazards: National Safety Council (NSC) was set up in 1966 by GoI to provide guidance and services to making workplace safer and environmentally friendly. Consultancy by NSC is provided in following fields for strengthening safety, health, and environment to mitigating the loss of life and human sufferings:

- Safely audit including fire safety, electrical safety and construction safety;
- Risk assessment;
- Hazard and Operability Study (HAZOP) study;
- Emergency management planning;
- NSCI safety rating system;
- National training courses to meeting needs of safety and to developing safety work culture in an organisation.

13.3 Identification of Hazards, Hazardous Events and Risk

Hazardous agents, including microbial pathogens and chemical contaminants, which get access to drinking water and distribution systems could affect the quality of the water and have an adverse impact on human health. Therefore, there is a need to describe the different chemical, biological, radiological, and physical hazards and also to identify various hazardous events leading to water in distribution systems becoming contaminated or to the supply being interrupted. Once potential hazards and hazardous events have been identified, the levels of risk need to be assessed so that priorities for risk management can be established.

The WHO defines hazards, hazardous events, and risk as follows:

- **A hazard** is a biological, chemical, physical, or radiological agent that has the potential to cause harm.
- **A hazardous event** is an incident or situation that can lead to the presence of a hazard (what can happen and how).
- **Risk** is the likelihood of identified hazards causing harm in exposed populations in a specified time frame, including the magnitude of that harm and/or the consequences.

Hazard and Operability Study (HAZOP): It is a structured and systematic examination of a complex and planned operation in order to identify and evaluate problems that may represent risks to equipment or personnel. The concept of HAZOP is to review the design and engineering issues. The technique is based on breaking the complex design of the process into a number of sectors called “nodes”. HAZOP, in essence, is a Process Hazard Analysis (PHA) method, a form of risk-management to identify, evaluate, and control hazards and risks in complex processes. It involves hazardous chemicals that cause injuries to workers and damage to property and organisation reputation if not properly addressed and handled. HAZOP process can be applied to plants, manufacturing facilities, and transport system, etc. The HAZOP is thus a structured and systematic technique for system examination and risk management.

13.4 Major Hazards

The following sections describe the major microbial, chemical, and physical hazards in distribution systems, as summarised in Table 13.1.

Table 13.1: Hazards that can be found in Drinking Water, Pipe Biofilms and Distribution Systems

Chemical Hazards causing agents			
Water Treatment Chemicals such as Chlorine, Sulphuric Acid, Calcium Hydroxide (lime), Sodium Hydroxide, Sodium Silicate, Aluminium Sulphate (Alum), Presence of chemicals in raw water such as Aluminium, antimony, arsenic, barium, benzo(a)pyrene, cadmium, chromium, copper, cyanide, disinfection by-products (including tri-halomethanes, haloacetic acids and *N*-nitrosodimethylamine), fluoride, iron, lead, mercury, nickel, pesticides, petroleum hydrocarbons, selenium, silver, styrene, tin, uranium, vinylchloride (some of the heavy metals need to be checked whether chemical or other hazards).			
Physical Hazards			
Turbidity, offensive odours, iron, colour, corrosion scales, sediment resuspension			
Microbial Hazards			
Bacteria	**Viruses**	**Parasites**	**Filamentous fungi and yeast**
Campylobacter jejuni/C. coli	Noroviruses	Cryptosporidium hominis/parvum	Aspergillus flavus
Escherichia coli (some strains)	Rotaviruses	Entamoeba histolytica	Stachybotryschartarum
Vibrio cholerae	Enteroviruses	Giardia intestinalis	Pseudallescheria boydii
Salmonella typhi	Adenoviruses	Cyclospora cayetanensis	Mucor
Other Salmonella spp.	Hepatitis A	Acanthamoeba	Sporothrix
Shigella	Hepatitis E	Naegleria fowleri	Cryptococcus
Legionella spp.	Sapoviruses	Some invertebrates, including water mites, cladocerans and copepods	
Non-tuberculous Mycobacterium spp.	-	-	-
Francisella tularensis	-	-	-

* This table does not represent an exhaustive list of hazards in drinking water, pipe biofilm or distribution systems.

13.5 Chemical Hazards

There are many chemical hazards that could contaminate water in distribution systems and make water unsafe for drinking. Some of the common chemical contaminants are unwanted residues of chemicals used in water treatment. In the distribution systems, many chemicals generate by reacting with the materials or from the material. Chemicals can also accumulate in the system in the form of scales or by entering in the distribution system through faults and breaks. If the water treatment chemicals are dosed at too high a concentration, it can cause hazards.

13.5.1 Hazards in Chemical Handling – Gases

Gases commonly used in water treatment in this country are listed in Table 13.2.

They are supplied in cylinders or drums. Some chemicals are generated at the plant itself. Exposure to the liquid form of the gases causes damage to human tissues such as skin burn. Most gases are heavier than air and displace air-containing oxygen. It is therefore important to have proper ventilation and use the right type of respirator.

Table 13. 2: Gases Used In Water Treatment Plants

Name and Formula	Common Name	Available Forms	Specific Gravity	Flamm-ability	Colour	Odour	Containers
Chlorine Cl_2	Liquid Chlorine	Liquid-Gas	1.468 at 0 °C	None	Greenish Yellow	Irritating	Cylinder One tonne
Carbon Dioxide, CO_2	Dry Ice	Liquid-Gas	0.914	None	Colourless	Odourless	Bulk Liquid under pressure

13.5.1.1 Chlorine

Chlorine is used as a disinfectant in drinking water as it is important in eliminating waterborne disease outbreaks. Chlorine is considered as a hazard in the water industry. Chlorine gas is poisonous to humans. It is very corrosive when in contact with water. Extreme care must be taken when working with chlorine to prevent accidental injuries to operators. Small amount can cause severe coughing and irritation on the nose, throat, and lungs, and even death.

Precaution for chlorine handling:

- All operating and storing rooms for chlorine gas appliances and containers shall be fireproof.
- Chlorine storage rooms should preferably be provided with chlorine gas alarm device which gives out an acoustic or an optical signal when the chlorine gas concentration is reached, the set value for which is 1.0 mg chlorine per cubic metre of air in case of a person working in the room and 20 mg chlorine per cubic metre of air when no human being is inside the room.
- The sensor for alarm device shall be placed not higher than 300 mm above the floors of the room.
- A bottle of ammonia is essential to detect leaks, etc., in case alarm device is not provided.
- Cylinder, as well as chlorine, shall be tested at every shift period for leaks, first by trying to detect the sharp irritating smell of chlorine, then by passing over each cylinder and around each valve and pipe connections, a rod with a small cotton- wool swab tied on the end, dipped in an aqueous solution of ammonia. If chlorine is present in the air, the swab will appear to smoke due to formation of white cloud of ammonium chlorine. If the leak appears

to be heavy, all persons not directly concerned should leave the area and the operator should put on his mask and make a thorough search of the leak.

Note — In tracing a leak, always work down-stream that is start at the cylinder and work down along the line of flow until the leak is found.

- Safety equipment like gas masks, rubber gloves, aprons shall be housed in easily accessible (unlocked) cupboard placed outside the chlorination room.

  Note — Faulty gas mask is worse than none at all. Hence these shall be tested frequently, and canisters shall be changed at proper intervals.

- First aid box and eye wash fountain shall be provided outside chlorinator room.
- The provisions shall be made for emergency disposal of chlorine from leaking containers.
- Water shall never be applied to the chlorine leak to stop it, as it will only make it worse.
- When a chlorine leak occurs, the ventilation system should be operated immediately before any person enters the chlorination room.

  NOTE — Ventilation system should be controlled from outside.

- The exhaust pipe of the apparatus shall lead to the open through the shortest path and the outlet of this exhaust pipe shall not be readily accessible.
- In case of fire, the cylinders and drums containing chlorine shall be protected by spraying with water since the containers can burst at temperatures of over 70 °C. Source of pressurised water shall be provided adjacent to the chlorination room.
- Fusible plug, a safety device, shall be provided over all cylinders and containers designed to melt or soften between 70 to 75 °C to preclude a buildup of hydrostatic pressure resulting from thermal expansion due to fire and other hazardous conditions.
- Before disconnecting the flexible leads from containers to gas headers, the cylinder valves should be closed first and then the gas under pressure should be drawn from the header and flexible leads before the header valve is closed.
- Solvents, such as petroleum, hydrocarbons, or alcohols should not be used for cleaning parts which come in contact with chlorine. The safe solvents are chloroform or carbon tetrachloride. Grease should never be used where it comes in contact with chlorine.
- No direct flame should be applied to the chlorine cylinder when heating becomes necessary.
- The protective hood over the valve should always be kept in place except when the cylinders arc in use.
- In addition to this, the relevant provisions of IS: 4263-1967 shall also be observed as far as applicable.

13.5.1.2 Carbon Dioxide

Carbon dioxide is used to lower pH in the water treatment process. The high acidity accomplishes the reduction on pH.

Anyone who handles carbon dioxide should be aware of its unique properties and potential hazards. Carbon dioxide is 1.5 times heavier than air and tends to accumulate in low or confined areas. It can displace oxygen and cause rapid suffocation as well as other serious physiological effects.

In addition, carbon dioxide can pose additional hazards such as exposure to extremely cold vapours or liquid or dry ice blockage of piping depending on its physical state.

The container label and safety data sheet (SDS) provide detailed hazard information and handling precautions. Always read and understand the label and the SDS before using any product and follow the instructions and safety precautions provided by your product supplier. These safety posters, provided by the Compressed Gas Association, provide basic safety information about the hazards associated with carbon dioxide.

Carbon Dioxide Safety Reminders

Carbon dioxide can create a hazardous atmosphere.

- Recognise and be aware of areas where carbon dioxide can accumulate.
- Monitor and ventilate for carbon dioxide as required by code.
- Never modify or tamper with carbon dioxide systems or equipment.
- Use required personal protective equipment (PPE) when working with carbon dioxide.
- Never enter an area of high carbon dioxide concentration without proper personal protective equipment (PPE).

Carbon dioxide has limited use in water treatment plants, but it is dangerous and causes suffocation due to lack of oxygen. Therefore, when using carbon dioxide keep in mind the safety requirements. Since the gas is a heavy vapour, it does not tend to diffuse away rapidly. Persons must be on guard when entering pits, manholes, wells, etc.

First aid involves moving the victim to fresh air, giving resuscitation, and getting medical attention.

13.5.2 Hazards in Chemical Handling – Acids

The antidote to all acids is neutralisation. Most often, large amount of water will serve the purpose. If acid is swallowed, then lime water or milk of magnesia may be needed. If vapours are inhaled, first aid usually consists of providing fresh air, artificially restoring breathing or supplying oxygen. Baking soda is used to neutralise acid falling on the skin.

Many acids are used in water treatment. However, in this country, sulphuric acid is extensively used. The properties of sulphuric acid are shown in Table 13.3:

Table 13.3: Properties of Sulphuric Acid

Name and Formula	Common Name	Available Forms	Specific Gravity	Flammability	Colour	Odour
Sulphuric Acid, H_2SO_4	Oil of Vitriol; Vitriol	Solution	1.841	N/A	Clear	Odourless

13.5.2.1 Sulphuric Acid

- Sulphuric acid is one of the most dangerous chemicals handled at the plant. The main hazard is from contact. Fumes are dangerous but normally at room temperatures, there are not many fumes.
- Always use protective clothes and equipment. Contact with the acid on body tissue

results in severe burns immediately. Immediately washing with water is essential.
- Clean the acid spill immediately. Do not leave the area until it is well marked or guarded. Neutralise the acid with soda ash and then flush it down the drain.

Prompt first aid is essential in removing sulphuric acid from the body. Point of contact must be washed under running water with alternating applications of mild alkaline solutions (bicarbonate of soda). Wash eyes with large amounts of water. If swallowed, do not induce vomiting but encourage patient to wash out his mouth with large amount of water and then drink as much water as possible. Get medical help immediately.

13.5.3 Hazards in Chemical Handling – Bases

The bases used in water treatment are known as hydroxides. They are used to raise pH. Compounds of sodium, calcium and ammonia are strong bases. Silicate, carbonate, and hypochlorite are weak bases. Table 13.4 lists some of the basic compounds used in water treatment in this country.

Table 13.4: Bases Used In Water Treatment

Name and Formula	Common Name	Available Forms	Specific Gravity or lbs/cuft	Flammability	Colour	Odour	Containers
Calcium Hydroxide and Calcium Oxide, $Ca(OH)_2$ and CaO	Hydrated Lime or Quicklime	Dry Powder, Lump	50-70	N/A	White	Dust	Bags, Bulk, Trucks
Sodium Hydroxide, NaOH	Caustic Soda	Lump, Liquid, Flake	1.524	May Cause Flammable Conditions	Opaque White	Toxic, Pungent	Drums, Bulk, Trucks
Sodium Silicate, Na_2SiO_3	Water Glass, or liquid glass	Liquid	1.35-1.42	N/A	Opaque	N/A	Drums, Bulk, Trucks

13.5.3.1 Calcium Hydroxide (Hydrated Lime)

- Lime has a great affinity for water and a great deal of heat is evolved when the two come in contact. Storage in damp places may cause a fire in nearby flammable materials. Calcium hydroxide (hydrated lime) is less troublesome than calcium oxide (quicklime).
- They should be stored in a cool, dry place. In damp places fire may be caused in nearby flammable material. Also do not mix dry quicklime with other chemicals that contain water of crystallisation like alum or ammonium sulphate.
- Persons exposed to lime dust must be protected with personal protective equipment. Prolonged exposure to lime dust causes dermatitis especially at points of perspiration. Face shields, chemical goggles must be used when inspecting lime slakers.
- First aid for lime burns is about the same for any caustic burn – thorough washing with

water.

13.5.3.2 Sodium Hydroxide (Caustic Soda)

- Dry caustic soda should be stored in a dry place where it will not be exposed to moisture, liquid caustic in steel covered tanks.
- Workers are exposed to splash and mist. They must wear protective equipment like safety goggles, face shields, rubber gloves aprons, boots, and cotton overalls.
- First aid is the same as for any caustic burn. Irrigate well with water.

13.5.3.3 Sodium Silicate

- Sodium silicate is a liquid. Although non-toxic, non-inflammable, and non- explosive, it presents the same hazards to the skin and eyes as other base compounds.
- Avoid prolonged contact with the skin. Wash with plenty of warm water. Use face shield and rubber gloves when working with the solution. Use goggles.

13.5.4 Hazards in Chemical Handling – Salts

The various salts (chemicals) used in water treatment in this country are given in Table 13.5.

Table 13.5: Salts Used In Water Treatment

Name and Formula	Common Name	Available Forms	Density, lbs/cu ft	Flammability	Colour	Odour	Containers
Aluminium Sulphate, $Al_2(SO_4)_3.18H_2O$	Alum, Filter Alum	Liquids, Powder, Lump	1.69, 38-67	None	Ivory	N/A	Bags, Tank Truck, Bulk
Ferric Chloride, $FeCl_3$	Ferrichlor, Chloride of Iron	Syrup, Liquid, Lump	60-90	None	Dark Brown, Yellow	N/A	Carboys, Tank Cars
Ferric Sulphate, $Fe_2(SO_4)_3$	Ferrifloc, Ferrisul	Powder, Granule	70-72	None	Red Brown	N/A	Bags, Drums
Ferrous Sulphate, $FeSO_4.7H_20$	Coppras, Green Vitriol	Crystal, Granule, Lump	63-66	None	Green	N/A	Bags, Drums, Bulk
Sodium Aluminate, $NaAlO_2$	Soda Alum	Dry Crystal, Liquid	(27°)	None	White, Green Yellow	N/A	Bags, Bulk
Copper Sulphate, $CuSO_4$	Blue Vitriol, Blue Stone	Crystal, Lump, Powder	60-90	None	Blue	None	Bags, Drums
Sodium Chlorite, $NaClO_2$	Technical Sodium Chlorite	Powder, Flake, Liquid	70 dry	Oxidiser	Light Orange	None	Tank Truck, 100 lb-Drums
Potassium Permanganate, $KMnO_4$	Permang-anate	Crystal, Powder	90-100	Oxidiser	Purple	None	Drums, Bulk

13.5.4.1 Aluminium Sulphate (Alum) and Ferrous Sulphate

- These materials should be stored in a clean dry place, for moisture has a tendency to cake the material.
- Handlers should wear protective clothing and protective cream on exposed skin surfaces because these chemicals can cause irritation to the skin and mucous membranes and serious injury to the eyes. Use the same precautions for liquid solutions, with added protection for the eyes.
- Do not use compressed air to clean dry feed machines and equipment. Keep covers on feeding equipment.
- Remember that mixtures of dry alum and quicklime can explode. Ferrous sulphate dust is more corrosive to equipment, and, when moist, is a good conductor of electricity. Ferrous sulphate dryers can also corrode essential instruments or equipment in the vicinity of dusty conditions. Electrical equipment in the area should be of the dust-proof type and frequently cleaned.
- First aid for skin irritations and mild burns should be the same as for any acid burn. Scrub with plenty of warm water and soap, followed by a good shower as soon as possible. For any irritation of the mouth and nasal passages, wash freely with warm water. If the material is in the eyes, flush with large quantities of warm water, and consult a physician.

13.5.4.2 Ferric Chloride

- This is a very corrosive compound and should be treated as you would treat any acid.
- The salt is highly soluble in water, but in the presence of moist air or light, it decomposes to give off hydrochloric acid, which may cause other problems regarding safety. When handling liquid ferric chloride, normal precautions should be taken to prevent splashing, particularly if the liquid is hot. Use a face shield to protect your eyes and rubber aprons to protect clothing.
- First aid for eyes exposed to the liquid is that the eyes must be flushed out immediately for 15 minutes with large amounts of water. Ferric chloride should also be washed off the skin with water, as prolonged contact will cause irritation and staining of the skin.

13.5.4.3 Ferric Sulphate

- Because of its acidic nature, operators using this compound should be provided with protection suitable for dry or liquid alum.
- Use protective clothing and a respirator. Avoid prolonged exposure to the dry form because of its acidic reaction with moisture on the skin, eyes, and throat.
- First aid for exposure to the eyes requires the eyes to be flushed immediately with lots of water. The skin should also be flushed with large amounts of water. Prolonged contact may cause irritation.

13.5.4.4 Sodium Aluminate

- There are few hazards with this compound, but as with other chemicals, you should use precautions when handling it.
- Use respiratory protection when handling the dry compound to prevent the inhalation of dust.
- First aid for eyes that are exposed is to flush with water; keep the skin clean with water.

13.6 Hazardous Events

Hazard is a biological, chemical, physical, or radiological agent that has potential to cause harm. Hazardous events are incidents or situations that can lead to the presence of a hazard. The hazardous events are grouped into three categories based on the circumstances or events that affect the integrity of the distribution system and the quality of the water within. These categories are:

- **Physical integrity**: breaks in the physical barrier of the distribution system that allow external contamination affecting the quality of the drinking water, including structural failures of the distribution system components (pipes, valves, storage reservoirs), cross-connections, backflow, and human activity (unsanitary activities during construction or vandalism).
- **Hydraulic integrity**: factors that could cause a water distribution system to lose its hydraulic integrity, such as changes in flow and pressure caused by poor operational controls of valves and pumps and impacts of repairs and maintenance.
- **Water quality integrity**: situations that could cause a loss of water quality due to processes that take place within the distribution system, such as biofilm growth, leaching, corrosion, water age, stagnation/high retention times (due to dead ends) and discolouration.

The types of hazards involved are identified as **Microbiological (M), Physical (P) and Chemical (C).** Table 13.6 summarises the typical hazardous events within a distribution system.

Table 13.6: Hazardous Events Associated with Distribution Systems

Category of event	Hazardous event	Hazard
System construction and repair		
Physical integrity	Contamination during construction of new water mains, microbial or chemical contamination during construction or renovation due to debris, vermin, soil, groundwater, or rainwater entering an open pipe (not capped) or fitting while the pipe/fitting is on the truck, stacked in the store yard, lying beside the trench or in the trench before connection	M, P, C
	Contamination of distribution system during new installations, including water meters, pumps, valve, or hydrant insertions	M, P, C
Hydraulic integrity	Sediment resuspension, sloughing of biofilms causing customer complaints due to incorrect valve operation (closed or opened) after repairs	M, P, C
Water quality integrity	Contamination from impurities in materials used in construction and maintenance of pipes, fittings, and tanks (e.g., copper, iron, lead, plasticisers, bituminous lining)	C
System operation		
Physical integrity	Corrosion leading to loss of structural integrity	M, P, C
Hydraulic integrity	Contamination from leaky water mains in areas of low pressure or intermittent water supply: ingress due to backflow through leaky joints, air valves, perforations	M, P, C
	Contamination from leaky sewer mains in areas of low	M, P, C

	pressure or with intermittent water supply: ingress due to backflow through leaky joints, air valves, perforations, leaking valves, and hydrants	
Water quality integrity	Discoloured water due to internal corrosion of unlined water mains (mild steel, cast iron, ductile iron) and accumulation of particles (e.g., sediments, manganese deposits), particularly at dead ends, due to long stagnation	P, C
	Survival of pathogens, growth of opportunistic pathogens and nuisance organisms in biofilms	M
Storage tanks		
Physical integrity	Microbial contamination from entry of birds and small animals or faeces through faults and gaps in: • roofs or hatches • overflow pipes and inlet control valves from upstream sources • air vents	M
	Ingress of contaminated groundwater from unsealed joints and cracks	M, P, C
	Internal corrosion of steel water storage tanks	C
	Security breaches from unauthorised access by humans, including vandalism, sabotage	M, P, C
Water quality integrity	pH increases in concrete tanks due to excessive detention times	P
	Corrosion of internal fittings and surfaces	C
	Sediment accumulation and biofilm growth in the bottom of the tank	M, C
Backflow		
Physical integrity	Accidental cross-connection between drinking water and non-drinking water assets during construction or maintenance, including opening a normally shut valve to allow recharging after repairs and failing to close after completion	M, P, C
Secondary disinfection		
Water quality integrity	Excessive chlorine above health-based guideline value (5 mg/L)	C
	Under dosing of chlorine leading to inadequate protection against ingress of microbial contamination or growth of biofilms	M
	Elevated disinfection by-products (DBPs) due to high levels of organic matter in source water	C

Ref: Water safety in distribution systems, published by WHO, 2014

13.6.1 Release of Hazards in Distribution Systems

Hazardous chemicals that can be leached from materials and fittings used in distribution systems are summarised in Table 13.7.

Table 13.7: Common Hazardous Chemicals That Leach from Pipe Materials and Fittings

Material	Hazard
Lead pipes	Lead
Copper pipes	Copper
Solders and fittings (brass and bronze alloys)	Lead, copper, cadmium, nickel, silver, tin
Iron pipes	Iron, arsenic
Galvanised pipes	Zinc, lead
Cement pipes and tanks and cement mortar	Calcium hydroxide (high pH)
Polyethylene pipes, liners, jointing and sealing compounds	Organic compounds
Rubber seals	N-Nitrosodimethylamine (NDMA), from reaction with chlorine.

Ref: Water safety in distribution systems, published by WHO, 2014

The range of factors that can influence the release of chemicals from materials and fittings includes:

- age of materials and fittings;
- water age/stagnation;
- pH;
- alkalinity;
- temperature;
- chlorine/chloramine residuals;
- chloride and sulphate;
- aggressive water (soft water, low alkalinity); and
- changes in treatment.

However, it can be difficult to identify independent impacts of individual factors. For example, assessing the impacts of chlorine and chloramine residuals can be compounded by consideration of alkalinity and pH. In some cases, elevated release of hazardous chemicals can occur when factors coincide – for example, when water stagnation coincides with ageing materials or low-pH water.

Age of materials and fittings

The age of materials can either increase or decrease the release of hazardous chemicals, depending on the mechanism of release – that is, leaching or corrosion. Leaching of chemicals tends to be greatest during the first weeks and months following installation, whereas concentrations of chemicals released by corrosion generally increase with age. Lead is a good example of this differential response. The release of lead from newly installed brass alloys and solders occurs relatively rapidly over the first few weeks and months and then declines, whereas lead released by corrosion from lead pipes increases with age.

The age of iron pipe and hydraulic disturbances influence the release of iron. Although scale buildup initially reduces corrosion, the eventual release of this scale from old tuberculated cast iron pipes can result in “red water”. Leaching of lime from concrete pipes, linings and mortars generally starts immediately after installation and decreases over time. Leaching can also occur when cement-based materials deteriorate.

Water age/stagnation

Stagnation tends to exacerbate leaching and corrosion. Leaching of lead and copper from pipes and fittings and lime from cement can be increased by stagnation. In contrast, copper leaching tends to be curtailed by the low dissolved oxygen levels found in stagnant water.

pH

The release of hazardous chemicals from materials and fittings can be influenced by pH. Generally, increasing pH values lead to decreased release of metals, largely due to decreased solubility at higher pHs.

Solubilisation of lead from pipes and alloys and galvanic corrosion of lead from solders all decrease at higher pHs. Surveys of water utilities have found that pHs above 8–9 correlated with decreased lead at consumers' taps. As a result, raising the pH in water supplies has been used as a control measure to reduce lead concentrations.

As pH increases, corrosion of iron pipes can increase, but iron concentrations in drinking water decrease due to the lower solubility of iron at higher pHs.

Alkalinity

Alkalinity can have varied impacts on the release of hazardous chemicals from materials and fittings. Higher alkalinities decrease corrosion and the release of iron from pipes and lime from cement pipes. In contrast, water utility and laboratory results show that higher alkalinities increase copper release.

The relationship between alkalinity and the release of lead is not clear.

Chlorine/chloramine residuals

The clearest evidence of corrosion associated with oxidising disinfectants such as chlorine and chloramines come from studies in which the concentrations of disinfectants or the disinfectants themselves (e.g., from chlorine to chloramines) were changed.

Free chlorine residuals have been shown to increase copper release at pHs below 7.5, but this copper release was greatly reduced or reversed at higher pHs. Similarly, iron corrosion has been reported to increase in the presence of free chlorine but increasing the pH above 7.8 decreased corrosion.

It has been found that chloramines accelerate the corrosion of copper at pH 6, but this is unlikely to occur in drinking water systems, as higher pHs are required to stabilise chloramine residuals.

Temperature

There is conflicting evidence on the impacts of temperature on corrosion. A survey of water utilities found no significant correlation between temperature and lead or copper concentrations in drinking water. In contrast, seasonal variations have been reported, with higher lead and iron concentrations being detected in warmer months of the year. It should be noted that temperature influences a range of parameters that may also have an impact on corrosion, including chlorine and chloramine residuals, biological activity, and water flows.

Chloride and sulphate

Chloride and sulphate can influence lead release. It is observed that chloride to sulphate mass ratio of less than 0.58 had lower lead concentrations than those with ratios greater than 0.58.

Aggressive water

Soft, low alkalinity water has been associated with leaching, particularly from cement- based materials. Cement-based pipes and mortars will leach lime in the first months and years after installation. The level of leaching depends on the total alkalinity and buffer capacity of the transported water, the type of cement used, the contact time between the water and the cement material, and the pipe diameter.

13.6.1.1 Treatment process changes with an impact on distribution

Changes in treatment processes, such as enhanced coagulation or replacement of chlorination with chloramination, can be implemented to improve water quality. However, they can also have unintended consequences, including increased corrosion.

Examples of possible treatment changes and their consequences are shown in Table 13.8.

Table 13.8: Advantages and Disadvantages Associated with Changes in Water Treatment Processes

Treatment change	Advantage	Disadvantage
Modified coagulation	• Reduced concentrations of precursors of DBPs • Improved removal of *Cryptosporidium* and *Giardia* • Improved disinfection (lower demand)	• Increased corrosion associated with lower pH, lower alkalinity, unless adjusted, increased chloride and sulphate. • Increased corrosion and increased inorganic compounds associated with higher coagulant dose rates. • Modifying coagulation can lead to reduced pH, changes in the chloride to sulphate ratio (depending on the choice of coagulant) and reduced alkalinity.
Replacement of chlorine with chloramines	• Increased residual in system providing protection against external contamination and growth of free-living pathogens • Biofilm control • Better control of biofilms and reduced production of total Trihalomethane (THMs). It increases the	• Increased corrosion • Initial release of biofilms from parts of the distribution system that previously did not receive water containing residual disinfectant • Nitrification • Potential issues for dialysis patients

Treatment change	Advantage	Disadvantage
	occurrence of non-tuberculosis mycobacteria, which may include opportunistic pathogenic species.	• Decreased initial disinfection requiring longer contact times • Production of N-nitrosodimethylamine (NDMA) • Mixing chlorinated and chloraminated supplies
Addition supplementary chlorination	• Increased residual in system providing protection againstexternal contamination and growth of free-living pathogens • Biofilm control	• Increased corrosion • Initial release of biofilms • Increased Disinfection-by-Products (DBPs)
Decreased pH (in chlorinated systems)	• Enhanced primary disinfection by chlorine • Lower DBPs by decreasing • chlorine dose	• Increased corrosion • Decreased residuals through distribution system

13.6.1.2 Water ageing

Water age has been reported as a major factor in the deterioration of water quality within distribution systems, leading to public health and aesthetic concerns. It was also discussed above in section 13.8.3.1 with regards to the release of hazards from materials and fittings. With respect to aesthetics, with increased water age, there can be an increase in water temperature and in issues associated with taste, odour, and colour. The two main mechanisms for deterioration of water quality are interactions with the pipe wall and the water, and reactions within the bulk water itself.

Water age can vary significantly within a system and is primarily controlled by system design and system usage. Factors contributing to increased water age include demand planning and the requirements for providing capacity to deal with events such as power outages and firefighting.

13.6.2 Determine Current Control Measures

Control measures are barriers necessary for preventing or reducing significant water quality risks. They need to be developed, implemented, and monitored for each hazardous event identified as significant in the risk assessment. In the context of the distribution system components, control measures are defined as those measures required in drinking water distribution systems that directly affect the safety or aesthetics of drinking water, either by preventing the occurrence of hazards or by inactivating, removing, or reducing them to acceptable levels.

Control measures can include a wide range of activities and processes. They can be:

- preventive (and incorporated in design, planning and construction processes and renewal

of infrastructure);
- treatment related (e.g., secondary disinfection);
- technical (e.g., operational and maintenance procedures); and
- behavioural (e.g., customer awareness programmes).

Control measures must be defined specifically and precisely for each significant hazardous event and adapted to the local conditions. They should never be imprecise or vague. Whereas the type and number of control measures will vary for each supply system, their collective implementation and maintenance are essential to ensure that water quality is controlled effectively. Only the current control measures being implemented by the water supplier should be included in the risk assessment.

Table 13.9 provides a list of control measures for typical hazardous events in the distribution system. Some of the control measures are applied during the design and construction of the water distribution system, whereas others involve a range of operational, emergency and programmed operating procedures (e.g., water main break repair procedure, water main cleaning, tank maintenance and cleaning, secondary disinfection, customer complaint management and other routine operating procedures).

Table 13.9: Examples of Control Measures

Hazardous event	Control measure
System construction and repair	
Contamination during construction of new water mains: microbial or chemical contamination during construction or renovation due to debris, vermin, soil, groundwater, or rainwater entering an open pipe (not capped) or fitting while the pipe/fitting is on the truck, stacked in the store yard, lying beside the trench or in the trench before connection	• Construction standards and specifications (including materials – storage, handling, transport, flushing, swabbing, disinfection, contact time and water quality testing) • Field compliance audits
Contamination of distribution system during new installations, including water meters, pumps, valve, or hydrant insertions	• Code of practice • Construction standards and procedures • Disinfection practices prior to commissioning
Contamination during water main repair: • an open main (not capped) when in the repair trench; could allow contamination, including petroleum products, from pumps used for dewatering • debris, soil, or groundwater remaining in the main after repairs and not removed during the main recharge operation	• Dewatering of trench prior to commencing repairs • Prevention of contamination of pipe material during storage, transport, and repairs **For mains ≤150 mm** • Flushing of water main – specify duration based on length of the main and minimum flow rate **For mains >150 mm**

Hazardous event	Control measure
	• Pipe cleaning (swabbing) and disinfection after repair • Water quality testing (visual/turbidity) prior to turning on the water main
Sediment resuspension, sloughing of biofilms causing customer complaints due to incorrect valve operation (closed or opened) after repairs	• Standard operating procedures for operation of valves after repairs
Contamination from impurities in materials used in construction and maintenance of pipes, fittings and tanks (e.g., copper, iron, lead, plasticisers, bituminous lining)	• Approved product standards for materials in contact with water • Approved product list • Compliance audits and materials checklist • Replacement of lead service lines
The use of inappropriate materials, including use of metallic products that are incompatible with existing materials in the system, causing corrosion	• Approved product standards for materials in contact with water • Approved product list • Compliance audits and materials checklist
System operation	
Corrosion leading to loss of structural integrity	• Approved product standards for materials in contact with water • Approved product list • Leak detection programme • Pipe and fittings replacement programme
Contamination from leaky water mains in areas of low pressure or intermittent water supply; ingress due to backflow through leaky joints, air valves, perforations	• Maintain positive pressure, provide continuous supply • Maintain minimum chlorine residuals in the distribution network; if necessary, install secondary/booster chlorination • Leak detection and repair programme • Pipe and fittings replacement programme • Design and construction specifications and standards
Contamination from leaky sewer mains in areas of low pressure or with intermittent water supply: ingress due to backflow through leaky joints, air valves, perforations, leaking valves, and hydrants	• Maintain positive pressure, provide continuous supply • Maintain minimum chlorine residuals in the distribution network; if necessary, instal secondary/booster chlorination • Leak detection and repair programme (sewer and water main)

Hazardous event	Control measure
	• Pipe and fittings replacement programme (sewer and water main) • Design and construction specifications and standards • Design and construction standards to maintain separation between water and sewer mains
Accumulation of biofilms, sediments, and particles in water mains due to low flow velocities in pipes and resuspension during high-flow events	• Design standards to achieve self-cleaning pipe velocities • Operate valves and pumps to avoid rapid surges in flows • Routine water main cleaning programme (in areas where self-cleaning velocities cannot be achieved) • Maintain minimum chlorine residuals in the distribution network; if necessary, instal secondary/booster chlorination
Resuspension of biofilms, sediments, scales due to flow reversals	• Operate valves and pumps to avoid flow reversals where possible • Routine water main cleaning programme • Maintain minimum chlorine residuals in the distribution network; if necessary, instal secondary/booster chlorination
Discoloured water due to internal corrosion of unlined water mains (mild steel, cast iron, ductile iron) and accumulation of particles (e.g. sediments, manganese deposits), particularly at dead ends, due to long stagnation	• Routine water main cleaning programme • Water main condition and criticality assessment and inspection programmes to prioritise replacement programme • Water main renewal programme • Improving contaminant reduction at treatment plant (e.g., minimise manganese level well below aesthetic level)

Hazardous event	Control measure
Survival of pathogens, growth of opportunistic pathogens and nuisance organisms in biofilms	• Controls to prevent pathogen intrusion due to ineffective treatment or distribution system integrity breaches (e.g., treatment targets, main repair procedures) • Maintain minimum chlorine residuals in the distribution network; if necessary, instal secondary/booster chlorination • Replacement of chlorination with chlorination • Reducing or preventing biofilm growth through proper maintenance
Elevated DBPs due to high levels of organic matter in source water	• Additional treatment to remove precursors – dissolved organic matter in source water (e.g., coagulation, magnetic ion exchange) • Alternative disinfection – chloramination • Reducing detention times (e.g., eliminating dead ends, increasing turnover through storage tanks during periods of low flow by dropping high water levels, taking tanks out of service during low flows)
Storage tanks	
Microbial contamination from entry of birds and small animals or faeces through faults and gaps in: • roofs or hatches • overflow pipes and inlet control valves from upstream sources • air vents	• Reservoir inspection and maintenance programme, including repair of faults/gaps • Disinfect tank after repairs • Maintain minimum chlorine residuals in the distribution network; if necessary, instal secondary/booster chlorination • Design and construction standards
Ingress of contaminated groundwater from unsealed joints and cracks	• Reservoir inspection and maintenance programme • Design and construction standards
Internal corrosion of steel water storage tanks	• Cathodic protection • Routine inspection and maintenance programme
Security breaches from unauthorised access by humans, including vandalism, sabotage	• Security fencing, locked gates, access hatches, alarms, routine security patrols, closed-circuit, television cameras

Hazardous event	Control measure
pH increases in concrete tanks due to excessive detention times	• Operate system to avoid excessive detention • Lower volume of water in tanks to increase turnover during periods of low flow
Corrosion of internal fittings and surfaces	• Design and construction standards • Reservoir inspection and maintenance programme
Sediment accumulation and biofilm growth in the bottom of the tank	• Reservoir cleaning programme included in routine inspection and maintenance programme
Secondary disinfection	
Excessive chlorine above health-based guideline value (5 mg/L)	• Monitor chlorine residuals and vary dose so that chlorine residuals stay within limits
Underdosing of chlorine leading to inadequate protection against ingress of microbial contamination or growth of biofilms	
Elevated disinfection by-products (DBPs) due to high levels of organic matter in source water	• Additional treatment to remove precursors – dissolved organic matter in source water (e.g., coagulation, magnetic ion exchange) • Reducing detention times (e.g., eliminating dead ends, increasing turnover through storage tanks during periods of low flow by dropping high water levels, taking tanks out of service during low flows)

13.6.3 Validation of control measures

All control measures should be validated to ensure their effectiveness. Validation is the process of obtaining evidence that control measures will be effective and achieve the required results. In other words, validation answers the question, “Will the control measures work?” Validation justifies the residual risk assessment scores assigned after consideration of the effectiveness of the control measures. Validation can take the form of:

- analysis of water suppliers’ historical data (e.g., operational and verification water quality data and field audit analysis to confirm that the current water main repair practice is adequate to remove contamination after a water main repair, analysis of historical annual backflow test reports for industrial/commercial customers);
- investigative monitoring during initial implementation of a new or modified control measure (e.g., laboratory water quality testing of new pipe material to confirm the conformity to relevant standards); and
- adoption of technical data from published studies, including evidence of the effectiveness of established industry best practices (e.g., evidence that installation of water meters with dual check valves prevents backflow from residential customers).

Validation related to significant risks will typically require assigning operational or critical limits, operational monitoring, and corrective actions for violation of critical limits. It is essential to validate the critical limits to ensure that they are continuously effective in controlling the significant risks, and violation of critical limits will be significant to public health.

It should be noted that validation is uniquely different from operational monitoring and verification monitoring. Operational monitoring determines whether control measures are working, whereas verification is required to confirm or reassure that the water quality delivered to consumers is safe and aesthetically acceptable.

Table 13.10: Examples of Validation of Control Measures

Hazardous event	Hazard	Control measure	Validation of control measures
Security breaches at water supply assets	M, P, C	• Security fencing, locked gates, access hatches, alarms, routine security patrols, closed-circuit television cameras	• Historical security inspection records indicate no security breaches in the past 2 years
Microbiological contamination of storage tanks due to faults in roofs, hatches, inlets, etc.	M, P, C	• Annual roof inspection programme	• Historical water quality data (*E. coli* results) and roof inspection reports indicate no breaches in roof integrity of all storage tanks in the past 12 months
Contamination during repair of ≤150 mm mains	M, P, C	• Dewatering of trench prior to commencing repairs • Prevention of contamination of pipe material during storage transport and repairs • Flushing of water main – specify duration based on length of the main and minimum flow rate • Water quality testing (visual/turbidity)	• Field audit reports for the past 12 months and checking of records indicate compliance with the repair procedure • Water quality data indicate that water complied with turbidity requirements and contained no *E. coli* after completion of repair • A study on water main repair practices that included microbiological testing after 50main breaks indicated that the “burst repair procedures” effectively

Hazardous event	Hazard	Control measure	Validation of control measures
		prior to turning on the watermain	controlled microbiological contamination
Microbial contamination, growth of biofilm organisms	M	• Maintaining chlorine Residual	• No E. coli detected in water samples, heterotrophic plate count numbers low • Published evidence of the effectiveness of chlorine in inactivating viral and bacterial pathogens and controlling biofilms (Olivieriet al., 1986; USEPA, 2002e, f)

The water supplier must be able to demonstrate, using historical water quality data, other monitoring data and operational procedures, that current control measures are effective in controlling the associated hazardous event. Typically, the control measures are validated when the WSP is developed for the first time and subsequently reviewed during annual and unscheduled audits of the WSP. Examples in Table 13.10 demonstrate how to validate control measures.

13.6.4 Re-assess and prioritise the risks

Most water suppliers adopt a simple semi-quantitative approach (section 13.9.1.1) for their risk assessment. It is common, but not essential, to assess the risks without considering the effect of current control measures. This "raw risk" assessment provides an insight into some hazardous events that can be a significant threat to public health if not adequately controlled.

The next step in the risk assessment process is to reassess the risks considering the effectiveness of current control measures. This remaining risk is defined as the "residual risk".

The objective of reassessment of risks is to determine the effectiveness of existing control measures in preventing or removing significant risks. Residual risks should be prioritised from the highest to the lowest risk:

- High residual risk rating due to lack of or inadequate control measures – If a control measure is inadequate, improvements should be investigated, including enhanced management of the control, such as tighter critical limits, better alarm systems and quicker response times. Additional control measures should be included in an improvement plan.
- Medium and low residual risk rating – Operational monitoring of control measures for these events is essential to ensure that the level of risk remains low. The effectiveness of these control measures is generally monitored via the monitoring of related standard operating procedures.

Examples of the reassessment of risks are shown in Table 13.11, assuming that existing control measures are effective. The next section deals with responses if operational monitoring indicates that control measures are not effective.

Table 13.11: Examples of Reassessment of Risks after Application of Control Measures

Hazardous event	Hazard	Inherent or raw risk (risk ignoring the effect of controls)				Current control measure	Residual risk (if control measure effective)			
		Likelihood	Severity	Risk Score	Risk Rating		Likelihood	Severity	Risk Score	Risk Rating
Contamination of treated water storage reservoirs from birds and animals	M	3	5	15	High	Prevention of contamination and maintenance of chlorine residuals	2	5	10	Medium
Security breaches at storage tanks	M, C	4	5	20	High	Storage area security (locked gates, alarms, remote cameras, routine inspection s)	1	5	5	Low
Contamination from water main breaks	M	3	5	15	High	Prevention of contamination through applying appropriate procedures for repairing faults and returning the main to service	1	5	5	Low
Entry of pathogens through backflow from illegal connection s	M	2	5	10	High	No current control	2	5	10	High

Hazardous event	Hazard	Inherent or raw risk (risk ignoring the effect of controls)				Current control measure	Residual risk (if control measure effective)			
		Likelihood	Severity	Risk Score	Risk Rating		Likelihood	Severity	Risk Score	Risk Rating
Elevated DBPs	C	3	3	9	Medium	No current control	3	3	9	Medium
Taste and odour complaints due to sloughing of biofilms in water mains	P	2	3	6	Low	Routine water main flushing programme	1	3	3	Low
Increase in pH in concrete tanks	C	1	5	5	Low	Reservoir operating rules for seasonal variations to ensure maximum 48-hour filling cycle	1	5	5	Low

Source: Water safety in Distribution System WHO- 2014

13.6.5 Risk management

The most effective means of consistently ensuring the safety of a water supply is through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in water supply from catchment to consumer. In such approaches, the abovementioned factors of risk identification, risk analysis, and risk mitigation is involved. The risk management will cater to managing all the aspects of the risk and make the water supply safe to use.

1. **Risk Assessments**: Risk assessments should be conducted to identify potential risks and to prioritise areas of concern. This can be done through a combination of quantitative and qualitative methods and should include an analysis of the potential financial, environmental, and health impacts of a water supply system.
2. **Implement Best Management Practices**: Once the areas of concern have been identified, best management practices and mitigation strategies should be implemented to reduce the potential for risk. This can include water treatment techniques and processes, infrastructure upgrades, and improved operating procedures.
3. **Educate and Monitor**: Education and training of staff and stakeholders is essential for successful risk management. Regular monitoring and audits should also be carried out to ensure that risks are being managed effectively.

4. **Establish Contingency Plans**: Water supply systems should have contingency plans in place to address any potential risks that may arise. These plans should include strategies for responding to potential risks, such as water rationing, water recycling, and alternative sources of water.

13.7 Accident Injuries and Deaths in Water Supply Systems

Metrics:

Figures of accidents/injury in various water works organisations or in utility concerns may be collected and included to show the extent of accidents. This can be in the following form or any other forms as available:

Utility	*Rates of accidents*
	OR
No. of employees	*Accident frequency rates*

$$\text{Injury Frequency Rate F.R.} = \frac{\text{Number of injuries} \times 1{,}000{,}000}{\text{Man-hours worked}}$$

$$\text{Severity rate S.R.} = \frac{\text{Number of days lost} \times 1{,}000{,}000}{\text{Man-hours worked}}$$

13.8 Identification of Accidents

13.8.1 Source

In developing a safety programme, it is necessary to know the source of accidents. It is then possible to take precautions and corrective action. Besides knowledge of accidents in the utility itself, review of records or information at other water supply systems or in other utilities is helpful. Record of injuries/accidents maintained by the concerned department of labour, industries olfactory department of the state can also be consulted. Other sources of information are safety manuals, insurance company brochures, etc.

The main dangers at a water works system include, but are not limited to, the following:

(a) physical injuries arising from handling objects, falling objects, lifting objects, falls, tools and equipment;
(b) stepping on or striking objects/slips, trips and falls;
(c) machinery;
(d) infections;
(e) toxic gases;
(f) chemicals;
(g) fire;
(h) electrical shock;
(i) too much noise;
(j) collapse of trenches during repair of water mains;
(k) confined space.

13.8.2 Location

The above dangers may exist at several locations in a water works system. These include, inter alia: intakes, pumping stations, transmission mains, distribution system, water treatment plants, Storage places which include chemical hazards, large open filters, handling of materials, cleaning of internal sewerage system, septic tanks, etc., mechanical and electrical hazards.

The person responsible for the safety programme should constantly be on the alert for hazards, which may cause an injury to a workman.

13.8.3 Types of Injuries

To draw up a safety programme, it is important to know the type of injury that is most prevalent in water supply systems. The general injuries occurring in water supply systems are: bruises, cuts, sprains, fractures, burns, eye irritation and injuries, shocks, irritation by gases and other occupational diseases, deaths, permanent disabilities, temporary total disabilities.

Statistical data of major type of accidents, which occur in water supply system in the country, have not been well documented. Some data which may serve as a rough guide to understand the overall injury pattern at one of the water utilities in the country is given in Table 13.12.

Table 13.12: Statistical Data of Major Type of Accidents

Cause of Accident	Percentage
Over exertion	20
Chemicals/ gases	15
Fall on same level	11
Struck by falling object Struck	10
by moving object Electrical	9
shock injuries Failure to wear	8
safe attire	6
Caught in/on in between moving objects	5
Burns	4
Horseplaying, mischief making Insect/	4
animal bite	3
Others	5

13.8.4 Cost Components of Accident

The cost component of accidents includes the following:

- Compensation paid to workers and/or affected persons
- Medical expenses incurred on the injured/accident persons
- Cost of repairing or replacement of equipment
- Loss of production and consequential payment of overtime/damages
- Legal expenses
- Industrial relations
- Loss of good will and reputation
- Resitting of injured person on resumption and/or additional cost of hiring a new person including training cost

13.9 Safety Programme

13.9.1 Introduction

Safety practices require good management. For years, there may be minor injuries like cuts and bruises, but suddenly there could be a loss of limb, eyesight or even death.

Safety organisation is what you make of it. It may be a full-fledged safety organisation with a Safety Officer with necessary staff. It could be only the person in charge of the plant with a few personnel picked out for special assignments. Everybody on the job knows what can happen under certain conditions but each is busy with his own duties and responsibilities. However, a safety officer works at safety full time. A Safety Committee may also be constituted. Whether you need a full-time safetyman or not depends on the size of the undertaking/organisation. *However, we need full-time attention to Safety.*

13.9.2 Safety Practice Programme

13.9.2.1 Preliminary Step

A safety programme is a must for a water supply system. It must have the full co- operation of the management; otherwise, it will not be successful. A safety officer who can devote part-time or full time to the job in a large organisation may be designated as responsible for the programme. In a smaller organisation, that person may be the officer in charge of the plant.

13.9.2.2 Records

Keeping injury records is necessary for a safety programme. It is also mandatory in some of the Acts or Rules and Regulations framed by the Government. With records, the programme is given direction and will succeed.

For maintenance of records, standard forms are available. The formats could include items such as:

(a) Accident report
(b) Description of the accident
(c) Doctor’s report
(d) Action taken
(e) Accident analysis

Frequency rate and severity rate may be worked out as in para. 13.10.

A summary of types and causes of accidents should be prepared periodically. A suggestive format is given in Table 13.13.

Table 13.13: Summary of Types and Causes of Accidents

Type of Injury	Primary Cause of Injury										
	Unsafe Act	Chemical	Falls	Handling Objects	Heat	Machinery	Falling Objects	Electrical	Striking	Misc.	Total

Fractures											
Sprains											
Eye Injuries											
Cuts											
Bruises											
Burns											
Miscellaneous											

There must be a review of all reports by the foreman/supervisor, safety officer and management. There must be recommendations to avert such accidents. A follow-up is necessary to see that proper action has been taken.

13.9.2.3 Searching out Hazards

Hazards can be removed and will give increase in safety and will cost little time and money to correct. Some methods are:

- To examine records for conditions and situations that has caused accidents, recall circumstances that led to the accidents. See if you can put your finger on some of the sore spots in your building, equipment or bad practices that are occurring.
- See what parts of the body are injured in the accidents. Protective gear may be required.
- Look around and inspect in an organised manner. Take help of your supervisors. Dig around for potential causes of personal injury and fire and health hazards.
- Be on the watch for unsafe practices and doing the job the wrong way. Always be on the watch.
- Reduce risks in the workplace, equipment, and materials. With the supervisory staff you can cut down the amount of personal handling of tools and materials. It may be cheaper to buy power equipment.
- See that the work is done in the right and safe way.

13.9.2.4 Motivation and Training

- For a good safety record, all individuals must be educated in safety measures. They must have conviction that accidents can be prevented. A safety programme must start on the new operator who has been freshly recruited or transferred from another work site. He must be exposed to the importance of safety, proper reporting, and policies. Copies of Safety Practices should be supplied to him. Deeper training can be given to him subsequently after a few months. In the case of an individual who has been transferred, only the specific safety requirements in the new job are to be explained to him.
- Training will include how to perform the job. The plant supervisor must train the individuals in all aspects of plant safety. This will include dangers of electrical hazards, fire hazards, handling of tools and proper maintenance of tools to prevent accidents. Special instructions for specific work in confined environment such as pits, manholes, gas etc. must be given.
- The training must be continuous and not a one-time affair. During refresher education, case studies can be discussed. Victims of injuries can give their experience on how the

accident happened. Safety posters placed at strategic points around the plant are a constant reminder and contribute to the continuing education.

- Proper guidance and use of tools, equipment must be given. Supervisors must continually check on proper use of tools. They must also see that the methods adopted are right and also safe.
- Motivate people to work safely when they are not being watched. Positive approaches like recognition of safety record, competitive interests, etc., can be tried. Importance of good personal relations, a high morale, and a sensitive management to the needs and interests of people plays a vital role in the programme of safety practices.

13.9.3 Operator Protection

13.9.3.1 Personal Safety Equipment

The first step in controlling an unsafe condition is to remove the hazard mechanically. A secondary measure of protection is to provide personal protective equipment to the workman. Study of records has indicated the large number of injuries to various parts of the body. Personal safety equipment is designed to help protect the person's eyes, face, head, nose throat, lungs, ears, hands, feet, and body. Such safety equipment cannot protect the worker from unsafe actions or conditions. It can only supplement safe work or work habits.

A. Head Protection

- All personnel working in any areas where there may be danger from falling, flying tools or other objects must wear approved hard hats. Such hats should be according to the relevant BIS. Special insulated hard hats must be worn when working around high voltage to protect from electrical shock.
- It is advisable to have detachable cradle and sweat bands for two reasons: (1) to permit easy replacement of cradles and sweat bands; and (2) to make possible assignment of one helmet to several workers each with his own cradle and sweat band for sanitary reasons.
- Once broken, the crown of a hard hat cannot be effectively repaired. It must be replaced.

B. Face and Eye Protection

- Impact goggles must be worn to protect against flying objects. They can be spectacle or cup goggles.
- Spectacle goggles must have rigid frame to hold lenses in proper position before the eyes. Frames must be corrosion-resistant and simple in design for cleaning and disinfection.
- Cup goggles should have cups large enough to protect the eye socket and to distribute impact over a wide area of facial bones.
- Chemical goggles and acid hoods for protection against splashes of corrosive chemicals. A hood treated with chemical-resistance material having a glass or plastic window gives good protection. There should be a secure joint between the window and the hood material.
- Face shields can be used against light impact. Plastic shields should be non-flammable, and free from scratches or other flaws, which introduce distortions.
- Welding masks must be used from splashes and radiation produced by welding.

- Protective creams are used to protect the skin from contamination and penetration by oils, greases, paints, dust, etc.

Figure 13.1: Gas Mask

C. Hands and Lower Arms

- Protective sleeves, gloves and finger pads are used for different types of hazards and jobs.
- Rubber and asbestos gloves should be long enough to come well above the wrist, leaving no gap between the glove and coat or shirtsleeve.
- Gloves or mittens having metal parts for reinforcements should never be used around electrical equipment.
- Linemen and electricians working on energised or high voltage electrical equipment require specially made and tested rubber gloves.

D. Body Protection

Overalls are sufficient for most jobs. Always use rubber aprons when working with chemicals. When working on ladders or scaffolding, use extreme caution to prevent falls.

E. Legs and Feet

- Leggings are provided where leg protection is necessary and are in the same category as coats, frocks and aprons, kneepads made of cloth, padding, rubber, cork are used on jobs where kneeling is required.
- Ordinary work shoes are acceptable for many jobs. They should have non-skid soles to prevent slips. Safety shoes are required where there is danger of dropping tools or materials on the feet. Toe guards have been designed for the men to wear when operating machines as air hammers, concrete breakers, etc. For working on electrical equipment suitable safety shoes must be used.

F. Respiratory Equipment

In all dusty areas, effective filter masks shall be used to guard against the specific hazard.

Hose Mask should be used by men entering tanks or pits where there may be dangerous concentrations of dust, vapor, gases, or insufficient oxygen. Hose mask with blower and the airline respirator are used where the hazard is immediate, i.e., hasty escape would be impossible or could not be made without serious injury if there is failure of the equipment.

Oxygen or air breathing apparatus, i.e., self-contained oxygen breathing equipment using cylinders or bottles of compressed oxygen or air, is used where required. This is a must when the length of the hosepipe on on-line supply of oxygen exceeds more than 45 m.

Gas Masks – Canisters consist of a face piece connected by a tube to a canister. Chemicals in the canister purify contaminated air. No one chemical has been found to remove all gaseous contaminants. It does not supply oxygen and can be used where there is sufficient oxygen.

Figure 13.2: Self Breathing apparatus

G. Ear Protection Hearing

Where noise levels are high and exceeds specified limits, effective ear-pads or earplugs must be used.

H. Training

Supplying the appropriate equipment to the worker does not solve the problem. The employee must know when, how, and where to use the equipment provided as well as its limitations. This requires that the men must be trained.

I. Personal Hygiene Practices

Every employee must practise personal cleanliness to prevent body infections. A clean plant is safer, both from physical accidents and infection. Hands must be washed with soap after working and before eating or smoking.

Use the first-aid kit for immediate treatment of minor cuts, bruises, and scratches.

J. Proper Use of Tools

Some of the basic tool rules are:

(a) Always select the right tool for the job. Screwdrivers are not prying bars. Pliers are not wrenches.
(b) Repair or replace broken or worn tools regularly.
(c) Never use tools on or near moving machinery.
(d) Be sure you have enough room if the tool should slip.
(e) Be sure you have good footing to prevent slipping.
(f) Wear well-fitted gloves except when hammering.
(g) Never wear rings or loose clothing around moving machinery.
(h) Always wear goggles whenever using any impact tools, power grinder or

sharpener.

(i) After using each tool, wipe, clean, and replace in carrier or work belt. A greasy wrench can be dangerous.

(j) Do not lay tools on top of ladders or where they may fall on someone working below.

(k) Always use non-sparking tools on any job where explosive gases could be present.

13.9.4 Safety in Plant Maintenance

13.9.4.1 Maintenance Hazards

Plant maintenance, also called housekeeping or cleaning up, is an important function of the treatment plant and essential for plant equipment. Maintenance requires an operator to handle machinery, manual and power tools, repair electrical equipment, enter pits, sumps, manholes, etc. All these functions can pose a hazard and cause injury, fire, disease, or death.

Fixed safety features are designed or built into the structures. However, there are instances where the maintenance engineer may alter or augment the existing structure. Prompt and effective maintenance can prevent many accidents.

13.9.4.2 Cleaning

Keeping the entire plant clean will provide a much nicer place to work. Just keeping the working areas free of tripping hazards will add safety in the plant. Cleaning should be performed when others are not exposed to danger or inconvenience. Wet floors become slippery. Use notices to warn people.

Provide and use trashcans for used oily rags. Hazardous waste, acids, and caustics should be cleaned up immediately.

Doorways, aisles, stairways, and workplaces must be kept free of rubbish to reduce hazards of tripping and fire.

13.9.4.3 Painting

Regular painting is done at most plants. The following considerations must be kept in mind:

- When working with toxic paints, i.e., containing lead, zinc, or organics, be sure to clean your hands before eating or handling food.
- Avoid exposing your skin to solvent and thinners and try not to use compounds such as carbon tetrachloride.
- When spray painting, use a respirator to avoid inhaling fumes.
- No smoking or open flames of any kind should be allowed around the area being painted.
- When painting or cleaning the spraying equipment avoid closed containers where heat is involved. At a certain temperature called the flash point, spray or vapours could ignite and burn the operator or start fires. Always clean the spray equipment in an area with sufficient ventilation.
- Be very careful when using scaffolding or ladders. They must be strong and in good repair.

- Rags containing paint or oil should be placed in a closed container to avoid fires.

13.9.4.4 Access to Equipment

Safe access to equipment will reduce dangers from falls. Ramps and step stairs provide the safest means. Slope of ramps and rise of steps should not be excessive. Step stairs should have hand railings and the tread at least 25 cms (9 in).

Vertical ladders should be discouraged. However, they are commonly employed. A vertical ladder of 10ft (3m) or more in length should be equipped with a hoop cage to enable the operator to regain his hold in case of a slip. Rungs of vertical ladders should not be less than 30 cms (12 in) or more than 40 cms (15 in) vertically. Minimum width should be 25 cms (9 in), preferably 30 cms (12 in) to 40 cms (15 in).

Adequate workspace around equipment is important.

13.9.4.5 Guards, Rails, Fencing, Enclosures, Shields

These are designed to prevent, slipping, falling, or contacting machinery when in operation. If they are missing, they should be replaced. When removed for repairs, put a temporary safety line. Protective devices must be replaced promptly.

Settling tanks, basins, manholes, sumps, and other underground structures must be provided with railings or fencing. Safety belts must be used where necessary.

13.9.4.6 Lighting

Adequate glare-free lighting should be provided especially in the vicinity of steps and vulnerable places. Flood lighting should be provided at suitable places for safety and security of the complex.

13.9.4.7 Ventilation

Ventilation is a major factor in water supply systems. This can be secured by:

(a) open exterior windows or door louvres;
(b) fresh air intakes and mechanical exhaust fans/ducts;
(c) use of forced-draft fans;
(d) use of portable air compressors or air blowers.

13.9.4.8 Safety from Equipment

When maintaining and operating equipment, the following precautions should be taken:

- Always stop the machine before removing any guard.
- Personally lock out all power before starting any equipment maintenance. Put a warning sign and tag on the lockout.
- Do not unlock any power which has been closed by others.
- Block any counterbalance or weighted machine to prevent dead movement.
- Have enough help and hoisting gear to handle heavy equipment safely.
- Block up under any heavy equipment when on jacks or hoists before starting work.
- Keep tools in a kit bag or belt (not on the floor).

- Keep goggles handy. Use them wherever needed.
- Don't be in a hurry. Haste makes accidents.
- An authorised person should handle overhead travelling cranes. Circuit breakers, limit switches, hook, and wire should be checked. Only standard hand signals, known to all, should be used. When loads are to be moved, give a warning and make sure everyone is in a safe position. Hard helmets must be used.
- When using portable power tools, use safety protective devices when operating grinding, chipping, buffing, or pavement breaking equipment. Extension cords provide a tripping hazard. When working in damp or wet conditions use rubber mats. Electric tools should be grounded. For pneumatic tools use safety clamps and connectors. Electrical cords and air hoses should be kept away from oils, chemicals, or sharp objects.
- Portable electric lamps should not be more than 24 volts and should conform to I.E. regulations.
- In gas or electric welding, the operator must be trained. Fire protection and personal protection practices must be followed. Storage of gas cylinders must be done with the same care as those of other gases in a water supply system.
- All safety valves in the system must be regularly inspected according to the maintenance schedule.
- Where forklifts are used, do not permit anybody, except the operator, to ride on it. Make sure the warning signals are operating. Check brakes. Make sure the forklift load is stacked properly before lifting or moving.

13.9.4.9 Lubrication Safety

1. Avoid lubricating machinery when it is running. If you have to do so, ensure that the lubricating point is at 30 cms away from the moving part or the lubricant should be piped outside a guard.
2. Wipe spilled oil or grease immediately.
3. Never point a grease gun at anyone. Never squirt grease into your hands.

13.9.4.10 Safety in Confined Spaces

Any place where oxygen deficiency or dangerous air contamination can occur and where ready ingress or egress for removal of a person is not available can be defined as a confined space. Some of such places are pits, manholes, basins, and tanks. Accumulation of gases and vapours in confined spaces can produce explosive mixtures.

Oxygen deficiency occurs when oxygen is removed or when another gas displaces it. Oxygen is removed from air when it is used up due to bacterial action; by the oxidation of metals; combustion; and when inert or toxic gases displace it.

When oxygen in air is reduced to less than 17%, shortness of breath takes place and further reduction leads to loss of consciousness. Death occurs at 10% or less. Toxic gases cause injury or death by their own action.

Safety checks must be carried out when working in such spaces. More information is available in the Manual on Sewerage and Sewage Treatment Systems Part B Operation and Maintenance issued by the Ministry of Urban Development, Government of India in Chapter 9.

When working in confined spaces ensure that sufficient air changes as required takes place.

13.9.4.11 Hazardous Energy Control (Lockout/Tagout)

a) Before any employee performs any servicing or maintenance on a machine or equipment where the unexpected energising, start-up, or release of stored energy could occur and cause injury, the machine or equipment shall be isolated from the energy source and rendered inoperative.

b) For hazardous energy control application at the Generating Facility, see Generating Facilities PRD.90.001 Lockout/Tagout System. For the Water Treatment Plant, see ADM.1.10.001 Lockout/Tagout Procedure. For other Lockout/Tagout applications, contact the Environmental Health and Safety Office.

13.9.5 Safety in Chemical Handling – Powders

13.9.5.1 Activated Carbon

1. One of the greatest dangers in carbon storage is the fire hazard. Storage bins for dry bulk carbon should be of fireproof construction and equipped with carbon dioxide equipment or water spray for fire control.
2. Bag storage should be in a clean dry place, in single or double rows with access aisles around every stack for frequent fire inspections, and to facilitate removal of any burning carbon.
3. Smoking should be prohibited at all times in the carbon handling and storage areas. Keep carbon away from heated pipes, or any possible fire hazard such as electric motors or electric wiring.
4. Dust-proof motors and explosion-proof electrical equipment that can be kept dust-tight should be used. Damp carbon dust is a conductor of electricity and can short circuit electrical equipment.
5. Dust masks should be worn when handling carbon, and good dust collecting equipment should be used. When loading carbon bins or hoppers, the personnel should also wear dust-proof goggles, a cap, and loose clothing tied at the wrists and ankles.
6. Controlling fires
   Activated carbon burns like ordinary charcoal, without smoke or flame, and glows with intense heat. Such fires are sometimes difficult to detect, and when found, are hard to handle. A fire in a large storage bin or stack may burn for some time before being discovered. The smell of charred paper from the bags, or an area of scorched paint on the side of the hopper is indication that a fire is in progress.

   Burning carbon should never be doused with a large stream of water, as the steam produced will scatter burning carbon in all directions. A fine spray or fog nozzle works much better. In working with a carbon fire in a confined area, remember there is danger from carbon monoxide, so air-supplied hoods or self-generating oxygen masks should be available.

   Most activated carbon has sufficient oxygen adsorbed in the material so that it can burn in the absence of air. Carbon will start to burn if a temperature of 350 to 450 degrees Fahrenheit is reached, depending on the type of material and the fineness of grinding. The best way to combat the fire is to reduce the surrounding carbon below this ignition point, by soaking with water from spray nozzles.

13.9.6 Fire Protection

Very little attention is paid to fires. Three elements cause a fire – fuel, oxygen, and a means of ignition. If one is missing, there is no fire. Firefighting is based on removing one of these elements. In any fire, only the cause or fuel for burning varies.

13.9.6.1 Classification of Fires

Table 13.14: Fire Classification

Class of Fire	Description	Extinguishing medium	IS No.
A	Fire involving ordinary combustible materials like wood, paper, textiles, etc. where the (constant air pressure) cooling effect of water is essential for the extinction of fires.	Water soda acid type Water type (gas pressure) Water type	934 940 6234
B	Fire in flammable liquids like oils, solvents, petroleum products, varnishes, paints, etc. where a blanketing effect is essential.	Foam Carbon dioxide Dry Powder	933 2878 2171 4308
C	Fires involving gaseous substances under pressure where it is necessary to dilute the burning gas at a very fast rate with an inert gas or powder	Carbon dioxide Dry Powder	2878 2171 4308
D	Fires involving metals like blanketing aluminium, zinc, potassium, etc., where the burning metals is reactive to water and which requires special extinguishing media or technique	Dry Powder Special dry powder for metal fire	2171 4861
E	Fires involving electrical equipment where the electrical non-conductivity of the extinguishing media is of first equipment importance	Carbon dioxide Dry Chemical powder when electrical is de- energised, same as for Classes A and B	2878 2171 4308

Note: “E” type category has been recently removed

13.9.6.2 Fire Extinguishers

There is no one extinguisher that is effective for all fires, so it is important that you understand the class of fire you are trying to control. One must be trained in the use of the different types of extinguishers, and the proper type should be located near the area where that class of fire may occur. A preventive maintenance programme for fire extinguishers requires a considerable amount of time from the operator and requires a system of record keeping.

Types of fire extinguishers

(a) **Stored Pressure, Cartridge Operated, Water Pump Tank, and Soda-Acid**

These are suitable for Class A fires. Proper maintenance is essential, and a schedule should be drawn up.

1. The method of operation for a stored pressure extinguisher is simply to squeeze the handle or turn a valve. The maintenance is also simple: check air pressure and recharge the extinguisher as needed.
2. For the cartridge type, the maintenance consists of weighing the gas cartridge and adding water as required. To operate, turn upside down and bump.
3. To use the water pump tank type of extinguisher, simply operate the pump handle. For maintenance, one has only to discharge the contents and refill with water annually or as needed.
4. The soda-acid type must be turned upside down to operate; it also requires annual recharging.

(b) **Foam Type**

Foam type of extinguishers will control Class A and Class B fires well. They, like soda- acid, operate by turning upside down and require annual recharging.

The foam and water type extinguishers should not be used for fires involving electrical equipment. However, they can be used in controlling flammable liquids such as gasoline, oil, paints, grease, and other Class B fires.

(c) **Carbon Dioxide (CO_2)**

Carbon dioxide extinguishers are common. They are easy to operate, just pull the pin and squeeze the lever. For maintenance, they must be weighed at least semi-annually. Many of these extinguishers will discharge with age. They can be used on a Class C (electrical) fire. All electrical circuits should be switched off, if possible, before trying to control this type of fire. A carbon dioxide extinguisher is also satisfactory for Class B fires, such as gasoline, oil, and paint, and may be used on surface fires of the Class A type.

(d) **Chemical Extinguishers**

Chemical extinguishers are either (1) cartridge-operated, or (2) stored pressure. These are recommended for Class B and C fires and may work on small surface Class A fires.

1. The cartridge-operated extinguishers only require you to rupture the cartridge, usually by squeezing the lever. The maintenance is a bit more difficult, requiring weighing of the gas cartridge and checking the condition of the dry chemical.
2. For the stored-pressure extinguishers, the operation is the same as the CO_2 extinguisher. Just pull the pin and squeeze the lever. The maintenance requires a check of the pressure gauges and condition of the dry chemical.

13.9.6.3 Danger Points

The danger points are:

- unattended storage rooms where combustibles are present;
- workshops with cleaning liquids, oil, and soaked rags;
- laboratories with chemicals, heaters, burners;
- offices where many papers are present.

13.9.6.4 Prevention

1. Emphasis should be on good housekeeping. A clean environment raises morale and reduces tendency for slovenliness and carelessness.
2. Rubbish and waste not properly cared for is the biggest fire hazard.
3. Oil-soaked waste or rags should be stored in metal cans and covered.
4. Additions, alterations must be of non-combustible materials.
5. Combustibles must be kept away from heating equipment or where flames are present.
6. Proper check and maintenance of electrical equipment and wiring should be carried out.
7. Automatic fire-alarm systems should be installed in fire-prone areas.
8. Fire extinguishers and firefighting equipment must be installed and maintained regularly.
9. Avoid careless use of matches, blow torches, Bunsen burners, or smoking.

13.9.6.5 Fire Due to Chemicals

1. Sodium chlorite, being used for odour control in waterworks, becomes explosive and a fire hazard in presence of organic matter. Even a spark or sunlight can set it off. When spilled on a wooden floor, fire is caused with the scuff of a shoe. Spillage on clothes has resulted in locker fires. Fires can be controlled by soda ash or sand — never water. It should be stored by itself far removed from organics, sulphur, or acid.
2. Activated carbon is another fire hazard and has been discussed in 13.12.5- Safety in Chemical Handling – Powders.

13.9.7 Safety from Electrical Hazards

Only qualified workers who have been trained in the avoidance of electrical hazards are permitted to work on or near exposed energised parts. Safety related work practices are employed to prevent electric shock or other injuries resulting from either direct or indirect electrical contact when work is performed near or on equipment or circuits which are or may be energised. The specific safety-related work practices must be consistent with the nature and extent of the associated electrical hazards.

13.9.7.1 General Rules

1. Only trained and qualified persons should be allowed to operate and maintain electrical equipment.
2. When servicing any electrical appliance, kill, lock out, and tag all power coming to it.
3. Be sure of proper footing so that you don't fall onto a live wire. Always make sure that the wire is not live. Use a pencil type tester.
4. Hand tools must have insulated handles. Insulated mats must be provided before electrical controls.
5. Ensure that all electrical systems, equipment, etc., are properly grounded.
6. Remove metallic rings, watches, eyeglasses. Don't use metallic tape measures or metal ladders.
7. Always mount and protect wires and cables to prevent tripping by persons.
8. Electrical controls should be in good working order, easy to reach, and plainly identified.
9. Be sure there is someone to help in case of emergency. Don't become careless or overconfident.

13.9.7.2 Electrical First Aid

1. Immediately free the victim from the live conductor by use of a dry wooden stick, (such as a broom or shovel handle), piece of rubber hose or plastic pipe, or other non-conductor. Never grab the victim or the wire with bare hands, or you will suffer the same consequences.
2. If unconscious or not breathing, artificial respiration should be started immediately and continued until relieved by doctors or professional.
3. Protect from shock by keeping the victim warm and calm.

13.9.8 Safety in Laboratory

Safety in handling and storage of chemicals has already been discussed in the preceding sections — Hazards in Chemical Handling, Operators do not experience a great deal of exposure to hazardous laboratory conditions. However, proper practices must be followed to avoid accidents.

13.9.8.1 Sampling Safety

1. Never take field samples with bare hands. Always wear gloves.
2. Do not climb over or go inside guardrails. Use poles, ropes, dippers, or other long-distance samplers.
3. When collecting gas samples, do not open tank cover completely. Instal a sampling port, if needed.
4. Wear an effective gas mask when taking gas samples.

13.9.8.2 Housekeeping

General cleanliness and correct storage of chemicals and equipment are important for accuracy as well as safety in the laboratory. Basic rules include:

1. Follow a daily general clean up schedule in the laboratory. Dirty glassware or clothing can encourage infection. Put all chipped, cracked, or broken glassware into containers marked ‘Broken Glass only’.
2. Have a special spot for storing each piece of equipment. After each use, clean, disinfect, and return to its rack.
3. Never work in a poorly ventilated room. Keep the laboratory well lighted. Do not crowd the laboratory. Have plenty of room.
4. Always clean up and discard any spills at once.
5. All workbenches or tables should have chemical resistant tops or be painted with chemical resistant paint frequently.
6. Do not store any other equipment in the laboratory.

13.9.8.3 Safety with Chemicals

1. Keep working amounts of chemicals stored out in the lab to a minimum.
2. All bulk chemicals should be stored in original containers, in a separate fireproof storeroom. Larger bulk containers should always be on the floor.
3. Have individual bulk siphons to transfer chemicals from bulk storage to working stock bottles.

4. All chemicals storage jars should stand on wide shelves with retaining rails to prevent them from being accidentally pulled or jarred off.
5. Strong and/or highly corrosive acid and base storage jars should stand in lead, plastic, or ceramic individual trays deep enough to contain the contents if the jar should break.
6. All chemical storage should be as low as possible and never more than shoulder height.
7. Clearly label all chemicals with common and chemical names, formula, strength, and date prepared or received. Replace these labels as needed to keep them legible.
8. Add red “Skull and Cross bones” labels to all containers of toxic chemicals.
9. Workers familiar with their properties must carefully dispose of used chemicals. They must not be flushed down the drain without due consideration of their effect on the sewer system.
10. Keep highly reactive chemicals stored far apart.
11. Perform all work that involves volatile acids, bases, or solvents in a hood. Be very cautious with nitric acid. Do not add it to substances that are easily oxidised or nitrated. This can cause a fire or explosion. Other examples are nitric acid with acetone; with benzene and toluene; with acetic acid.

13.9.8.4 Safety with Equipment

1. Only trained experienced technicians should operate laboratory equipment, especially pressure units.
2. Exact, clear operating procedures, for autoclaves, water stills, and any other special pressure equipment will be permanently posted near same.
3. Valves and switches on such equipment shall be clearly numbered in their order of use. All electrical equipment must be well grounded. Inspect all electrical cords for wear or cracks in insulation and replace as necessary.
4. Manufacturer’s operations, warranty, service, and safety instructions shall be kept in a permanent file.
5. All equipment shall be set up away from gas and electric service switches or valves.

13.9.8.5 Safety with Glass

1. Wear gloves any time you are working with glass.
2. Hold rod or tube in contact with stopper and twist to insert.
3. Wear full or wrap-around goggles or a face shield when working glass.
4. Always support glass units with several padded clamps firmly anchored.
5. Properly shatter and discard all chipped or cracked glassware.

13.9.8.6 Safety in Laboratory Procedures

1. Never pipette by mouth. Always use a bulb.
2. Know your procedure and follow a checklist.
3. Always wear safety glasses or goggles in the laboratory.
4. Never wear contact lenses in the lab.
5. Have a viewing window so visitors won’t enter the laboratory.
6. Always wear a rubber apron when working with chemicals or running any reaction.

13.9.8.7 First Aid and Fire Prevention in the Laboratory

1. Have an adequate supply of a good eyewash at all times.
2. Keep several fire blankets in an easily accessible location.
3. Special fire extinguishers clearly labelled and checked for monthly charge, for chemical and electrical use should be openly mounted.
4. Emergency numbers for fire and medical help should be clearly and permanently posted above every phone.
5. All employees, and especially laboratory technicians, should have extensive, regularly refreshed, first aid training.

13.9.9 Safety Practices during Repair and Operation of Water Mains

13.9.9.1 Planning

A safety practice during construction and maintenance of the water distribution system has two major aspects — preparation and planning and operation. Usually, previous methods are followed, and these are revised on past experience. However, if we want to complete routine or special jobs successfully, we must plan them. This will eliminate possible hazards.

Proper maps of the system must be maintained and studied. A study of the character of the area in which the work is to be carried out is an accident prevention item.

13.9.9.2 Traffic Control

1. Warning signs must be placed well ahead of the work area. Signs, barricades and used tyres can be used.
2. Vehicles can be parked between work area and the coming traffic.
3. Use red warning lights or flashers during the night.
4. Use a flag man for one way operation.
5. Traffic police must be informed, and their help taken.

13.9.9.3 Safety Practices in Repair and Laying of Pipes

1. Excavations should be closely watched. Type of soil must be studied, and necessary precautions taken to provide adequate side slopes or to shore up the trench. The proximity of poles and buildings must be taken into consideration.
2. All soil must be stacked at least three feet from the edge of the trench.
3. Repair of broken mains is a hand job. The ground is usually saturated or washed out. Care must be taken to protect other utilities especially electric cables which can be dangerous. Welding must be done in dry conditions.
4. The workmen must use safety hats and other protective equipment.
5. Only one trained and experienced man should give signals to a crane operator.
6. The inspection of the equipment to be used should be done before it is sent to the site. In case of a burst main, the advance crew should carry plans showing the location of valves to be closed, barricading equipment, signage, valve, and chamber keys, etc. Portable pumps to drain out the water should also be sent.
7. The pipe for replacement must be blocked to prevent it from rolling. Proper equipment should be used when lowering it into the trench. Sufficient men should also be engaged.
8. When the job is completed, cleaning up must be done to prevent hazards to others.

13.10 Health and Safety Practices in Water Works

i) The aspect of health and safety of staff in any workplace of a utility cannot be overemphasised.

Workplace safety refers to the limitation of elements that can cause harm, accidents, and other negative outcomes in the workplace. It represents a culmination of policies, behaviours, and precautions that work to limit hazards, accidents, and other kinds of harm in a work environment.

More often than not, workplace safety directly affects the productivity and well-being of your workforce, and these directly affect the quality of output of your business. Hence, employers must strive to create a safe environment that offers an acceptable level of risk for all employees. Job Hazard Analysis (JHA) for all jobs that hazards exist should be performed and documented, then all employees should be trained on these JHAs. Daily job briefings to discuss the day's work and the hazards associated with that task should be conducted prior to each job, if personnel or job status changes.

Also, employees must be quick to identify situations and conditions in the workplace that can jeopardise their safety or expose them to unacceptable risk levels. National Occupational Safety and Health (OSH) profile, prepared by Directorate General, Factory Advice Service and Labour Institutes in collaboration with International Labour Organisation (ILO), is a comprehensive national policy guideline on major OSH laws and regulations including The Factories Act, 1948, and various Acts and Regulations applicable to specific industries, like docks, mines, building and other construction works , boilers, dangerous machines, motor transport , plantation, shops, petroleum related industries, inflammables, insecticides, chemicals, air, water, environment, etc. While these guidelines and acts deal more on the regulatory safety, facilities, and compensation aspects, specific risks are involved in each type of utility have to be clearly understood by the employers and workers so that appropriate safety measures, precautions can be planned and put in place. In addition, in case of an accident, the action to be taken based on nature of accident and victim's condition has to be displayed and be educated to the managerial and supervisory level staff so that minimum time is wasted in speedy treatment, and restoration of services.

ii) Major nature of workplace hazards are:

- Electrical accident;
- Exposure to dangerous chemicals;
- Machinery and tools hazard;
- Fire accidents;
- Falling and tripping due to obstructions, insufficient illumination;
- Suffocation;
- Drowning;
- Use of Improper tools and tackles.

iii) The hazards are different at different location of a water supply system. The table below gives a brief idea of the different risks involved are explained in table 13.15.

Table 13.15: Components of Water Supply System and the types/reasons of Hazards

S. No.	Component of water supply system	Type/reasons of Hazard
1	River, dam, impounding reservoir, intakes	Drowning, suffocation, fall
2	Pumping stations	Drowning fall, electrical shock, fire, tools related injuries, crane, noise fatigue
3	Water treatment plants	Fall and drowning, falling from steps, slipping due to wet floor, suffocation due to chlorine plant leaks and breakdowns, inhaling, fire.
4	Cross-country pipelines	Travel related accidents, Leak repair related accidents, fall, injury by tools, working in congested area like valve chambers, loading and unloading equipments
5	Small/booster pumping stations	Electrical shock, fire inadequate working space, low illumination
6	Overhead tanks feeder lines	Fall, drowning, and leak-repair related accidents

iv) Some important types, causes, and prevention methods are briefed below:

A. Electrical accidents:

i. Electrical accidents are caused by unprotected exposure to electrical outlets, use of improper un-insulated/under-insulated tools or aged instruments, use of unsafe extension cords, wet hands and area, lack of use of personal protective equipment, failure to isolate circuits and before working.

Electrical burns, electrical fires, and electrical shocks are three major types of electrical accidents. Electrical shocks occur when bodily contact with electricity causes the current to run through your body and in severe cases, it can lead to heart or respiratory failures.
Electrical fires occur when un-insulated wiring or broken circuits come in contact with flammable material in the workplace.

ii. A few things to do when electrical accidents, especially shocks and burns, happen in the workplace.

- Disconnect power supply to the equipment from which the victim suffered.
- Stand on a dry insulating mat and remove the appliance (drill, etc.) using an insulated glove or wooden broom, from the victim’s possession.
- Avoid touching the victim with your hands until power supply is disconnected.
- Check whether the casualty is conscious by calling his/her name, to open his eyes, pinching his ears lightly, etc.
- DO NOT move the casualty unless the environment or situation is dangerous, cramped, or uncomfortable.
- If the casualty is responsive, call emergency services now.
- If the casualty is not responsive, the first priority is to open the casualty's airway and check for breathing. Open the airway by lifting the chin and tilting the head back. This will free the tongue from the back of the throat. If

you are unable to open the casualty's airway in their current position, roll them onto their back. Check the mouth for any obvious instructions.

Then, check for breathing as follows:

1. LOOK for the rise and fall of the chest.
2. LISTEN for the sounds of breathing.
3. FEEL for air on your cheek.
4. Carry this out for up to 10 seconds.

If the casualty is breathing: Put them into the recovery position and then call for emergency help. Continually monitor and record vital signs – breathing, pulse, and responsiveness – until help arrives. Call for emergency service ambulance, etc. immediately.

If the casualty is not breathing normally:

Any person with experience or training in cardiopulmonary resuscitation (CPR) can be asked to carry out CPR. Continue CPR till emergency service arrives or till the victim recovers normal breathing.

Exposure to electricity can cause burns to the skin, and in severe cases, the internal organs. The electricity may cause “entry” and “exit” burns – for example, entering via a hand and leaving via the feet.

For responsive casualties, cool burns for a minimum of 10 minutes under cold water.

For unresponsive casualties, cool the burn with wet dressings (or special burn dressings) after placing them in the recovery position.

DO NOT:

- burst any blisters;
- apply adhesive dressings;
- remove damaged skin;
- apply ointments/creams;
- cover with “fluffy” dressings;
- affix dressings too tightly;
- apply butter/fats or other substances commonly believed to cool burns;
- remove damaged clothing;
- apply ice.

Other Injuries:

Muscle spasms/seizures: These may be present for some time after the exposure to electricity and indicate a seriously ill casualty.

Action in the event of a major seizure:

1. If standing, the casualty will almost definitely collapse during a major seizure. Try to control the fall.

2. Ensure the safety of the casualty by removing any objects that may cause injury if struck.
3. Place padding under the head. Improvise, if necessary, with clothing.
4. DO NOT place anything inside the casualty's mouth.
5. Loosen any clothing that may restrict the airway.
6. Try to time the seizure. When the seizure has subsided:
   a. Check the casualty's responsiveness and airway, breathing, and circulation (ABC).
   b. If unresponsive and breathing normally or semi-conscious, place the casualty in the recovery position. Continue to monitor ABC and other injuries.
   c. If unresponsive and not breathing, perform CPR.

Casualties with no apparent injury:

If no injury is present and the casualty appears well, it is still advisable to take the casualty to a hospital or medical facility for a check-up, as certain organs/systems within the body may be affected several hours after a shock.

iii. To protect the staff and prevent electrical shock accidents in the workplace, employers and employees must take extra care to practise workplace safety habits. Specifically, here are a few precautions you can take:

Always inspect the working area for un-insulated wires, broken cord, and exposed electrical circuits beforehand.

- Do not make use of faulty electrical equipment at all times.
- Workers must wear personal protective equipment.
- Isolate electrical equipment before working on them.
- Have a prompt system for reporting and documenting electrical shock incidents in the workplace.
- Always use electrical insulated gloves while operating HT circuit breakers, Isolators, changing HT fuses, etc., and stand on rubber mats.
- Use only insulated cutting players or screw drivers for attending to electrical equipment.
- Keep the fire protection system properly and periodically checked and updated.
- Use rubber insulated boots and not steel cap boots while attending to electrical work.
- Discharge any electrical equipment of residual potential before touching them. Keep the discharge rod (hickory rod) connected to the earth and the equipment while working and till the personnel come down and away from the equipment after repairs.
- Obtain proper line clearance messages preferably twice and by two people before accessing any line equipment.
- List out all activities of isolation when the work is started. Once the work is completed use the same list to reconnect, so that all checks are done.
- Do not work alone. Always keep at least one more person observing the

operation from a distance for response in an emergency.

B. Exposure to hazardous Chemicals

i. Toxic chemicals in the workplace like liquid chlorine, bleaching powder, etc., can also hamper the safety of employees, especially when they are exposed to these substances without appropriate caution.

Chlorine (Cl_2) which is supplied in pressurised cylinders in liquid form, and dosed as a gas at lower pressure is a greenish-yellow gas with a pungent, irritating odour. Exposure to low levels of chlorine can result in nose, throat, and eye irritation. At higher levels, breathing chlorine gas may result in changes in breathing rate and coughing, and damage to the lungs. Additional symptoms of exposure to chlorine can be severe. Workers may be harmed from exposure to chlorine. The level of exposure depends upon the dose, duration, and work being done.

ii. Prevention: Use of liquid chlorine for water disinfection has been prevalent for over a century. Despite being toxic, the chlorine is the most preferred disinfectant on account of lower cost and easy availability. In small towns, a cylinder of liquid chlorine (approx. one tonne net), will last for over 25 days. Keeping a spare full cylinder at the plant site is not safe. Smaller cylinders of about 52 kgs are also available which can be used in such small plants. This will reduce the volume of storage and thereby the extent of risk.

Almost all other disinfection methods are less hazardous compared to use of liquid chlorine. Site generation of HOCl by electrolysis of brine solution, or use of sodium hypochlorite solution, are better alternatives. However, they are required in larger volumes as they generate only about 30% of free chlorine.

Other methods of disinfection such as ozonisation, ultraviolet treatment, etc., are effective as spot disinfectant, but do not maintain a residual disinfectant in water which is required in pipeline supplies, travelling through multiple environment to the consumer.

All chlorine plants and chlorine storage areas shall have appropriate safety and protective equipment whose numbers may vary based on the size of the treatment plant and quantity of liquid chlorine being handled and stored. These are detailed in the subsequent paras.

Do not work on chlorine cylinders or apparatus when alone; always keep at least one more person observing the operation from a distance for response in an emergency.

iii. Treatment: Symptoms include coughing, breathing difficulty, burning in the mouth and eyes, blurry vision and skin irritation, vomiting sensation, etc.

- Move the victim away from the accident spot to an open space at a higher level. Chlorine gas is heavier than air.
- In case of skin irritation wash the skin area with water, soap, and water.
- In case of eye irritation, flush the eyes with running water for 10 to 15 minutes after removing any contact lenses.
- In case some chlorine has been consumed (drunk), give milk or water to drink immediately, unless the victim has convolutions or vomiting.
- In case of inhalation try to get fresh air or artificial respiration. Check respiratory

rate and note any trauma. In case if no pulse is detected, provide CPR. If not breathing, provide artificial respiration. If breathing is laboured, administer oxygen or respiratory support.

iv. Safety in Service Reservoir

The safety of reservoirs is of paramount importance to ensure the supply of potable water to its consumers. Possible hazardous events that may pose a risk to drinking water quality in reservoirs include intrusion of chemicals, sediments, animals, birds, insects, and harmful materials from various sources. Keeping the above in view, the safety of reservoirs could be ensured by adopting a suitable methodology for the security and safety of these reservoirs.

Along with the safety of the reservoirs, the protection of reservoir's premises is also very important and should be taken care of. The premises should be cordoned off and warning signs erected to prevent unauthorised people entering the area to avoid the possible threat of deliberately destroying or damage the structures.

Study of records indicate that the large number of injuries are related to various parts of the body. Personal safety equipment is designed to help protect the person's eyes, face, head, nose, throat, lungs, ears, hands, feet, and body. Further details are mentioned in relevant sections of this Chapter of this manual for reference. Signs for personnel safety shall be as per format given in Figure 13.3.

Figure 13.3: Sign for Head Protection (Source IS 9475:2005)

Public Address system

Public related safety issues should be addressed properly regarding the safety norms and gears required to be followed during the construction, working and O&M of the water supply system.

First Aid Facilities

There should be proper instructions and supplies regarding first-aid facilities in case of emergencies. The first-aid kit should be located at a reachable location with a proper signage as shown in Figure 13.4.

Figure 13.4: Sign for First Aid and Indication of direction to First Aid (Source IS 9457:2005)

Fire fighting

A proper firefighting equipment should be present with proper signages as shown in Figure 13.5.

Figure 13.5: Fire Safety Signs

v. Requirement of Safety Systems at Water Treatment Plant against chlorine hazard:

a) All such installations must have written safe work procedures, but not limited to:

- Cylinder change
- Leak detection and control
- Use of repair kit and container repair
- Checking protocol
- Respiration protocol
- Self-breathing apparatus protocol
- Disposal of damaged containers
- Routine maintenance of equipment

b) All the water treatment plants that have chlorination system and use chlorine for disinfection should have following safety arrangements in place to meet the emergency situation:

- On-site emergency plan
- Breathing apparatus
- Emergency kit
- Leak detectors
- Neutralisation tank
- Scrubber system
- Siren system
- Communication system
- Tagging system for equipments
- First aid including tablets and cough mixtures
- Exhaust fans
- Facility for testing of pressure vessels, chlorine lines, etc.
- Training and mock drill
- Safety showers and eye fountain
- Water curtain around storage facility
- Protecting hoods for tonne-containers
- Fire extinguishers

- Windsock
- Placards in local language for public cautioning, first aid and list of different authorities with phone numbers
- Personal protective equipments, viz., protective glass, clothings, gloves, shoes, helmet, goggles, etc.
- Placards at strategic locations showing Material Safety Data Sheet (MSDS), International Chemical Safety Card (ICSC), etc., of chlorine.

c) Storage and Handling of Chlorine Cylinders

The chlorine has a great potential for creating hazard, hence, there is need to observe certain precautions for the storage, use and handling of chlorine cylinders at site. Some of the measures, which need to be observed in this regard, are given as follows:

- Do not store the cylinders in exits or egress routes.
- Cylinder storage area should be well ventilated.
- Cylinders should not be stored in damp areas, near salt or corrosive chemicals, fumes, heat or where exposed to the weather.
- Cylinders should be stored in an upright position.
- Always use proper trunnions to place the cylinder on ground.
- Cylinders shall be secured with a chain or appropriate belt above the midpoint, but below the shoulder.
- They must be stored in such a way that cylinders are used in the order in which they are received.
- Avoid storing cylinder longer than one year without use.
- Cylinders shall be kept at least 20 ft. away from all flammable, combustible or Storage areas that have a non-combustible wall at least 5 ft. in height and with a fire resistance rating of at least 30 minutes may be used to segregate gases of different hazard classes in close proximity to each other.
- Cylinders should not be dragged, rolled, or physically carried. A lifter, hand truck, monorail, etc., should be used to carry or transport the cylinder in the premises.
- Magnets should not be used for lifting cylinders.
- The cylinders should not be painted by users.
- Close valves on gas cylinders when the system is not in use.
- Do not open the cylinder if the valve is corroded.
- Check equipment and lines frequently owing to the corrosive nature of chlorine.
- Never attempt to modify, alter, or repair containers and valves. These tasks should be carried out by the suppliers.
- Remove regulator after use and flush with dry air or nitrogen.
- Only the wrenches and tools provided by the cylinder supplier should be used to handle the valve. Pliers or other tools should never be used instead.
- Never attempt to apply Thread seal tape (also known as

polytetrafluoroethylene (PTFE) tape, Teflon tape, or plumber's tape) or other sealing material to tight the seal. The tightening should be achieved metal to metal else the valve or regulator should be replaced.

- Never use oil or grease on the regulator of a cylinder valve.
- An operator must be given proper training to handle the cylinder.
- Always follow the chlorine suppliers' recommendations to dispose off leaking or damaged cylinders.
- Maintain effective chlorine detection system at strategic locations; Neutralisation tanks for immersion of leaky cylinder in alkali solution, decontamination, and scrubber systems to absorb the escaped chlorine gas from the environment.

d) Personal Protective Measures

There is always chance of leakage or spillage of chlorine gas at water treatment facility and there is likelihood of excessive gas levels in case the leaked gas is not controlled, and this can adversely affect the plant staff and people in the vicinity area. It is, therefore, strongly recommended to have respiratory protection in the form of full-face gas masks with proper canisters or supplied air respirators (SAR) at site which can be used by the staff in times of emergency.

The skin effects of chlorine can generally be controlled by good personal hygiene practices. If very high gas concentrations or liquid chlorine is present, full protective clothing, gloves, and eye protection should be used. The following are recommended in this regard:

- Butyl rubber, neoprene, nylon (resistance to breakthrough longer than eight hours), nitrile rubber and other material with similar properties are among the recommended protective materials.
- It is not recommended to use a very thin natural rubber, neoprene, nitrile, and PVC gloves of 0.3 mm or less.
- Polyethylene and polyvinyl chloride are also not recommended.
- Use SAR or chemical cartridge respirator with cartridge to protect against Cl_2 up to 5 ppm.

vi. Machinery and Tools Hazard

Proper training in handling tools, operating crane, lifting, moving, and lowering of equipments, handling couplings, operating valves, conveying tools from outside to inside a chamber or vice versa, and a calm supervision are key attributes in preventing accidents while handling machinery and tools. Use of helmets, boots and reflective jackets while moving equipment, goggles while welding and Harness while climbing high ladders should be followed scrupulously. Small care like avoiding talking on phone, watching other activities etc will save a lot of accidents, and consequent issues.

Movement of overhead travelling crane should have alarm system to warn the workers on the shop floor; wire-ropes, hooks, etc., should have proper locking and latching system to prevent accidental fall of equipment.

Machine Guarding

a) No machine guard shall be altered, manipulated, or bypassed during operation of the machine.
b) No machine guard shall be removed from any machine except to perform required maintenance.
c) Any guards removed to perform required maintenance shall be immediately replaced, and the machine shall not be operated with the guards removed.

v) Fire Accidents: Waterworks and water pumping stations come under low hazard category, Group G-Industrial buildings as per IS 1641.Fire accidents are generally rare in waterworks. However, as there is likely to be some stock of lubricants, cotton waste, plastic articles, and other material which are flammable, risk of fire accident cannot be ruled out.

- Mandatory use of FRLS cables (fire retardant and low smoke) has substantially reduced fire due to electrical short circuit. This has to be specified during construction.
- Fire safety measures as per national building code and surrounding clearances as per IS 1643, Wiring, transformer spacing, transformer oil pits, etc. as per IS 1646, selection of firefighting apparatus as per IS 5986 are to be followed. In case of large pumping stations use of advanced fire control for power transformers, like nitrogen injection, external hydrant systems as per IS 13039 and IRDA tariff advisory committee manual is also to be referred to.

vi) Falling and tripping due to obstructions, insufficient illumination:

- Provide adequate illumination in all areas of work.
- Use non-skid flooring and also anti-skid shoes in watery and slushy areas.
- Check every day for dropped tools, rods, ladders ropes, etc., in all walkways and maintenance areas. Cultivate habit of cleanliness and dry floor in entire plant area.
- Use hard hat and boots. Observe presence of handrails in staircases and use them. If heavy loads are to be carried, keep at least one more person along.

vii) **Suffocation:** This happens when working in a cramped inhospitable environment like in a valve chamber, well, or while cleaning debris from old wells. This can be prevented by:

- Allowing Some Time For Air Entry (If Possible, Using Air Blower) Into An Unused, Or Old Chamber;
- Making Room For More Ventilation By Opening The Cover As Much As Possible, And Not Crowding;
- Using a rope tied to the working personnel which can be used for climbing up and also tugging signal. Keep the worker inside always within vision;
- Using mechanical equipments as far as possible for such works.

viii) **Drowning:** All boats shall contain sufficient number of life jackets and other safety gear. When working on gates, trash rack under water, proper harness shall be worn. As far as possible, maintenance works on gates, etc., shall be carried out off the water and only minimum works like checking for alignment, leak, etc., as inevitable, shall be done in the sump area. Dewatering pumps shall be checked regularly and kept in working condition. No work shall be carried out after dark.

ix) Use of Improper Tools and Tackles

Here again, proper training and imparting knowledge in handling tools and their proper use is very important.

x) Some useful safety practices:

a. Training in firefighting, first aid: All supervisory and working staff should undergo regular training in firefighting and first aid, which are usually conducted by State Governments. (Directorate of fire services, Civil defence and home guards).

b. Emergency response procedure: Emergencies are categorised as Category I to Category V.

c. Category I – Minor emergencies are those which may or may not cause damage or injuries and which are not likely to develop to a magnitude that warrants evacuation and can be controlled effectively using the resources available within the premises.

d. Category II – Major emergencies are those which are likely to develop or have developed to a magnitude that warrants evacuation from the plant/section and can be controlled effectively using resources within the factory.

e. Category III – Major emergencies are those which may cause material damage or injuries and likely to have an impact on entire factory. Such emergencies may be controlled using resources within the factory and available in the near industries, fire brigades.

f. Category – IV: This type of major emergency is likely to have an impact on a large geographical area perhaps involving the entire local area. Resources from outside may be required to control such emergency. During such emergency, the site management has to co-ordinate with District Emergency Authorities to initiate actions as per off-site emergency plan apart from initiating actions as per its "On-site emergency management plan". Category – V: Major emergencies that can occur outside the plant/factory during transportation of raw materials /product. Assistance from industry, police authority and fire brigades may be required to control such emergencies. The management has also to co-ordinate with the District Emergency Authority to initiate actions as per "Off-site Emergency Management Plan".

g. Suitable step-by-step emergency action plan in case of all the above emergencies have to be drafted and kept in display at the Supervisor's office.

h. Expected action by the person discovering the accident, by the immediate senior, by the site head/plant engineer, and list of in-house facilities, list of emergency contact numbers and persons should be displayed and updated from time to time.

i. Assembly area marking: A specific area may be marked in case of large plants for the workers to assemble so that they can be instructed on action plan/evacuation, etc., may be marked. And shown in the plant area plan.

j. Welfare facilities for workers like hygienic toilets, rest room, pantry facilities, transport and medical facilities should be ensured in each section of waterworks so that the worker is free of work fatigue and is able to direct his attention on the day to day works.

k. Use of protective gear during shift duty like earbuds in pumping stations where sound fatigue and hearing disability would occur over a period of time, should be ensured by supplying the ear buds and insisting on the shift staff using them.

l. Rotation of duties reduce monotony of the job in shift duties and improve the workers' response to maintenance works. This also improves the availability of workers of all skill in a plant.

m. In case of large staff colonies, allocation of funds for recreational activities for the staff and family members, educational medical facilities should be provided.

n. Cross country pipeline leaks: Any burst or major leak in a cross-country pipeline or a feeder line inside a town has its own problems. The leak/accident should not only be addressed early but inconvenience to the public like traffic, nearby compound walls buildings. Huts and settlements shops, other utilities, etc., also have to be addressed. The first step is to isolate and barricade the area and stop water supply in the concerned line and drain it through neighbouring scour valves, after precautions against flooding. Other utilities like power lines both overhead and underground should be informed, so that they are aware of any interruption in their services, and also need to switch off power supply or similar action. Traffic police should be informed to divert traffic through other roads. Mobilisation of leak/valve repair tools lifting and material handling equipments and resources should be taken up on priority to attend to such repairs. Crowding of the spot by public, street vendors, and others not connected with the work should be strictly avoided, by barricading and with police help. Repair work the pipeline at the repair spot and neighbourhood should be flushed of any silt and repair dirt, sample taken for testing before opening it for public use. The test results of the water sample should also be observed for any contamination, and flushed again, if necessary, till an acceptable quality is ensured. The location of leak should be backfilled, and consolidated as required, for restoration of all services in the area.

xi) **Documentation and Reporting:** All water works should maintain an accident register where all accidents should be recorded, with time, date, reason, victim's condition, and treatment thereafter, and rectification in safety issues taken up. This has to be reviewed during annual safety audit for compliance. Any case of repeated accident in the same place or for same reason should be investigated and escalated to a higher level for any corrective measures like change in equipment/building plan, additional safety feature improved lighting space clearances and further training to staff. At all times, the observations and views of the lowest level worker for a safe comfortable work environment should be heard and acted upon. These should also be documented, recognising the contribution of such workers/supervisors in improvement of workplace safety and environment.

xii) **Safety Audit:** A safety audit should be conducted once every year and all observations of non-conformity to safety regulations should be recorded and set right after which they shall be checked again before certifying the audit as completed. It is also a good practice to incentivise and reward such installations with full compliance to annual safety audit, and zero accident record.

xiii) **Safety is not to be delegated to a specific officer or person:** It is the responsibility of all the staff to actively participate in implementation of safety practices by themselves and urge their colleagues also to follow them for their own safety, welfare, health, and efficient performance.

13.10.1Safety in Vehicle Operation

a) Only those employees specifically authorised and who possess a valid licence or permit for the equipment being used shall operate company- owned motor vehicles or personally owned vehicles on company business.
b) Drivers shall know and obey all state and local motor vehicle laws applicable to the operation of their vehicle.
c) The driver shall drive at safe speeds no greater than that permitted by law. Traffic, road,

and weather conditions shall be given consideration in determining the safe speed within the legal limit at which the vehicle shall be operated.

d) A driver shall not permit unauthorised persons to drive, operate, or ride in or on a company vehicle.
e) All employees and other occupants are required to wear seat belts.
f) Employees shall not be permitted to ride on the fenders, running boards, engine hoods, top of cabs, sides of the bed, tailgates, or buckets of aerial trucks.
g) Standing up in a vehicle while it is in motion is prohibited. Wait until the driver has made a complete stop before mounting or dismounting vehicles.
h) Crew members are not allowed to ride in the back of trucks while on public roads. Employees shall not ride on trailers.
i) Vehicles shall not be fuelled with the engine running.

13.10.2Inspections

a) The driver shall determine that brakes are in a safe operating condition before operating equipment. If brakes are not working properly, they must be corrected before vehicle is used.
b) The driver shall inspect windshield wipers frequently and see that they are in good operating condition and that the windows and windshield give sufficient visibility for safe operation of vehicle.
c) All lights and reflectors of the vehicle shall be inspected by the driver doing any night driving. If found defective, they shall be repaired immediately.
d) Drivers shall report any defects which may have developed during the day to their supervisor. Items which affect safety shall be repaired prior to continued vehicle operation.

13.10.2.1 Exhaust Gas

a) The driver shall not operate the motor in any garage except when driving in or out.
b) The motor shall not be warmed up inside a garage nor shall the driver test motor operation in a garage unless the exhaust gas is carried directly to outside atmosphere or doors and windows are open so that adequate ventilation exists.

13.10.2.2 Operations

a) The operator of a motor vehicle shall clearly signal his intention of turning, passing, or stopping.
b) Drivers shall be prepared to stop, and the right-of-way shall be yielded in all instances, where necessary, to avoid an accident.
c) Drivers shall be courteous toward other operators and pedestrians. They shall operate their vehicles in a safe manner and shall yield the right of way to pedestrians and other vehicles when failure to do so might endanger any person or other vehicle.
d) Drivers shall use the "two-second" rule to allow a sufficient distance when following another vehicle so that they can safely stop their vehicle.
e) Drivers shall exercise added caution when driving through residential and school zones.
f) When entering or leaving any building, enclosure, alley or street where vision is obstructed, a complete stop shall be made, and the driver shall proceed with caution.
g) Trucks on which derricks or booms are erected above traveling height shall not be moved except under the immediate direction of a designated employee who shall give his or her undivided attention to the movement.

h) Before a radio equipped vehicle is driven under or adjacent to energised equipment, especially in substation areas, the radio antenna shall be lowered and clearance-checked in order to ensure that proper clearances will be maintained between the vehicle and energised equipment.
i) All ignition systems shall be turned off and no smoking shall be permitted while refuelling.
j) Trucks, particularly if heavily loaded, shall be in a lower gear on steep grades.

13.10.2.3 Parking

a) When parking on a roadway, vehicles shall park off the travelled road surface whenever possible. When vehicles must park closer than 10 feet to the travelled road surface to do work, appropriate warning devices shall be used.
b) Trucks or trailers stopped on any public roadway shall be protected by proper warning lights, reflectors, or red flags in accordance with state or local requirements. Refer to Section 6, Work Zone Safety.
c) Vehicles shall not be parked on bridges or over culverts, except when necessary for work.
d) When it is necessary to park on an incline, the driver shall make sure the vehicle is left in a safe position. The engine shall be turned off, the vehicle placed in the lowest gear or "park" position and the parking brake set. The front wheels shall be cut into the curb or if a curb is not present, the rear wheels shall be chocked.

13.10.2.4 Backing

a) Whenever possible, the vehicle shall be positioned to avoid the necessity of backing later.
b) Extreme caution shall be exercised when backing a vehicle to avoid injury to persons and to prevent property damage. If another employee is present, this person shall be stationed at the rear of the vehicle to assist the driver in backing the vehicle safely.
c) When backing a vehicle which has an obstructed view to the rear:

   i. Walk around the vehicle to check on all obstacles before entering the vehicle to operate it.
   ii. A reverse signal (back-up alarm) audible above the surrounding noise level shall be used; or, an observer shall signal that it is safe to back.
   iii. Back slowly.
   iv. Watch both sides, but do not depend entirely on mirrors.
   v. In any difficult backing situation, have one person outside the truck acting as a guide, when such help is available.

13.10.2.5 Stopping on Highway

a) Stopping on the highway shall be avoided.

   i. When it is absolutely necessary to stop on the highway, extreme caution shall be used. Warning signals and lights shall be used.
   ii. Rotating beacon shall be used if vehicle is so equipped.
   iii. Taillights/emergency flashers shall be used.
   iv. Flares or reflectors shall be placed to give adequate advance warning.

b) If work is in progress, traffic control devices (together with flagmen where necessary) shall be used. Refer to Section, Work Zone Safety.

13.10.2.6 Trucks and Trailers

a) Before moving a truck, it should be inspected to see that material is properly loaded and secured and that the crew is safely aboard.
b) Truck loads should not exceed their rated and licensed capacity. Maximum load on any dual wheel axle is 18,000 pounds. Maximum height for any unit is 13 feet, six inches and total width, except mirrors, is eight feet.
c) Where objects extend more than three feet to the front or the rear of any vehicle, they shall be equipped with a red flag during the daylight hours and a red light at night for loads extending to the rear, with an amber light for loads extending toward the front.

13.10.2.7 Seat Belt Requirements

a) Vehicle drivers shall properly wear the provided safety belt(s) and require that all passengers wear safety belts. **NOTE:** An employee may be exempted from this requirement due to a medical disability, provided the employee presents to his/her supervisor a physician's statement certifying such disability prevents safety belt use.
b) Refer to the *Vehicle Operator's Manual* for other requirements.

13.10.3Vehicle Accident Reporting Procedures

a) Employees who operate a city, rental, or personal/private vehicle to conduct official city business must report the following, whether on or off duty, to their immediate supervisor by the end of their assigned shift, or if not on shift, by the commencement of the next assigned shift:
    i. Any loss of driving privileges or adverse change of the terms and conditions of the driver's licence;
    ii. Any loss of appropriate insurance or adverse change of the terms and conditions of insurance; or
    iii. Any vehicle collision.
b) The driver, when involved in an accident, shall stop, and give their name and their employer's name and address. The employee shall also secure the name and address of others involved in the accident and witnesses to the accident. The driver shall also note position of vehicle after the collision in reference to edge of road, sidewalk line, centre of intersection, etc.
c) The driver shall not discuss or argue the causes or results of an accident with other parties but shall secure all pertinent facts and information. The driver shall answer questions when asked by proper authority.
d) Within 24 hours of any involvement on a collision, employees shall complete and file the Report of Vehicle Damage/Accident Incident Form with Risk Management.
e) As required, employees shall comply with all directions and complete required reports from applicable state and local law enforcement agencies.
f) Reference the *Vehicle Operator's Manual* for additional requirements.

13.11 First Aid

1. The ideal goal is to have every person trained in first aid and CPR. A more realistic approach is to have two persons in each crew and shift trained. This training can be imparted through the Red Cross, fire departments, or other organisations.
2. These crew medics can be made responsible for keeping all first-aid kits well- stocked. They could serve as instructors for the rest of the fellow workers.

3. First-aid kits must be prominently displayed at various points at the plant and in the vehicles. Special attention must be given to the most hazardous areas like laboratories, workshops, chemical handling facilities, etc.

13.12 Disaster management plan for water supply systems

The term “disaster” implies a natural unforeseen calamity which would have a wider impact on human life, property, and assets created. “Safe drinking water” is one of the basic needs and without its availability in adequate quality and quantity, there could be serious impacts on human and animal health. Drought could lead to scarcity of water due to depletion of ground water table and/or drying up of surface water sources. It could also lead to failure/damage of pumps due to increased suction head. Disasters like flood, tsunami, avalanche, landslide, and hailstorm could result in wash- off/damage of water supply assets created, thus resulting in disruption of supply of safe drinking water. Therefore, in any type of disaster, proper management of drinking water supply to the affected people on an “immediate basis” is an essential requirement. Maintaining environmental sanitation and individual hygiene are also equally important to reduce/eliminate chances of disease prevalence/outbreak of epidemics.

Preparedness

The most important component of preparedness is planning for all hazards. The plans have to be linked with those of other support departments, and also at various levels. Experience has shown that destruction from natural hazards can be minimised by the presence of a well-functioning warning system, combined with preparedness on the part of the vulnerable community. A community that is prepared to face disasters receives and understands warnings of impending hazards and has taken precautionary and mitigation measures will be able to cope better and resume their normal life sooner. Ministry of Drinking and Sanitation will technically advice state PHED/RWSS departments with equipments/resources used for emergency water and sanitation during response. The details of nature of disasters and the preparedness has been explained in Table 13.16. The list of Nodal agencies for early warning of Disasters is in Table 13.17 and Table 13.18 details the Contact Details of the Nodal Agencies

Early Warning

The early warning systems for different disasters should be in place so that the concerned administrative machinery (MDWS) at national level can initiate appropriate actions to minimise loss of life and property. These should give an indication of the level of magnitude of the mobilisation required by the responders. The goal of any warning system is to maximise the number of people who take appropriate and timely action for the safety of life and property. Ministry of Drinking and Sanitation will contact various nodal agencies at national level mandated for disseminating early warning bulletins.

Table 13.16: Preparedness for Different Types of Diasters

Nature of Disaster	Key Technical Preparedness	Responsible Person	Sources for reference
Floods and Cyclones	**Drinking water supply** • Raising tube-wells, hand- pumps, and platforms above flood water level to prevent contamination. • Accurate maps showing updated water supply systems facilities should be maintained at all times. • Essential stockpiling of supplies like water purification tablets, essential spare parts including detailed user and safety instructions (IEC) in local language etc must be ready in a warehouse. • Identifying and maintaining lists of mobile water purification installations available for supplying clean drinking water. • Ensuring water supply systems and traditional water sources are maintained and kept functional. • Water Quality assurance – Ensuring water quality and regular chlorination of drinking water sources (both at source and point of collection) should be taken up on priority with suitable water quality monitoring system in place. • All technicians must be trained on repair and restoration of water sources in emergencies. • For areas prone to floods, appropriate approaches to sanitation such as raised latrines, pit liners or rings, sealed pits/Eco-san toilets must be constructed. • Safe management of sanitation waste to prevent outbreak of disease and maintaining a clean environment/identifying and maintaining lists of mobile toilets units. • Identification of new bore wells, dug wells, sanitary wells of high yield using HGM maps. • Identify high yielding agricultural bore wells for hiring.	EE/JE/AE, RWSS	NDMA Guidelines – “Minimum standards of relief for drinking water” and “Minimum standards of relief for Sanitation and hygiene”/State Relief Codes

Nature of Disaster	Key Technical Preparedness	Responsible Person	Sources for reference
	• Prepare adequate plans with route maps to supply safe drinking water through tankers for vulnerable areas covering villages in drought areas, month-wise, identifying sources, routes, delivery points, storage structures, etc. • Monitor continuously rural and urban drinking water. • Availability in drought affected areas. • Undertake repairs of all tube-wells and hand pumps to make all tube- wells operational and instal additional tube-wells after proper identification of sites with desired yield using HGM maps and geo- physical methods. • Steps to be taken for repair, rehabilitation, replacement, rejuvenation, and augmentation of existing water supply schemes so that they are all functional and supply water at maximum efficiency. • Implement small schemes like bunding in river as relief work to augment water supply. • Identify water supply systems that are defunct or low yielding and take up artificial recharge structures to benefit the sources through MNREGS, NRDWP Sustainability funds. • Collaborate with NGO's, CBO's in raising awareness. • Close monitoring of ground water level and assessing feasibility of drilling of tube wells at various depths. Regional Directors of CGWB may be contacted by State agencies in this regard. • In very critical situations transportation of water for drinking purposes by special trains from outside regions must be considered. Source of water, infrastructure for filling rakes and for unloading and for distribution to households has to be planned. States have to indicate requirement to Railways.		

Nature of Disaster	Key Technical Preparedness	Responsible Person	Sources for reference
	• Adoption of traditional methods of water storage and completion of ongoing storage projects on top priority. • To reduce the water losses due to evaporation, special chemicals can be used as retardants. • Promote different rainwater harvesting systems, as drought proofing measures through MNREGS as the first priority. • Promote construction of check dams and rejuvenation of other traditional sources • Promote wise water management, dual water supply systems, water saving habits of daily life. • Small cisterns can be erected, and submersible pumpsets installed in bore wells where the water level has reduced, for storage of water, and taps can be provided all around the cisterns. • Wherever surface sources of assured capacity are available, they may be preferred by putting infiltration wells in the rivers or by construction of summer storage (SS) tanks to store water during summer. • Construction of cattle troughs in adequate quantity near hand pumps by collecting run-off and near water storages. • Put in place single toll-free number and centralized / computerised call centre for registering complaints received on phone, in writing and through internet and provide redressal.		
Earthquakes	• Identify vulnerable/weak points of water supply schemes, mainly covering number of villages in seismic area, specially storage tanks and treatment plants • Prepositioning of water tankers specially with pumps • Prepositioning of HDPE tanks to provide mobile / temporary storage in the shelter zone	EE/JE/AE, RWSS	NDMA Guidelines – “Management of Earthquakes”

Nature of Disaster	Key Technical Preparedness	Responsible Person	Sources for reference
	• Prepositioning of stock of chlorine tablets to avoid contamination or epidemic outbreak • Prepositioning of DG sets / solar pumps / electric pumps / drilling rigs / pipes and other related misc. items for immediate restoration of water supply schemes		
Drought	• A detailed contingency plan for supply of drinking water in rural areas to be formulated with technical help from the Central Ground Water Board (CGWB) and utilising, if need be, the rigs and other capital equipment from the CGWB • Identify habitations / villages indicating the month from which they are likely to face water scarcity. • Ensure water quality testing of drinking water sources through laboratories and at village level by trained persons with field test kits. • Identify all water sources like dams, reservoirs, tanks etc. and plan for reserving requirement of drinking water in the event of water scarcity at the earliest to avoid conflict with agricultural demand. • Reservation of water for drinking purposes in multipurpose water reservoirs • Planning for availability and supply of hardware viz. pipes, DG sets, HDPE tanks, vehicles, hand pump repair kits, hand pumps, motors, drilling machines and equipment etc. and chemicals used for water treatment should be done. • Different types of technical assistance and models available with Central Government agencies, scientific and educational institutions should be taken to tackle the situation.	JE / AE, RWSS	Base material: Rajasthan Drought Relief Manual
Tsunami	**Drinking water supply** • Essential stockpiling of supplies like water purification tablets, essential spare parts including detailed user and safety	EE / JE / AE, RWSS	

Nature of Disaster	Key Technical Preparedness	Responsible Person	Sources for reference
	instructions (IEC) in local language must be kept in a warehouse. • Coastal area population must be advised by the authorities, not to use well water which gets flooded with water after tsunami for drinking purpose. These wells will remain unsafe for some more time and in future the local authorities must drain all the wells before they can be used. • Water trucking provision / mobile water purification units should be made available for drinking water supply to tsunami relief camps and welfare centres with clear water quality inspection mechanisms. • Technically feasible technologies must be selected while determining cleaning methods for wells and other sources. • Agreed standards and procedures should be maintained to minimise the risk of collapse during dewatering. • Disinfection of the water and water quality testing should be carried out post cleaning. **Sanitation** • Arrangements for providing temporary sanitary toilets, mobile toilets and for cleaning and disinfecting them twice daily should be planned. • Prior discussion on the prototype of latrine design must be carried out with PHED, DRDA and NGO partners. **Solid and liquid waste management** • For areas prone to tsunami, appropriate approaches to sanitation such as raised latrines, pit liners or rings, sealed pits/Eco-san or tanks must be considered. • Proper mechanism must be designed for solid and liquid waste segregation and separating organic waste and inorganic wastes to avoid potential public health risk.		

Nature of Disaster	Key Technical Preparedness	Responsible Person	Sources for reference
Cyclones, Tsunami, Floods, Landslides, Avalanches and Earthquake	**Drinking water supply** Objective: Ensure the availability of minimum safe drinking water and sanitation taking into account privacy and dignity • Amenities in cyclone shelters such as drinking water, bathing, and toilet facilities for large number of people during the disaster phase must be taken into account. • Water Quality assurance: - Ensure water quality and regular chlorination of drinking water sources (both at source and point of collection) is taken up on priority including detailed user and safety instructions in the local language with a suitable water quality monitoring system in place. • Protect existing water sources from contamination, adding chlorine tablets in water for residual disinfection. • Provide soaps, detergents, bleaching powder, and Jerry cans, including messages in the local language on handling of water and disposal of excreta and solid waste. • If tankering water, always ensure there are tanks with tap stands for tankers to discharge the water, rather than people collecting straight from the back of the tanker. Also ensure appropriate disinfection of water is done. • When tankering water, always factor in the exit strategy before implementing the activity.	EE / JE / AE, RWSS	NDMA Guidelines – "Minimum standards of relief for drinking water" and "Minimum standards of relief for Sanitation and hygiene"
	• Follow standards and procedures to minimise the risk of collapse during dewatering; disinfection of the water; water quality testing should be carried out post cleaning of all water sources. • Provide water facilities close to the toilets for hand washing and anal cleansing apart from flushing. • Train village water persons who traditionally operate the GP owned piped water supply schemes. Training inputs need to		

Nature of Disaster	Key Technical Preparedness	Responsible Person	Sources for reference
	be provided in areas like disinfection of water using bleaching powder, storage of bleaching powder and checking residual chlorine. **Sanitation** • For areas prone to floods, appropriate approaches to sanitation such as raised latrines, pit liners or rings, 'sealed pits' toilets must be considered. • Hand washing must be addressed for all latrines constructed – either at the latrine or at the household level – by the promotion and provision of soap and hand-washing devices. • Women must be consulted about their requirements to manage their menstrual hygiene needs. • Where possible, female bathing cubicles should be included in a screened courtyard design with toilets. • Camp school latrines should be semi-permanent whereas permanent structures are built for existing schools. It is important to match the construction materials of the school building. **Hygiene promotion** • Continuous IEC activities encouraging and motivating the individuals to use toilets. • Provide audio-visual aids for encouraging toilet utilisation. • Provide pictorial representations of toilet use, quantum of water use, hand washing and basic cleanliness. • Disease surveillance and organising hygiene promotion in camps/embankments must be done. • Provision should be made to support adolescent girls and women to address menstrual hygiene management; especially when the communities are forced to leave home to stay in camps with very little belongings. Sanitary		

Nature of Disaster	Key Technical Preparedness	Responsible Person	Sources for reference
	cloth/disposable sanitary napkin should be provided to adolescent girls and women. Proper disposal system is established in the form of incinerator or other mechanism		
Drought	• Construction of exploratory wells in drought prone areas by the State Govt. with assistance from CGWB and NGO's and energise them as quickly as possible and use for mitigating water scarcity. • Construction of check dams or percolation tanks should be taken up to improve recharge of the ground water sources. • Drilling of new bore wells of high yield using HGM maps • Implement small schemes like bunding in river as relief work to augment water supply. • Collaborate with NGO's in raising awareness. • In critical situation transportation of water for drinking purposes by water tankers or special trains from outside regions must be considered. • Construction of different rainwater harvesting systems, as drought proofing measures. • Deepening of riser pipes in hand pumps. • Deepening of bore wells and open wells and raising of parapets of open wells. • Flushing of bore wells and disinfection of all hand pumps and bore wells frequent reboring and energisation of tube wells. • Introduce regulatory measures for regulating the drawl of groundwater around drinking water sources in affected area. • Construction of cisterns wherever submersible pumpsets are installed for storage of water and taps can be provided all around the cisterns.	JE / AE, RWSS	Rajasthan Drought Relief Manual and NDMA Guidelines – "Minimum standards of relief for drinking water" and "Minimum standards of relief for Sanitation and hygiene"

Table 13.17: Nodal agencies for Early warning of Disasters

Early Warning Nodal Agencies		
Type of Disaster	**Nodal Agency**	**PHED to monitor key parameters**
Cyclone	IMD/Regional Meteorological centre	1. Intensity of rainfall 2. Period of rainfall
Tsunami	Indian National Centre for Oceanic Information Services	1. Height of tidal wave 2. Speed of tidal wave
Floods	CWC	1. Intensity of rainfall 2. Period of rainfall 3. Quantum of release of water 4. Water supply assets in low lying/flood prone/flood plain areas, water quality and disinfection
Landslides	GSI	1. Intensity of rainfall (if applicable) 2. Distribution network/treatment plants situated on steep slopes prone to landslides
Avalanches	Snow and Avalanche Study Establishment	1. Wind speed 2. Intensity of rainfall 3. Overhead service reservoirs without braces 4. Water supply assets on hills/hill slopes
Heat and Cold waves	IMD	1. Quality of drinking water
Earthquake	IMD	1. Water retaining structures 2. Water treatment plants
Drought	Department of Agriculture	1. Intensity and period of rainfall 2. Declining ground water levels 3. Drying up of surface water bodies 4. Poor recharge of aquifers 5. Wilting of crops

Table 13.18: Contact Details of Important Nodal Agencies

Important Nodal Agencies' Contact Details			
Name/Organisation	**Disaster type**	**Address**	**Contact Details**
Control room Disaster Management Division, Ministry of Home Affairs, Government of India	All disasters	Integrated Operations Centre, Ministry of Home Affairs Room No. 12 North Block, New Delhi	Ph.: (011) 23092763, 23092885, 23092923, 23093054, 23093563, 23093564, 2309356 Fax.: (011) 23093750
Indian Meteorological Department Dy. Director (Meteorology)	Cyclone, Earthquake & Avalanche	Dy. Director General of Meteorology, Lodhi Road New Delhi	Ph.: (011) 24690279 E-mail: amss20042000@yahoo.co.in
Indian National Centre for Oceanic Information	Tsunami	Indian National Centre for Ocean Information Services (INCOIS), "Ocean Valley", P.B No.21, IDA Jeedimetla P.O, Hyderabad – 500 055, India	Ph.: (040) 23895002
Central Water Commission	Floods	SWC, Sewa Bhavan, RK Puram, New Delhi - 110066	Ph.: (011) 26108855 Fax.: (011) 26195516
Geological Survey of India (GSI)	Landslides	27, J.L. Nehru Road Kolkata - 700016 West Bengal	Ph.: (033) 22861676 Fax: (033) 22861661
Department of Agriculture	Drought	Dr Rajendra Prasad Road, New Delhi - 110001	(011) 23382719
Ministry of Drinking Water and Sanitation (MDWS)	Water and Sanitation	9th Floor, Paryaravan Bhawan, CGO Complex, Lodhi Road,	Ph: (011) 24361043 Fax: (011) 24364113 E-mail: jstm@nic.in

		New Delhi - 110003	
National Disaster Management Agency (NDMA)	Disaster Management	NDMA Bhawan A-1 Safdarjung Enclave New Delhi - 110 029	Ph.: (011) 26701728 Fax: (011) 26701729 E-mail: info@ndma.gov.in

13.13 Conclusion

It is to be remembered that safety is the responsibility for everyone and implementation of a safety programme is a must from the management point of view. Many accidents occur due to the human negligence. Ultimate responsibility may be that of management, but the operator cannot also be relieved of his responsibility. The operators decision-making abilities and general behaviour (response time, sense of alarm, etc.) are important. Be on the lookout for factors that disrupt the flow of action between the operator’s natural senses and actions and the tools and machines.

ANNEXURES

ANNEXURES

[ANNEXURE NUMBERING IS CHAPTER RELEVANT]

Annexure 3.1: Sanitary Inspection Form for Deep Borehole with Mechanised Pumping

I. Type of facility: Deep borehole with mechanised pumping

1. General information: .... System name: ....
2. Code number linked to scheme ID: ....
3. Date of visit: ....
4. Water sample taken? …….. Sample No. ……… E. coli/100 ml ....

II. Specific diagnostic information for assessment risk

1. Is there a latrine or sewer within 30 m of the pump house? Y / N
2. Is the nearest latrine unsewered? Y / N
3. Is there any source of other pollution within 30 m? Y / N
4. Is there an uncapped well within 100 m? Y / N
5. Is the drainage around pump house faulty? Y / N
6. Is the fencing damaged, allowing animal entry? Y / N
7. Is the floor of the pump house permeable to water? Y / N
8. Does water form pools in the pump house? Y / N
9. Is the well seal insanitary? Y / N

Total score of risks …./9
Risk score: 7–9 = High; 3–6 = Medium; 0–2 = Low

III. Results and recommendations:
The following important points of risk were noted:

Signature of surveyor:

Comments:

Sanitary inspection form for borehole with hand pump

I. Type of facility: Borehole with hand pump

1. General information: .... System name: ....
2. Code number linked to scheme ID: ....
3. Date of visit: ....
4. Water sample taken? …….. Sample No. ……… E. coli/100 ml ....

II. Specific diagnostic information for assessment risk

1.	Is there a latrine within 10 m of the borehole	Y/N
2.	Is there a latrine uphill of the borehole?	Y/N
3.	Are there any other sources of pollution within 10 m of the borehole? (e.g., animal breeding, cultivation, roads, industry, etc.)	Y/N
4.	Is the drainage faulty, allowing ponding within 2 m of the borehole?	Y/N
5.	Is the drainage channel cracked, broken, or needs cleaning?	Y/N
6.	Is the soakage pit missing or ponding?	Y/N
7.	Is the apron less than 1 m in radius?	Y/N
8.	Does spilt water collect in the apron area?	Y/N
9.	Is the apron cracked or damaged?	Y/N
10.	Is the hand pump loose at the point of attachment to apron?	Y/N

Total score of risks …./10

Risk score: 9–10 = Very high; 6–8 = High; 3–5 = Medium; 0–3 = Low

III. Results and recommendations:

The following important points of risk were noted

Signature of surveyor:

Comments:

Sanitary inspection form for protected spring

I. Type of facility: Protected spring

1. General information: .... System name: ....
2. Code number linked to scheme ID: ....
3. Date of visit: ....
4. Water sample taken? …….. Sample No. ……… E. coli/100 ml ....

II. Specific diagnostic information for assessment risk

1.	Is the spring unprotected?	Y/N
2.	Is the masonry protecting the spring faulty?	Y/N
3.	Is the backfill area behind the retaining wall eroded?	Y/N
4.	Does spilt water flood the collection area?	Y/N
5.	Is the fence absent or faulty?	Y/N
6.	Can animals have access within 10 m of the spring?	Y/N
7.	Is there a latrine uphill and/or within 30 m of the spring?	Y/N
8.	Does surface water collect uphill of the spring?	Y/N
9.	Is the diversion ditch above the spring absent or non-functional?	Y/N
10.	Are there any other sources of pollution uphill of the spring (e.g., solid waste)?	Y/N

Total score of risks …./10

Risk score: 9–10 = Very high; 6–8 = High; 3–5 = Medium; 0–3 = Low

III. Results and recommendations:

The following important points of risk were noted:

Signature of surveyor:

Comments:

Sanitary inspection form for rainwater collection and storage

I. Type of facility: Rainwater collection and storage

1. General information: .... System name: ....
2. Code number linked to scheme ID: ....
3. Date of visit: ....
4. Water sample taken? …….. Sample No. ……… E. coli/100 ml ....

II. Specific diagnostic information for assessment risk

1. Is rainwater collected in an open container? Y/N
2. Are there visible signs of contamination on the roof catchment (e.g., plants, excreta, dust)? Y/N
3. Is guttering that collects water dirty or blocked? Y/N
4. Are the top or walls of the tank cracked or damaged? Y/N
5. Is water collected directly from the tank (no tap on the tank)? Y/N
6. Is there a bucket in use and has the bucket been left at a place where it can become contaminated? Y/N
7. Is the tap leaking or damaged? Y/N
8. Is the concrete floor under the tap defective or dirty? Y/N
9. Is there any source of pollution around the tank or water collection area? Y/N
10. Is the tank clean inside? Y/N

Total score of risks …./10
Risk score: 9–10 = Very high; 6–8 = High; 3–5 = Medium; 0–3 = Low

III. Results and recommendations:

The following important points of risk were noted: (list nos. 1-10)

Signature of surveyor:

Comments:

Sanitary inspection form for piped water supply with service reservoir and mechanised pumping

I. Type of facility: Piped water supply with service reservoir and mechanised pumping

1. General information: .... System name: ....
2. Code number linked to scheme ID: ....
3. Date of visit: ....
4. Water sample taken? …….. Sample No. ……… E. coli/100 ml ....

II. Specific diagnostic information for assessment risk

1. Does the pipe leak between the source and storage tank? Y / N
2. Does surface water collect around any standpost? Y / N
3. Can animals access within 10 m of the reservoir? Y / N
4. Is open defecation prevalent or is cattle dung observed within 50 m of the reservoir? Y / N
5. Is there a sewer within 30 m of any tap stand or reservoir? Y / N
6. Are the pipes corroded? Y / N
7. Are there signs of leaks in the main pipes? Y / N
8. Are the reservoirs used for human and cattle bathing? Y / N
9. Are the buried pipes ever checked for leakage? Y / N
10. .Are storage tanks cleaned at specified intervals? Y / N

Total score of risks …. /10
Risk score: 9–10 = Very high; 6–8 = High; 3–5 = Medium; 0–3 = Low

III. Results and recommendations:

The following important points of risk were noted: (list nos. 1-10)

Signature of surveyor:

Comments:

Sanitary inspection form for the source of dug well (ringwell)

I. Type of facility: Dug well (Ringwell)

1. General information: …............. System name: ....
2. Code number linked to scheme ID: ....
3. Date of visit: ....
4. Water sample taken? …….. Sample No. ……… E. coli/100 ml ....

II. Specific diagnostic information for assessment risk

1. Is there a latrine or sewer within 30 m of the dug well? Y / N
2. Is the wall of the well lined properly and the well covered is adequately? Y / N
3. Is open defecation prevalent or is cattle dung found within 50 m of the ring well? Y / N
4. Is the well used for bathing and washing clothes? Y / N
5. Is there any water drainage facility available around the platform of the well, and does the drainage facility leads to water stagnation within 30 m of the wall? Y / N
6. Does the well have fixed stainless steel/aluminium buckets with a chain pulley for drawing water? Y / N
7. Is the well deep? Y / N
8. Does the water of the well appear visibly clean? Y / N
9. Is there any other source of pollution within 10 m of the well (e.g., animal breeding, cultivation, roads, industry, etc.)? Y / N
10. Was the well chlorinated during the last 7 days? Y / N

Total score of risks .... /10
Risk score: 9–10 = Very high; 6–8 = High; 3–5 = Medium; 0–3 = Low

III. Results and recommendations:

The following important points of risk were noted: (list nos. 1-10)

Signature of surveyor:

Comments:

Annexure 3.2: Causes of Failure of Wells

Sources	Causes of failure							
	Incorrect design	Poor construction	Corrosion	Faulty operation	Adverse aquifer conditions	Mechanical failure	Incrustation	Inadequate development including silting
1) Dug well with or without steining	✓	✓		✓	✓			✓
2) Dug-cum-bore wells								
(i) With PVC casing	✓	✓		✓	✓	✓		✓
(ii) With MS casing	✓	✓	✓	✓	✓	✓		✓
3) Cavity bores								
(i) With PVC casing	✓	✓		✓	✓	✓		✓
(ii) With MS casing	✓	✓	✓	✓	✓	✓		✓
4) Infiltration galleries								
(i) Lined with brick masonry	✓	✓		✓	✓			✓

Sources	Causes of failure							
	Incorrect design	**Poor construction**	**Corrosion**	**Faulty operation**	**Adverse aquifer conditions**	**Mechanical failure**	**Incrustation**	**Inadequate development including silting**
(ii) Lined with non-metallic perforated pipes	✓	✓		✓	✓		✓	✓
(iii) Lined with non-ferrous metallic perforated pipes	✓	✓		✓	✓		✓	✓
(iv) Lined with MS perforated pipes	✓	✓	✓	✓	✓		✓	✓
5) Radial collector wells								
(i) Radial with non-metallic perforated pipes	✓	✓		✓	✓		✓	✓

Sources	Causes of failure							
	Incorrect design	Poor construction	Corrosion	Faulty operation	Adverse aquifer conditions	Mechanical failure	Incrustation	Inadequate development including silting
(ii) Radial with non-ferrous metallic perforated pipes	✓	✓		✓	✓		✓	✓
(iii) Radial with MS perforated pipes	✓	✓	✓	✓	✓		✓	✓
6) Tube wells (bore wells)								
(i) With PVC casing and screen pipes	✓	✓	✓	✓	✓	✓	✓	✓
(ii) With MS casing and screen pipes	✓	✓		✓	✓	✓	✓	✓
7) Bore wells	✓	✓	✓	✓	✓	✓	✓	✓

Annexure 3.3: Well Problems and their Suggested Solutions

S. No.	Type of well	Problem	Probable cause	Solution suggested
1	Dug well	1. Silting 2. Decrease in yield 3. Pollution	1. Overpumping 2. Adverse aquifer conditions 3. Subsurface liquid waste inflow from different sources	Desilting can be done manually with buckets. Desilting can be done by using submersible mud pumps. Discharge should be reduced so that there is no inflow of silt with water. Rehabilitation procedure as per 3.5.8 (I) should be followed. Source of pollution to be identified through sanitary survey and removed/plugged forthwith.
2	Dug-cum-bore well	1. Silting 2. Decrease in yield 3. Mechanical failure	1. Overpumping 2. Adverse aquifer conditions 3. Falling of foreign objects in the bore	Apart from the solution suggested in Sl. No. 1, the rehabilitation procedure for mechanical failure mentioned in 3.5.8 (III) should be followed. Development should be done with the help of an air compressor using the surging and pumping technique.
3	Cavity bore	1. More silting 2. Decrease in yield 3. Mechanical failure	1. Overpumping 2. Adverse aquifer conditions 3. Falling of foreign objects in the bore 4. Collapse of cavity	For mechanical failure rehabilitation procedure mentioned in 3.5.8 (III) should be followed. The cavity reconstruction and desilting of the bore should be done with the help of an air compressor using the surging and pumping technique.
4	i) Radial collector well ii) Infiltration galleries	1. Silting in well caisson/sump well 2. Decrease in yield	1. Overpumping 2. Adverse aquifer conditions 3. Incrustation of radials 4. Blocking of screens with fine granular material 5. Damage to MS screens due to corrosion	Apart from the solution suggested in Sl. No. 1, the rehabilitation procedures mentioned in 3.8.5 may be followed. Backwashing with the help of an air compressor should be done to flush sand from the blocked screens. Screens should not be allowed to become aerated and should not be kept unused for long periods.
5	Tube well	1. Silting of tube well 2. Decrease in yield	1. Overpumping 2. Adverse aquifer conditions 3. Incrustation of screens and aquifers 4. Falling of foreign objects in the bore	Rehabilitation procedures suggested in 3.5.8 (I, II, III), 3.5.6, 3.5.9 and 3.5.10 may be followed.

S. No.	Type of well	Problem	Probable cause	Solution suggested
		3. Mechanical failure	5. Damage to MS screens due to corrosion	
6	Bore well	1. Silting of bore well 2. Decrease in yield 3. Drying up of bore well 4. Mechanical failure	1. Overpumping 2. Adverse aquifer conditions 3. Incrustation and silting of fractures and fissures 4. Falling of foreign objects in the bore	Rehabilitation procedures suggested in 3.5.8 (I, II, III), 3.5.9, and 3.5.10 may be followed.

Annexure 4.1: Format to Report and Repair Visible Leaks

LEAK DETECTION FORM

Leak Form No		DMA/DMZ no		Service Station		Sub Division	
Time of Detection		Date of Detection		Team Name/ID			
Leak Location Address							
Nearest Landmark							
Leak Point Schematic							

Location of Leak	Centre Road	Side Road	Road Shoulder	Footpath	
Type of Pavement	Asphalt (A)	Concrete (C)	Macadum (M)	Concrete/Cement Tiles (T)	
GIS Information					
Size of Pipeline	mm	Material of Pipe		Appurtenances	
Supply Day:	Y / N	Supply Hours:		Leak Priority:	1 | 2 | 3 | 4
Leak Detection Method:			Sign of Old Leak repair:	Y	N
Damage to Pavement	Y / N	Details		Water Flowing	
Type of Leak; Estimated	Service Connection,	Mains	Appurtenances		
Requirement of Special Machine/Equipment/Material; Comment				Sign:	

LEAK REPAIR FORM

Time of Repair	Start		Date of Repair		Team Name/ID			
	Finish							
Leak Visible during Repair		Y / N	Leak repair during supply hour	Y / N	Pavement Type	A	C	M	T

Size of Excavation	CUM	Tools of Road Cutting	Manual	Pneumatic	Hydraulic	Excavators/JCB
L: B:	B: D:	Tools for Exavation	Manual	Pneumatic	Hydraulic	Excavators/JCB

Safety Precautions	Y / N	Barricades	Safety Poles	Cones	Tapes	Safety Gears	Helmets/ Shoes/ Gloves/ Ref Jacket
Dewatering Done	Y / N	Size of Pump		No of Hours			

Leak Repair Team	Unskilled Workers		Plumber/ Fitter		Others

Actual Pipe alignment Sketch

N

Actual Pipe Size		Pipe Depth		No of Leaks		Leak Location	At point of	Y	At other Point
No of Pipes		Pipe Material		Appurtenances			Detection	N	Distance:

Leak Found	Yes	No	If No	Leak point Inaccesible	Sewage/ Other water leak	Other:

Type of Leak	Service Connection,	Mains	Appurtenances	Others

Leak Details								
	Ferrule	Service Pipe	Main Pipe joint Tighten/ Flanged	Pipe Joint Weld	Main pipe crack Circumferentrial/ Longitudinal	Valve	Air Valve	Old Disconnected HSC

Old Leak Repair	Yes		Permanent		If Temp,	
evidence	No	Leak Repair Type	Temporary		Reasons	

Leak Repair Inventory	Tools	Equipments	Material	Fittings	Repair Works	Others

Accident Reported	Y / N		Damage to other Utility	Y / N	Action Taken	

Road/ Pavement Restoration Details		Sign:

Annexure 5.1: Materials of Chlorine Equipment and Ancillaries

S. No.	Equipment	Material
1.	Piping rigid	Seamless carbon steel ASTM A 106 grade “B” schedule 80 or equivalent BIS-1030-1974
2.	For gas below atmospheric pressure	Rigid uPVC (for under shed), polyethylene tube, HDPE (outside shed)
3.	Piping (flexible)	Annealed copper with cadmium plating
4.	Globe valves	Body: Forged carbon steel Trim: Monel or hastelloy “C” Stuffing box: PTFE or graphite packing
5.	Ball valves	Body and end piece: Forged carbon steel, ASTM A 105 or equivalent IS Seat: PTFE Ball: Monel
6.	Springs	Tantalum alloy, hastelloy
7.	Gasket	Lead containing 2% to 4% antimony or bonded asbestos
8.	Chlorinator	Vacuum regulator body: Carbon steel Regulator diaphragm: FLUON, FEP Cabinet: FRP “0” ring and gaskets: Fluorocarbon lead oxide (litharge cured) viton
9.	Pressure gauge	Diaphragm: silver, tantalum, hastelloy, monel alloy liquid: fluorocarbon (silicon oil) fluorolube “MO”10
10.	Differential regulator	Body: uPVC, ABS, ebonite, PVDF
11.	Pressure relief valve	Body: uPVC, ABS, ebonite, PVDF stem: Ag, hastelloy, monel
12.	Injector	Block: ebonite or PVC, ABS
13.	Evaporator	Vessel: boiler quality steel
14.	Rupture disc	Silver: monel, tantalum, hastelloy “C”
15.	Rotameter	Glass: borosilicate Float: PTFE, tantalum, hastelloy, glass
16.	Filter media	Glass wool
17.	Diffuser and solution line	Rigid uPVC, saran or rubber lined steel, HDPE, natural rubber hose
18.	Pressure reducing valve	Body: Ductile cast iron Diaphragm: FPM (viton) ECTFE/FEP plugs: silver or tantalum, hastelloy Seats: PTFE
19.	Check valve springs	Tantalloy/hastelloy
20.	Non-permanent joints	Mixture of linseed oil and white lead or mixture of linseed oil and graphite or teflon tape
21.	Permanent joints	Glycerine and litharge
22.	Screws	Monel and stainless steel

Annexure 5.2: List of Safety Systems at Chlorination Plant

1. Breathing apparatus.
2. Emergency kit.
3. Leak detectors.
4. Neutralisation tank.
5. Scrubber system.
6. Siren system.
7. Display of boards in local language for public cautioning, first aid and list of different authorities with phone numbers.
8. Communication system.
9. Tagging system for equipment.
10. First aid including tablets and cough mixtures.
11. Exhaust fans.
12. Testing of pressure vessels, chlorine lines, etc., every year as per factory act.
13. Training and mock drill.
14. Safety showers.
15. Eye fountain.
16. Personal protective equipment.
17. Protecting hoods for tonne containers.
18. Fire extinguishers.
19. Wind cock.
20. CCTV.

Annexure 5.3: Trouble Shooting Chart for Vacuum-type Chlorinator

Trouble	Cause	Remedy
1. Required gas flow not achieved at start-up.	a) Insufficient ejector vacuum caused by insufficient water supply by pressure or excessive back pressure. b) Leakage at vacuum line connection at outlet from flowmeter, rate control valve, differential from flowmeter, differential pressure regulator, and/or inlet to ejector. c) Vacuum line(s) if flexible, crimped.	a) Refer to Trouble at S. No. 6. b) Inspect each connection and remake, if necessary. c) Replace vacuum tubing and arrange line(s) to eliminate crimping.
2. Required gas flow rate is not achieved on start- up following an extended period of shutdown.	a) Insufficient ejector vacuum. b) Leakage at vacuum line connection at outlet of flowmeter, rate control valve, differential pressure regulator, or inlet to ejector. c) Vacuum line(s), if flexible, crimped. d) Leakage around flowmeter gaskets.	a) Refer to Trouble at S. No. 6. b) Inspect each connection and remake if necessary. c) Replace vacuum tubing and arrange line(s) to eliminate crimping. d) Inspect and align flowmeter or replace gaskets.
4. Flowmeter float observed bouncing and/or maximum gas flow cannot be achieved during normal operation.	a) Gas inlet filter of vacuum regulator dirty. b) Rate valve dirty. c) Flowmeter dirty. d) Ejector water supply pressure fluctuating too wide (float bounce) or insufficient ejector vacuum.	a) Replace gas inlet filter assembly. b) Clean rate valve. c) Clean flowmeter. d) Correct water supply pressure as necessary.
5. Flowmeter fails to indicate gas flow during normal operation but there is no out-of-gas indication.	a) Rate valve plugged. b) Gas flowmeter plugged. c) Vacuum lines, if flexible, crimped.	a) Clean rate valve. b) Clean gas flowmeter. c) Replace vacuum tubing and re-arrange lines to eliminate crimping.
6. No gas indication during normal operation.	a) Gas supply valve(s) closed. b) Gas supply exhausted. c) Clogging of filter in vacuum regulator.	a) Open gas supply valves. b) Replenish gas supply. d) Replace filter.

Trouble	Cause	Remedy
7. Insufficient ejector vacuum.	a) Y-strainer in water supply line is dirty reducing available supply pressure. b) Back pressure is greater than value listed for one of the following reasons: i) solution valve, if present, not fully open ii) solution line, if present, partially blocked iii) back pressure at point of application has increased above its original value. c) Ejector nozzle and/or throat dirty.	a) Clean Y-strainer. b) Open solution valve, clean solution line. c) Clean nozzle and/or throat.
7. Loss of gas feed.	a) Dirty or plugged ejector nozzle. b) Insufficient water pressure to operate ejector. c) No gas supply	a) Check for vacuum in ejector. Clean nozzle. b) Provide proper water pressure. c) Replenish gas supply.
8. Flooded feeder.	a) Dirt lodged on the ejector check valve seat.	a) Clean or replace seat or O-ring.

Annexure 5.4: Standards Related to Chlorinators

1.	BS: 1500	—	For tonners.
2.	IS: 7681	—	Specification for welded low carbon steel gas cylinders for chlorine gas.
3.	IS: 3224	—	Specification for valve fittings for compressed gas
4.	IS: 4263	—	Code of practice for chlorine.
5.	IS: 10553	—	Parts I and II: Requirements for chlorination equipment.
6.	IS: 5844	—	Recommendations for hydrostatic stretch testing of compressed gas cylinders.
7.	IS: 4379	—	Identification of contents of industrial gas cylinders.
8.	IS: 646	—	Specification for liquid chlorine.
9.	IS: 8198	—	Code of practice for steel cylinders for liquefied chlorine
10.	IS: 5845	—	Code of practice for visual inspection of low pressure welded steel gas cylinders in use.
11.	IS: 8868	—	Periodical inspection interval of gas cylinders in use.
12.	IS: 9200	—	Methods of disposal of unserviceable compressed gas
13.	IS: 5903	—	Recommendation for safety devices for gas cylinders.
14.	IS: 3710	—	Filling ratios for low pressure liquefiable gases contained in cylinders.

Annexure 5.5: Report Format

FORMAT 1

Daily report on operation and maintenance of ___________________MLD Water Treatment Plant. Prepared by: [Name of Department/Contractor]
Report for: [Date]

A. Consumption Records

S. No.	Item	Meter reading or other records	Daily quantity	Average per m^3 of raw water	Remarks
1	Raw water quantity received at plant inlet				
2	Alum/PAC quantity consumed				
3	Poly-electrolyte quantity consumed				
4	Chlorine consumed				
5	Electrical power consumed				

B. Quality Records

S. No.	Particulars	At 6.00 hrs	At 12:00 hrs	At 18:00 hrs	At 24:00 hrs	Average	Remarks
1	Turbidity of raw water (6 hourly on report day)						
2	Turbidity of clarified water						
3	Turbidity of filtered water						
4	Residual chlorine in CCT						
5	Coliform bacteria in filtered water						
6	E-coli in filtered water						

C. Quantity of Filtered Water

S. No.	Particulars	Quantity in 24 hrs	Remarks
	Quantity of filtered water from		

1	Stream No. 1 (for Bed No. 1 – _____)		
2	Stream No.2 (for Bed No. 2 – _____)		

D. Operational

S. No.	Unit	From hrs	To hrs	Total time	Remarks
D.1	Filter				
	Bed No. – 1				
	Bed No. – 2				
	Bed No. – 3				
	Bed No. – 4				
	Bed No. – ..				
D.1.2	Downtime				
	Bed No. – 1				
	Bed No. – 2				
	Bed No. – 3				
	Bed No. – 4				
	Bed No. – ..				
D.2	Clarifiers				
D.2.1	Operational clarifiers				
	Clarifier – 1				
	Clarifier – 2				
	Clarifier – ..				
D.2.2	Downtime				
	Clarifier – 1				
	Clarifier – 2				
	Clarifier – ..				
D.3	Other units				
D.3.1	.... Downtime				
D.3.2	.... Downtime				
D.3.3	.... Downtime				

Signed by: ________________________________

Designation: ________________________________

On behalf of:

Department/Contractor: ________________________________

FORMAT 2

Monthly report on operation and maintenance of ____________________MLD Water Treatment Plant. Prepared by: [Name of Department/Contractor]
Report for: [Date]

A. Consumption Records

S. No.	Item	Reading on last date of month	Reading of the month	Quantity month	Average per 1000 m^3 water per day	Remarks
A.1	Raw water quantity received at plant inlet					
A.2	Chlorine quantity consumed					
	For pre-chlorination					
	For post chlorination					
A.3	Alum/PAC quantity consumed					
A.4	Poly-electrolyte quantity consumed					
A.5	Electrical power consumed					

B. Quality Records

S. No.	Particulars	Average during month	Maximum during month	Minimum during month	Remarks
B.1	Turbidity of raw water				
B.2	Turbidity of clarified water				
B.3	Turbidity of filtered water Stream No. 1 (for Bed No. 1 –..)				
	Stream No. 2 (for Bed No. ....)				
B.4	Residual chlorine in filtered water				

B.5	Coliform				
B.6	E-coli				

Signed by: ________________________________

Designation: ________________________________

On behalf of:

Department/Contractor: ________________________________

Annexure 8.1: Record Keeping for Water Sample

			Date:
Sampling location address/details		**Latitude and latitude of sampling location**	
Sample Description/Type e.g., source, WTP, distribution		**Sample Collected by**	
Date of Sampling		**Date of receipt of Sample**	
Date of Start of Analysis		**Date of Completion of Analysis**	

S. No.	**Parameters**	**Result**	**Method Reference**	**BIS: 10500-2012 Desirable/Permissile limit**
Physico-chemical Parameters				
1.	pH			6.5-8.5
2.	Electrical Conductivity (µS/cm)			-
3.	Total Dissolved Solids (TDS) (mg/L)			500-2000
4.	Turbidity (NTU)			1-5
5.				
6.				
Bacteriological Parameters				
	Total Coliforms CFU/100ml*			Shall not be detectable in 100 mL sample
	Thermotolerant Coliforms* (Faecal Coliforms) CFU/100ml			Shall not be detectable in any 100 mL sample

Additional parameters should be added in the Table.

Water Quality: Metals

S. No.	**Sample code**	**As**	**Al**	**Co**	**Cd**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Pb**	**Zn**
BIS Limit (mg/L) (IS:10500-2012)		**0.01**	**0.03-0.2**	**-**	**0.003**	**0.05**	**0.05-1.5**	**1.0**	**0.1-0.3**	**0.02**	**0.01**	**5.0-15**
Detection Limit (mg/L)												
1.	**Sampling location**											

Analysed by **Verified and authorized by**

Conditions:

Annexure 8.2: Sanitary Surveillance for Surface Water Sources

I.	**General Information**		
1.	Source Information and name of the ULB	:	
2.	Code No.	:	Address …………………………………………
3.	Date of visit	:	……………………………………………………

II.	**Specific diagnostic information of assessment**	**Risk**
1.	Is there any human habitation upstream, polluting the source?	Y/N
2.	Are there any farm animals upstream, polluting the source?	Y/N
3.	Is there any crop production or industrial pollution upstream?	Y/N
4.	Is there a risk of landslide or mudflow (causing deforestation) in the catchment area?	Y/N
5.	Is the intake installation unfenced?	Y/N
6.	Is the intake unscreened?	Y/N
7.	Does the abstraction point lack a minimum-head device (weir or dam to ensure minimum head of water)?	Y/N
8.	Does the system require a sand or gravel filter?	Y/N
9.	If there is a filter, is it functioning badly?	Y/N
10.	Is the flow uncontrolled?	Y/N
	Total Score of risks:	…./10

Contamination risk score: 9–10 = very high; 6–8 = high; 3–5 = intermediate

III. **Results and recommendations**

The following important points of risk were noted: (list nos. 1–10) and the authority advised on remedial action.

Signature of Sanitary Surveyor

Annexure 8.3: Sanitary Surveillance for Deep Borehole with Mechanical Pump

I. General Information	
1. Source information:	Name of the ULB……………………………………….
2. Code no ………………………………	Address………………………………………………… ……
3. Date of visit…………………………	
II. Specific diagnostic information for assessment	**Risk**
1. Is there a latrine or sewer within 15-20m of the pump house?	
2. Is the nearest latrine a pit latrine that percolates to the soil, i.e., un-sewered?	
3. Is there any other source of pollution (e.g., animal excreta, rubbish, and surface water) within 10m of the borehole?	
4. Is there an uncapped well within 15-20m of the borehole?	
1. Is the drainage area around the pump house faulty? Is it broken, permitting ponding and/or leakage to the ground?	
6. Is the fencing around the installation damaged in any way which would permit any unauthorised entry or allow animals access?	
7. Is the floor of the pump house permeable to water?	
8. Is the well seal intact?	
9. Is the chlorination functioning properly?	
10. Is chlorine present at the sampling tap?	
Total score or risks	
(Communication risk score: 9–10 = very high; 6–8 = high; 3–5 = intermediate; 0–2 = low)	
III. Results and Recommendations	
The following important points of risk were noted.......................(List nos. 1–10), and the authority advised on remedial action.	
Signature of Sanitary Surveyor …………………………………………………	

Annexure 8.4: Sanitary Surveillance for Water Treatment Plant

Ì. General information Water Treatment Plant	
1. Date of Survey	
2. Address	
3. Security of plant Fence (Y/N)	Security Guard (Y/N)…………………..
II. Source	
1. Type of water source	Reservoir……………………... Stream………………………… River……………………………. Well……………………………... Others………………………….
III. Intake	
1. Is the intake adequate with respect to:	Location? Y/N……………………………... Structure? Y/N……………………………. Maintenance? Y/N………………………. Pollution sources in the vicinity? Y/N………………...
IV. Treatment processes employed	
1. Pre-sedimentation	
2. Pre-disinfection/oxidation	Chlorine gas Bleaching powder Other
3. Aeration	
4. Coagulation and flocculation	Lime Alum PAC Coagulant aids
5. Sedimentation	
6. Filtration	
7. Disinfection	
8. Other processes (specify)	
V. Sedimentation	
1. No. of sedimentation tank	
2. Frequency of desludging	
3. Type of desludging facility	
4. Method of sludge disposal	
5. General appearance of clarified water	
6. Turbidity (NTU) at inlet	
VI. Filtration	
1. No. of filtration	
2. Filtration rate	
3. Filter run	
4. Depth of gravel	
5. Depth of sand	
VII. Backwashing	

1. Criteria used for initiating backwashing:	Air scour:	… ....Rate … .... Duration
	Water scour:	… .... Rate … .... Duration
2. Distribution of air and water supply in the sand bed:	Even Uneven	
3. Capacity of clean water for backwash		
4. Any mud balls or cracks in the filter bed?	Before backwash……………………………... After backwash ……………………………….	
5. Where does the wash water go?		
VIII. Chlorination		
1. Any interruption in chlorination?		
2. Frequency of interruption:		
3. Cause of interruption:		
4. Type of chemical used:		
5. Dosage of chemical		
6. Safety equipment and measures		
7. Reserve stock of disinfectant	Quantity:	
8. Storage conditions		
IX. Clear-water tank (s)		
1. No. of tanks		
2. Capacity of each tank		
3. Concentration of free residual chlorine		
4. pH		
5. Chemical used for pH adjustment and its dosage		
6. Any leak in the tank		
7. Is the tank properly covered and locked?		
8. Any scum or foreign substance in the tank?		
9. Are air vents and overflow pipes protected by screens?		
X. Process control		
1. Jar test	Yes/No/Frequently	
XI. Record keeping		
1. Chemical consumption		
2. Process-control tests		
3. Others		
XII. Maintenance		
1. Screen	Cleaning………………………………………… Calibrating/oiling/greasing……………………………	

2. Pumping facility		
3. Chlorine-dosing facility		
4. Alum-dosing facility		
5. Instrument (gauge, recording, devising, etc.):		
6. General housekeeping		
7. Storage of chemicals	Adequate/Inadequate……………………………………….	
XIII. Personnel		
1. No. of present staff	Permanent…………………………………... Casual…………………………………………...	
2. Academic level of the most senior operator of the treatment plant		
3. Length of service in present water-treatment plant		
4. Total experience in water treatment		
XIV. Complaints received		
1. From operations:	……………………………..	
2. From management:	……………………………..	
XV. Problems (if any) with:		
1. Pre-sedimentation:	Y/N	
2. Aeration:	Y/N	
3. Coagulation and flocculation:	Y/N	
4. Sedimentation:	Y/N	
5. Filtration:	Y/N	
6. Disinfection:	Y/N	
7. Other processes:	Y/N	
8. Process control:	Y/N	
9. Record keeping:	Y/N	
10. Maintenance:	Y/	
XVII. Remedial measures recommended		
1. Measures to be taken immediately	…………….. ……………..	
2. Measures to be taken later on	……………... ………………	
Have problems identified in the previous sanitary survey been corrected? …………………. ………………….		
Signature of Sanitary Surveyor……………………………………………………		

Annexure 8.5: Sanitary Surveillance for Piped Distribution System

1.	General Information	:	
2.	Code No.	:	Address ………………………………………………
3.	Date of visit	:	………………………………

II. Specific diagnostic information of assessment **Risk**

1.	Is there any point of leakage between source and reservoir?	Y/N
2.	If there are any pressure break boxes, are their covers unsanitary? If there is a reservoir:	Y/N
3.	Is the inspection cover unsanitary?	Y/N
4.	Are any air vents unsanitary?	Y/N
5.	Is the reservoir cracked or leaking?	Y/N
6.	Are there any leaks in the distribution system?	Y/N
7.	Is the area around the tap stand unfenced (dry stone wall and/or fencing incomplete)?	Y/N
8.	Does water accumulate near the tap stand (requires improved drainage canal)?	Y/N
9.	Are there human excreta within 10 m of the tap stand?	Y/N
10.	Is the plinth cracked or eroded?	Y/N
11.	Does the tap leak?	Y/N

Contamination risk score: 10–11 = very high; 6–9 = high; 3–5 = intermediate; 0–2 = low

III. Results and recommendations

The following important points of risk were noted: ……… (list nos. 1–11) and the authority advised on remedial action.

Signature of Sanitary Surveyor

Annexure 8.6: Water Inspection Form for Filling Stations, Tanker Trucks & Household Tanks

I. Type of facility: Filling Stations, Tanker Trucks and Household Truck		
1. General Information:	Name of the ULB………………………………………….	
2. Code No….. Address ………………………………………………………		
3. Water authority/community representative signature ………………………………………………		
4. Date of visit………………………………………		
5. Water sample taken………………….	Sample No…………….	Thermotolerant coliform grade…………
Specific diagnostic information for assessment Risk	**Risk**	
II. Tanker filling stations		
Is the chlorine level at the filling station less than 0.5 mg/litre?	(Y/N)	
Is the filling station executed from the routine Quality-control programme of the water authority?	(Y/N)	
Is the discharge pipe unsanitary?	(Y/N)	
I. Tanker trucks		
Is the tanker ever used for transporting other besides drinking water?	(Y/N)	
Is the filler hole unsanitary, or is the lid missing?	(Y/N)	
Is the delivery hose nozzle dirty or stored unsafely?	(Y/N)	
II. Domestic storage tanks		
Can contaminants (e.g., soil on the inside of the lid) enter the tank during filling?	(Y/N)	
Does the tank lack a cover?	(Y/N)	
Does the tank need a tap for withdrawal of water?	(Y/N)	
Is there stagnant water around the storage tank?	(Y/N)	
Total score of risks………/10		
Contamination risk score: 9-10 = very high; 6-8 = high; 3-5 = intermediate; 0-2 = low		
III. Results and recommendations		
The following important points of risk were noted.....................................(List nos. 1–10), and the authority advised on remedial action.		
Signature of Sanitary Inspector………………………………………………….		

Annexure 8.7: Suggested Minimum Annual Frequency of Sanitary Inspections

Source and mode of supply	Water supply agency	Surveillance agency
Gravity spring	1	1
Piped supply: groundwater sources (springs and wells) with or without treatment	1	1
Treated surface source of piped supply, with chlorination		
< 5,000 population	1	1
5,000–20,000 population	2	1
20,000–50,000 population	6	1
50,000–1,00,000 population	12	2
>1,00,000 population	24	2

Annexure 9.1: Annual Inspection of Pumping Station

Date					
Mechanical	General condition of the equipment				
	Water Pump			Sump Pump	Remarks
	No. 1	No. 2	No. 3		
1. Pump					
Bearings					
Foundation					
Coupling					
Column assembly					
Discharge head					
Valves					
Delivery piping					
Header					
Flowmeter					
2. Gates					
Gate Operating Lever (manual)					
Gate Operating Lever (motor)					
Stems					
3. Crane and Hoist					
4. Trash racks/screens					
Drive chain					
Bearings					
Gear reducers					
Belt conveyor					
Surge control					
	Electrical				
14. Motors					
15. Motor bearing					
16. Switchgear Control gear					
17. Motor control centre (MCC)					
18. Starters					
19. Cables					
20. Capacitors					
21. Substation Equipment					
Date					
Mechanical	General condition of the equipment				
	Water Pump			Sump Pump	Remarks
	No. 1	No. 2	No. 3		
General					
1. Water Levels	Elevation	Remarks			

Forebay					
Sumps					
Building and grounds	Date				
	Remarks				
1. Sump					
2. Forebay					
3. Structure					
4. Fire extinguishers					
5. Tools and cabinets					
6. Painting					
7. Caulking					
8. Grating, rails, and ladders					
9. Water system and plumbing					
10. Louvers and ventilators					
11. Windows					
12. Doors					
Remarks					

Annexure 9.2: Trouble Shooting for Centrifugal/Jet/VT/Vacuum/Submersible Pumps

(a) Centrifugal Pump

Trouble	Possible causes (Numbers as per list below)	List of causes
The pump does not deliver water. (Water not delivered to Reservoir or WTP).	1, 2, 3, 5, 6, 7, 9, 10, 15, 18, 21, 23, 26, 28, 29, 30, 31, 33, 40, 41, 42	1. Pump not fully primed, i.e., pump or suction pipe. 2. Pressure at the eye of the impeller has fallen below vapor pressure causing cavitations (Check for clogging on the suction side. If no clogging is observed, take action as against Sr. No. 3). 3. The suction lift is too high. (Reduce suction lift after calculating permissible suction lift from NPSHa and NPSHr). 4. Excessive amount of air in liquid. 5. Air pocket in suction line (Check whether any point in the suction line is above the centre line of the pump and, if so, lower the line). 6. Air leaks into the suction line. 7. Air leaks into the pump through stuffing boxes or a mechanical seal. 8. The net opening area of the foot valve is less. 9. Foot valve/strainer partially or fully clogged or silted up. 10. Suction bell mouth or foot valve insufficiently submerged. (Lower the inlet for adequate submergence for vortex-free operation as stipulated in Manual on Water Supply and Treatment). 11. Water-seal pipe clogged. 12. Seal cage improperly mounted in stuffing box, preventing sealing fluid from entering space to form the seal. 13. Circular motion in suspended suction pipe observed. (The problem indicates occurrence of vortex. Take remedial action as per C or G in Fig. 9.5). 14. Foot valve leaks.
Insufficient discharge delivered.	2, 3, 4, 5, 6, 7, 8, 9, 10, 13, 16, 17, 18, 20, 21, 23, 24, 27, 28, 29, 30, 31, 33, 39, 40, 41	
Insufficient pressure developed.	2, 3, 4, 21, 23, 24, 26, 2 7, 28, 33, 39	
The pump loses prime after starting.	4, 5, 6, 7, 10, 16, 17, 18	
The pump requires excessive power.	22, 25, 28, 33, 37, 38, 49, 53, 54, 55, 56, 58	
The stuffing box leaks excessively.	34, 36, 44, 45, 46, 47, 48, 50, 51, 52	
Gland packing has a short life.	11, 12, 34, 36, 44, 45, 46, 47, 48, 49, 50, 51, 52	
The bearing has a short life.	17, 20, 32, 34, 35, 36, 37, 39, 41, 44, 48, 51, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63	
The pump vibrates or is noisy at all flows.	10, 17, 19, 20, 22, 33, 34, 35, 36, 37, 38, 40, 41, 43, 45, 46, 47, 48, 51, 52, 53, 55, 56, 57, 58, 59, 60, 61, 62, 63, 65	
The pump vibrates or is noisy at low flow.	1, 2, 3, 9, 10, 17, 20, 21, 27, 39.	
The pump vibrates or is noisy at high flow.	25, 28	
The pump oscillates	38	

Trouble	Possible causes (Numbers as per list below)	List of causes
axially.		15. Flap of foot valve jammed.
Coupling fails.	34, 36, 38, 60, 62	16. Concentric taper in suction line causing air pocket (Replace with eccentric taper).
Pump overheats and/or seizes.	1, 2, 3, 11, 12, 17, 20, 24, 26, 27, 31, 34, 36, 37, 38, 44, 45, 46, 47, 48, 49, 50, 53, 54, 55, 56, 57, 58	17. Occurrence of vortex in intake, sump or well (Check whether all parameters for vortex-free operation are satisfied. Take recommended remedial measures as per Fig. 9.5). 18. Casing not air-tight and therefore breathing in. 19. . Short bend/elbow on suction side. 20. Inadequate clearance below suction bell mouth. (Raise bell mouth to achieve recommended clearance for vortex-free operation as per manual on water supply and treatment). 21. Speed too low for pump driven by diesel engine. 22. Speed too high for pump driven by diesel engine. 23. Wrong direction of rotation. 24. Total head of system higher than design head of pump. 25. Total head of system lower than pump design head. 26. Static head higher than shut off head of pump. 27. Pump characteristics unsuitable for parallel operation of pumps. 28. Burst or leakage in pumping main. 29. Pumping main partially or fully clogged. 30. Air trapped in pumping main. 31. Malfunctioning of line valve causing partial or full closure. 32. Capacity of thrust bearing is adequate. 33. Foreign matter in the impeller. 34. Misalignment. 35. Foundations not rigid or broken/loose foundation bolts or supporting structural member (RCC/structural steel beams) not

Trouble	Possible causes (Numbers as per list below)	List of causes
		rigid [Dismantle existing foundation and cast new foundation. Strengthen supporting RCC/structural steel beams]. 36. Pump (impeller) shaft bent. 37. Rotating part rubbing on the stationery part. 38. Pump shaft bearing (bush bearing or antifriction bearing) worn. 39. Wearing rings worn. 40. Impeller damaged. 41. Impeller locking pin or collet loose. 42. Pump shaft or transmission shaft broken. 43. Transmission shaft bent (not true). 44. Shaft or shaft sleeves worn or scored at the packing. 45. Gland Packing improperly installed. 46. The incorrect type of gland packing for operating conditions. 47. The shaft is running off the centre because of a worn bearing or misalignment. 48. Rotor out of balance, causing vibration. 49. Gland too tight, resulting in no flow of liquid to lubricate gland. 50. Failure to provide cooling liquid to water-cooled stuffing boxes. 51. Excessive clearance at bottom of the stuffing box between shaft and casing, causing interior packing to be forced into the pump. 52. Dirt or grit in sealing liquid leads to scouring of the shaft or shaft sleeve. 53. Excessive thrust is caused by mechanical failure inside the pump or by the failure of the hydraulic balancing device, if any. 54. Excessive grease or highly viscous oil in anti-friction bearing housing or lack of cooling causes excessive bearing temperature. 55. Lack of lubrication causes

Trouble	Possible causes (Numbers as per list below)	List of causes
		overheating and abnormal friction in anti-friction bearing, bush bearing, or transmission shaft bearing. 56. Improper installation of anti- friction bearing (damage during assembly, incorrect assembly of stacked bearings, use of unmatched bearings as a pair, etc.). 57. Dirt in bearings. 58. Rusting of bearing from water in housing. 59. Mechanical seal is worn out. 60. Coupling bushes or rubber spiders are worn out or wear in coupling. 61. Base plate or frame not properly levelled. 62. Coupling unbalance. 63. Bearing loose on the shaft or in housing. 64. The reflux valve (NRV) does not close to tight closure during shut down or after power failure or tripping. 65. Critical speed is close to the normal speed of the pump.

(b) Jet Pump

The troubles and causes for the centrifugal pump are generally applicable for jet pumps except for troubles regarding cavitation.

(c) V.T. Pump

Trouble	Possible Causes (Numbers as per list below)	List of Causes
The pump does not deliver water. (Water not delivered to discharging end, i.e., reservoir/WTP).	1, 3, 4, 8, 10, 11, 13, 15, 16, 17, 18, 27, 28	1. Pressure at the eye of the impeller has fallen below vapor pressure. 2. Excessive amount of air in liquid. 3. Strainer partially or fully clogged or silted up. 4. Inlet bell mouth or suction case insufficiently submerged. 5. Circular motion in suspended column
Insufficient discharge delivered.	1, 3, 4, 5, 6, 7, 8, 10, 11, 14, 15, 16, 17, 18, 19, 25, 26, 27, 48	

Trouble	Possible Causes (Numbers as per list below)	List of Causes
Insufficient pressure developed.	1, 2, 8, 10, 12, 13, 14, 15, 19, 25	pipes of V.T. pump observed. (The problem indicates the occurrence of the vortex. Take remedial action as per C or G in Fig. 9.5. If not corrected, the column pipe may crack). 6. Occurrence of vortex in intake, sump, or well. (Check whether all parameters for vortex-free operation are satisfied. Take recommended remedial measures as per Fig. 9.5). 7. Inadequate clearance below suction bell mouth. (Raise bell mouth to achieve recommended bottom clearance for vortex-free operation as per manual on water supply and treatment). 8. Speed too low for pump driven by diesel engine. 9. Speed too high for pump driven by diesel 10. Wrong direction of rotation. 11. Total head of system higher than design head of pump. 12. Total head of system lower than pump design head. 13. Static head higher than shut off head of pump. 14. Pump characteristics are unsuitable for the parallel operation of pumps. 15. Burst or leakage in pumping main. 16. Pumping main partially or fully clogged. 17. Air trapped in pumping main. 18. Malfunctioning of line valve causing partial or full closure. 19. Foreign matter in the impeller. 20. Misalignment. 21. Foundations are not rigid or broken/loose foundation bolts or supporting structural members (RCC/structural steel beams) not
The pump requires excessive power.	9, 12, 15, 19, 23, 24, 35, 40, 41, 42, 44	
The stuffing box leaks excessively.	20, 22, 30, 31, 32, 33, 34, 36, 37, 38, 48	
Gland packing has a short life.	20, 22, 30, 31, 32, 33, 34, 36, 37, 38	
The pump vibrates or is noisy at all flows.	1, 5, 6, 7, 19, 20, 21, 22, 23, 24, 25, 26, 27, 29, 31, 32, 33, 34, 37, 39, 41, 42, 43, 44, 45, 46, 47, 49, 50, 51, 52, 53, 54, 57	
The pump vibrates or is noisy at low flow.	1, 3, 4, 14, 25	
The pump vibrates or is noisy at high flow.	12, 15	
The bearing has a short life.	1, 5,6, 7, 20, 21, 22, 23, 25, 27, 30, 34, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54	
Pump overheats and/or seizes.	1, 5,6, 7, 11, 13, 14, 18, 20, 22, 23, 24, 30, 31, Or 32, 33, 34, 35, 36, 39, 40, 41, 42, 43, 44	
Coupling fails.	20, 22, 24, 29, 46, 53	
The pump rotates in the reverse direction on shutdown or after power failure or tripping.	55, 56	

Trouble	Possible Causes (Numbers as per list below)	List of Causes
		rigid. 22. Pump (impeller) shaft bent. 23. Rotating part rubbing on a stationary part. 24. Impeller shaft bearing (bush bearing) or Thrust bearing (in discharge head if the motor is VSS or thrust bearing in hollow shaft motor) worn. 25. Wearing rings worn. 26. Impeller damaged. 27. Impeller locking pin or collet loose. 28. Pump shaft or line shaft broken. 29. Line shaft bent (not true). 30. Shaft or shaft sleeves worn or scored at the packing. 31. Gland Packing improperly installed. 32. Incorrect type of gland packing for operating conditions. 33. Shaft running off centre because of worn bearing or misalignment. 34. Rotating assembly out of balance, causing vibration. 35. Gland too tight, resulting in no flow of liquid to lubricate gland. 36. Failure to provide cooling liquid to water-cooled stuffing boxes. 37. Excessive clearance at bottom of the stuffing box between shaft and casing, causing interior packing to be forced into the stuffing box. 38. Dirt or grit in sealing liquid leads to scouring of the shaft or shaft sleeve. 39. Excessive thrust is caused by mechanical failure inside the pump or by the failure of the thrust bearing. 40. Excessive grease or highly viscous oil in anti-friction bearing housing or lack of cooling causes excessive bearing temperature. 41. Lack of lubrication causes overheating and abnormal friction in anti-friction bearing, bush bearing,

Trouble	Possible Causes (Numbers as per list below)	List of Causes
		or line shaft bearing. 42. Improper installation of anti-friction bearing (damage during assembly, incorrect assembly of stacked bearings, use of unmatched bearings as a pair, etc.). 43. Dirt in bearings. 44. Rusting of bearing from water in housing. 45. Mechanical seal is worn out. 46. Coupling bushes are worn out or wear in coupling. 47. Discharge head ~~or~~ not properly levelled 48. Water leaking out from stuffing box in discharge head of V.T. Pump. 49. Screw bearings of Line shaft loose or worn out (in case of oil lubricated V.T. pump). 50. Rubber bearings (in case of water lubricated V.T. pump) worn out. 51. Spiders holding shaft enclosing tube or line shaft loose or broken. 52. Line shaft screw bearing loose in joint with shaft enclosing tube. 53. Coupling unbalance 54. Bearing loose on a shaft or in housing. 55. Pins of non-reverse ratchet striking up, a tooth is broken or worn. 56. The reflux valve (NRV) does not close to tight closure during shut down or after power failure or tripping. 57. Critical speed is close to the normal speed of the pump.

(d) Vacuum Pump

The troubles and causes for the centrifugal pump are generally applicable for vacuum pumps, except that priming is not necessary and troubles regarding cavitation are not applicable.

Normally vacuum generating capacity of the vacuum pump is limited to 600 mm of Hg, i.e., 8.13 m. Hence top of the vacuum pump should not be above 8.0 m from the water level in the sump.

(e) Submersible Pump

<table>
<tr><th>Trouble</th><th>Possible Causes (Numbers as per list below)</th><th>List of Causes</th></tr>
<tr><td>The pump does not deliver water (water not delivered to discharging end, i.e., reservoir/WTP).</td><td>2, 4, 5, 7, 10, 11, 12, 22, 23</td><td rowspan="7">1. Excessive amount of air in liquid.
2. Suction case was insufficiently submerged. (Lower the pump for adequate submergence for vortex-free operation as stipulated in Manual on Water Supply and Treatment).
3. Occurrence of vortex in intake, sump, or well. (Check whether all parameters for vortex-free operation are satisfied. Take recommended remedial measures as per Fig.9.5).
4. Wrong direction of rotation.
5. Total head of system higher than design head of pump.
6. Total head of system lower than pump design head.
7. Static head higher than shut off head of pump.
8. Pump characteristics unsuitable for parallel operation of pumps.
9. Burst or leakage in pumping main.
10. Pumping main partially or fully clogged.
11. Air trapped in pumping main.
12. Malfunctioning of line valve causing partial or full closure.
13. Sandy or muddy water pumped from bore/tube well. (In case of muddy water, close delivery valve and open scour valve till clear water is pumped out. In case of sandy water, close delivery valve partially until clear water is pumped out).
14. Foreign matter in impeller.
15. Misalignment.
16. Foundations not rigid or broken/loose foundation bolts or supporting structural member (RCC/structural steel beams) not rigid.
17. Pump (impeller) shaft bent.</td></tr>
<tr><td>Insufficient discharge delivered.</td><td>2, 3, 4, 5, 8, 9, 10, 11, 12, 22</td></tr>
<tr><td>Insufficient pressure developed.</td><td>1, 4, 5, 7, 8, 9, 14, 20</td></tr>
<tr><td>Pump requires excessive power.</td><td>6, 9, 14, 18, 19, 26</td></tr>
<tr><td>Ingress of pumped water into the motor</td><td>27</td></tr>
<tr><td>Pump vibrates or is noisy.</td><td>6, 8, 14, 15, 16, 17, 18, 19, 20, 21, 22, 24, 25, 26, 27, 28, 29, 30, 32</td></tr>
<tr><td>Pump rotates in reverse direction on shutdown or after power failure or tripping.</td><td>31</td></tr>
</table>

Trouble	Possible Causes (Numbers as per list below)	List of Causes
		18. Rotating part rubbing on stationery part. 19. Pump shaft bearing (bush bearing or antifriction bearing) worn. 20. Wearing rings worn. 21. Impeller damaged. 22. Impeller locking pin or collet loose. 23. Pump shaft is broken. 24. Shaft running off centre because of worn bearing or misalignment. 25. Rotating assembly or motor/rotor out of balance, causing vibration. 26. Excessive thrust is caused by mechanical failure inside the pump or by the failure of the thrust plate/bearing. 27. Mechanical seal is worn out. 28. Wear in coupling. 29. Frame not properly levelled. 30. Coupling unbalance. 31. Reflux valve (NRV) does not close to tight closure during shut down or after power failure or tripping. 32. Critical speed is close to the normal speed of the pump.

(f) VFD Pump

Trouble	Possible Causes
Overheating	Pump operated at too high a frequency or ambient temperature is too high. Caused by inadequate ventilation, malfunctioning in cooling system, incorrect programming of the VFD settings, or overloading of the motor.
Electrical noise and interference in other electrical devices	Pump generate electrical noise, which cause interference with other electrical devices in the same system like interference with the signals from the sensors or VFD, leading to inaccurate readings or system malfunctions. Caused by poor grounding, improper wiring, or damaged cables.
Mechanical failure	Pump operated at too high frequency or if there is excessive wear and tear on the components. Caused by poor maintenance or inadequate lubrication.
Inconsistent performance	Programming is incorrect or motor is not properly calibrated. Caused by operator error or faulty sensors.
Voltage spikes	Experiencing voltage spikes, which can damage the motor or other components. Caused by power surges or lightning

Trouble	Possible Causes
	strikes, or by faulty electrical components.
Faulty display	Damaged cables or a malfunctioning display unit.
Motor vibration	Misalignment of the motor, imbalanced impellers, or worn bearings.
Operate outside of its designed specifications	Incorrect programming leading to issues such as low efficiency or reduced lifespan.
High noise level	Cavitation, loose parts, or impeller imbalance.
Low flow rate	Clogged filter, a worn-out impeller, or incorrect VFD settings.

Annexure 9.3: Trouble Shooting for Electric Motor

S. No.	Trouble	Cause	Remedy
1	**Hot bearings**	• Bent or sprung shaft • Excessive belt pull • Misalignment • Bent or damaged oil rings • Oil too heavy or too light • Insufficient oil level • Badly worn bearings • Bearing loose on shaft or in bearing housing • Insufficient grease • Deterioration of grease or lubricant contaminated • Excessive lubricant • Overloaded bearing • Broken ball or rough races	• Straighten or replace the shaft. • Decrease belt tension. • Correct coupling alignment. • Replace or repair oil rings. • Use recommended oil. The use of oil of too light grade is likely to cause the bearings to seize. • Fill the reservoir to a proper level when the motor is at rest. • Replace bearings. • Remetal shaft/housing or replace the shaft or bearing housing. • Maintain proper quantity of grease in bearing. • Remove old grease, wash bearings thoroughly with kerosene and replace them with new grease. • Reduce the quantity of grease. The bearing should not be more than two- thirds filled. • Check alignment, side thrust and end thrust. • Clean housing thoroughly and replace the bearing.
2.	**Motor dirty**	• Ventilation passage blocked. Windings are coated with fine dust or lint (dust may be cement, sawdust, rock dust, grain dust, and the like) • Bearing and brackets coated inside • Rotor winding coated with fine dust / cement	• Dismantle the entire motor and clean all windings and parts by blowing off dust and, if necessary, varnish. • Clean and wash with a cleaning solvent. • Clean and polish the slip ring. Clean rotor and varnish.
3.	**Motor stalls**	• Motor overloaded • Low voltage • Open circuit • Incorrect control resistance of wound motor resistors • Mechanical locking in	• Check for any excessive rubbing or clogging in the pump • Correct voltage to the rated value. • Fuses blown, check overload relay, starter, and push button. • Check the correct sequence. Replace broken resistors.

S. No.	Trouble	Cause	Remedy
		bearings or at air gap	• Dismantle and check bearings. Check whether any foreign matter has entered the air gap and clean it.
4.	**Motor does not start**	• No supply voltage or single phasing or open circuit or voltage too low • Motor may be overloaded • Starter or switch/breaker contacts are improper • Initial starting torque of load too high, starter • Rotor defective • Poor stator coil connection • Mechanical locking in bearings or at air gap	• Check the voltage in each phase. • Start on no load by decoupling. Check for cause of overloading. • Examine starter and switch/breaker for bad contact or open circuit. Make sure that the brushes of the slip ring motor are making good contact with the rings. • If of squirrel cage type and with auto- transformer. Change to a higher tap. • If of slip ring type, lower the starting resistance. • Check for broken rings. • Remove end shields and check end connections. • Dismantle and repair. Clean air gap if choked.
5.	**Motor runs and then stops**	• The power supply system is faulty • Overload replay trips • Mechanical locking in bearings or at air gap	• Check for loose connections or single phasing in switches, Breakers, starter, bus bars, and conductor. • Examine overload relay setting. Ensure that the relay is set correctly to about 120%–130% of load current. Check whether the dashpot is filled with the correct quantity and grade of oil. • Consult manufacturer whether suitable for design duty and load. • Dismantle and repair. Clean air gap if choked.
6.	**Motor does not accelerate to the rated speed.**	• Voltage is too low at motor terminals because of line drop • Improper connection • Broken rotor bars	• Check voltage, change tapping on the transformer. • Check that all brushes are ridings on rings. Check secondary connections. Leave no lead poorly connected. • Look for cracks near the rings.
7.	**Motor**	• Excess loading	• Reduce load. (Note that if the

S. No.	Trouble	Cause	Remedy
	takes too long to accelerate.	• Timer setting of the starter is not correct • Defective squirrel cage rotor • Applied voltage too low	motor is driving a heavy load or is starting up a long line of shafting, acceleration time will be more). • Check whether the timer setting of star-delta or autotransformer starter is less than the acceleration time required for the torque of driven equipment. • Replace with the new rotor. • Correct the voltage by changing the tap on the transformer. If voltage is still low, take up the matter to the power supply authority.
8.	**Wrong rotation**	• Wrong sequence of phases	• Interchange connections of two leads at the motor or switchboard for two phases.
9.	**Motor overheats while running**	• Check for overload • End shields may be clogged with dust, preventing proper ventilation of the motor • Motor may have one phase open • Unbalanced terminal voltage • Weak insulation • High or low voltage • Rotor rubs on stator bore	• If overloaded, check and rectify the cause for overloading. Overloading may be due to system fault, e.g., if the pipeline bursts, the pump may be operating at a low head, causing an overload of the motor. Vortices in the sump also may cause overload. • Blow off dust from the end shields. • Check to make sure that all leads are well connected. • Check for faulty leads, connections from the transformer. • Check insulation resistance, examine and revarnish or change insulation. • Check the voltage of motor and correct it to the extent possible. • Replace worn bearings. • Check for the true running of the shaft and rotor.
10.	**Motor vibrates after connection s have been made**	• Motor misaligned • Weak foundations or holding down bolts loose. • Coupling out of balance • Driven equipment unbalanced	• Realign. • Strengthen base plate/foundation; tighten holding down bolts. • Balance coupling. Balance rotating elements of driven equipment on a dynamic balancing machine.

S. No.	Trouble	Cause	Remedy
		• Defective ball or roller bearings • Bearings not in line • Rotor unbalanced • Single phasing. • Excessive end play • Resonance from supporting structure or foundation or vibration of adjoining equipment	• Replace bearing. • Line up properly. • Rebalance rotor on a dynamic balancing machine. • Check for an open circuit in all phases. • Adjust bearing or add a washer. • Seek consultation from an expert.
11.	**Unbalanced line current on the polyphase motor during normal operation**	• Unbalanced terminal voltage • Single phase operation • Poor rotor contacts in control wound rotor resistance • Brushes are not in a proper position in the wound rotor	• Check leads and connections. • Check for open contacts or circuits in all phases. • Check control devices. • See that brushes are properly seated.
12.	**Scraping noise**	• Fan rubbing air shield or striking insulation • Loose on the bed plate	• Check for cause and rectify. • Tighten holding down bolts
13.	**Magnetic noise**	• Air gap is not uniform • Stator stamping loose • Loose bearings • Rotor unbalance • Crack in rotor bar	• Check and correct bracket fits or bearing. • Retighten stamping. • Correct or replace the bearing. • Rebalance on a dynamic balancing machine. • Replace.
14.	**Motor sparking at slip rings**	• Motor may be overloaded • Brushes may not be of the correct quality and may not be sticking in the holders • Slip ring dirty or rough • Slip rings may be ridged out of turns.	• Reduce the load. • Use brushes of the grade recommended and fit properly in the brush holder. • Clean the slip rings and maintain in smooth glossy appearance and free from oil and dirt. • Turn and grind the slip rings or in a lathe to a smooth finish.
15.	**Leakage of oil or grease on winding**	• Thrust- bearing oil seal damaged. • Excessive oil, grease in bearing.	• Clean the spilled oil on winding. Replace the oil seal. • Reduce quantity to the correct extent. Grease should be filled up to a maximum two-third space in bearing housing.

Annexure 9.4: Trouble Shooting for Capacitors

S. No.	Trouble	Cause	Remedy
1.	**Leakage of heclor***	• Leaking welds and solders • Broken insulators	• Repair by soldering. • Replace insulators.
2.	**Overheating of unit**	• Poor ventilation • Overvoltage	• Arrange for circulation of air either by reinstalling in a cooler and ventilated place or arrange for proper ventilation. • Reduce voltage, if possible. Otherwise, switch off capacitors.
3.	**Current below normal value**	• Low voltage • Element fuses blown • Loose connections	• Correct the voltage. • Replace capacitor. • Tighten carefully.
4.	**Abnormal bulging**	• Gas formation due to internal arcing	• Replace the capacitor
5.	**Cracking sound**	• Partial internal faults	• Replace the capacitor.
6.	**HRC Fuse blowing**	• Short, external to the units • Over-current due to over-voltage and harmonics • Short circuited unit • kVAR rating higher	• Check and remove the short. • Reduce the voltage and eliminate harmonics. • Replace the capacitor. • Replace with the bank of appropriate kVAR.
7.	**Capacitor not discharging**	• Discharge resistance low	• Correct or replace the Discharge resistance.
8.	**Unbalanced current**	• Insulation or dielectric failure	• Replace capacitor unit.

* Leakage of Heclor from terminals, insulators or lid, etc., is not a serious trouble. After cleaning, the nuts should be tightened carefully, Araldite shall be applied if necessary, and the capacitor should be put into the circuit. If the leakage continues, refer the matter to the manufacturer.

Annexure 9.5: Trouble Shooting for Starters, Breakers, and Control Circuits

S. No.	Trouble	Cause	Remedy
1.	**Starter/breaker not switching on**	• Non-availability of power supply to the starter/breaker • Overcurrent relay operated • Relay reset is not operating • Castle lock is not locked properly	• Check the supply. • Reset the relay • Clean and reset relay. • Remove the lock and lock it properly.
2.	**Starter/breaker not holding at ON-Position**	• Relay contacts are not contacting properly • Latch or cam is worn out	• Check and clean the contacts. • Readjust latch and cam.
3.	**Starter/breaker tripping within short duration due to operation of overcurrent relay**	• Overcurrent relay setting incorrect • Moderate short circuit on the outgoing side • No or less oil in dashpot • Dashpot oil is not of proper grade • Sustained overload • Loose connection	• Check and reset to120%–130% of normal load current. • Check and remove the cause of the short circuit. • Fill oil up to the level mark. • Check and use oil of the correct grade. • Check the overcurrent setting. • Check for short circuits or earth faults. • Examine the cause of overload and rectify it. • Clean and tighten.
4.	**Starter/breaker not tripping after overcurrent or short circuit fault occurs**	• Lack of lubrication to the mechanism • Mechanism out of adjustment • Failure of latching device • Mechanical binding • Relay was previously damaged by a short circuit • Heater was assembled incorrectly • Relay not operating due to: • Blown fuse • Loose or broken wire	• Lubricate hinge pins and mechanisms. • Adjust all mechanical devices, i.e., toggle stops, buffers, and springs, as per the manufacturer's instructions. • Examine surface, clean, and adjust latch. If worn or corroded, replace it. • Replace overcurrent relay. (and heater, if provided) • Replace the overcurrent relay and heater. • Review installation nstructions and correctly instal the heater assembly. • Replace fuse.

S. No.	Trouble	Cause	Remedy
		• Relay contacts damaged or dirty • Damaged trip coil • C.T. damaged	• Repair faulty wiring; ensure that all screws are tight. • Replace damaged contacts. • Replace coil. • Check and repair/replace.
5.	**Overheating**	• Poor condition of contacts. • Contacts out of proper alignment • Contacts are burnt or pitted • Loose power connection • Sustained overcurrent or short circuit/earth fault • Poor ventilation at the location of starter / breaker	• Clean and polish contacts. • Align the contacts. • Clean the contacts with smooth polish paper, or if badly burnt/pitted, replace contacts. (Contacts shall be cleaned with smooth polish paper to preserve faces. The file should not be used.) • Tighten the connection. • Check cause and rectify. • Improve ventilation.
6.	**Overheating of auto transformer unit**	• Winding design improper • Transformer oil condition poor	• Rewind. • Replace transformer oil in auto-transformer unit.
7.	**Contacts chatter**	• Low voltage • Poor contact in the control circuit • Defective or incorrect coil	• Check voltage condition. Check momentary voltage dip during starting. Low voltage prevents magnet sealing. Check coil voltage rating. • Check the push button station, (stop button contacts), auxiliary switch contacts and overload relay contacts and test with a test lamp. • Check for loose connections in control circuits. • Replace coil. Rating should be compatible with system nominal voltage.
8.	**Contacts welding**	• Abnormal inrush of current • Low voltage prevents the magnet from sealing • Short circuit	• Check for grounds and shorts in the system as well as other components such as the circuit breaker. • Check and correct voltage. • Remove short circuit faults and ensure that fuse or circuit breaker ratings are correct.

S. No.	Trouble	Cause	Remedy
9.	**Short push button and/or overheating of contacts**	• Filing or dressing • Interrupting excessively high current • Discoloured contacts caused by insufficient contact pressure, loose connections, etc. • Dirt or foreign matter on the contact surface • Short circuit	• Do not file silver tips. Rough spots or discolouration will not harm tips or impair their efficiency. • Check for short circuit, earth fault, or excessive motor current. • Replace contact springs, and check contact for deformation or damage. Clean and tighten connections. • Clean with carbon tetrachloride. • Remove fault and check fuse or breaker rating whether correct.
10.	**Coil open circuit**	• Mechanical damage • Burnt out coil due to overvoltage or defect	• Examine and replace carefully. Do not handle coil by the leads. • Replace coil.
11.	**Magnets and other mechanical parts worn out / broken**	• Too much cycling • Dust and dirt or mechanical abuse	• Replace part and correct the cause of damage.
12.	**Noisy magnet (humming)**	• Defective coil • Magnet faces not mating correctly • Dirt oil or foreign matter on magnet faces • Low voltage	• Replace coil. • Replace magnet assembly. Hum may be reduced by removing magnet armature and rotating through 180°. • Clean magnet faces with carbon tetrachloride. • Check system voltage and voltage dips during starting.
13.	**Failure to pick up and/or seal**	• Low voltage • Coil open or shorted • Wrong coil • Mechanical obstruction • Poor contact in the control circuit	• Check system voltage and voltage dips during starting. • Replace coil. • Check coil voltage rating, which must include system nominal voltage and frequency. • With power off, check for free movement of contact and armature assembly. Remove foreign objects or replace the contactor. • Check and correct.
14.	**Failure to drop out**	• Gummy substances on pole faces or in the mechanism • Voltage not removed	• Clean with carbon tetrachloride. • Check the control circuit. • Replace contactor. • Replace contactor.

S. No.	Trouble	Cause	Remedy
		from the control circuit • Worn or rusted parts causing binding, e.g., coil guides, linkages • Residual magnetism is due to the lack of air gap in the magnetic path • Improper mounting of starter	• Review installation instructions and mount properly.
15.	**Failure to reset**	• Broken mechanism, worn parts, corrosion, dirt, etc.	• Replace the overcurrent relay and heater.
16.	**Open or welded control circuit contacts in over current relay.**	• Short circuit in control circuit with too large protecting fuses • Misapplication, handling too heavy currents	• Rectify short circuits in general. Fuses over a 10A rating should not be used. • Check the rating and rectify it.
17.	**Insufficient oil in breaker / starter (if oil cooled)**	• Leakage of oil	• Locate the point of leakage and rectify it.
18.	**Oil dirty**	• Carbonisations of moisture from the atmosphere	• Clean the inside of the tank and all internal parts. Fill with fresh oil.
19.	**Moisture present in the oil**	• Condensation of moisture from the atmosphere	• Clean the inside of the tank and all internal parts. Fill with fresh oil.

Annexure 9.6: Trouble Shooting for Transformer

Sl. No.	Fault	Trouble Shooting Procedure	Cause	Remedy
1.	**Abnormal noise**	Listen to noise at various points of the transformer and find out the exact location by means of a solid piece of wood or insulating materials placed on the body of the transformer tank at various points. This helps in determining whether the noise originated from the inside of the transformer or is an external noise	a) External Noise: A loose fixing bolt/nut of the transformer b) Noise originating from inside: i) Small transformer; the noise may be possibly due to the windings having become slightly slack ii) Big transformer (Local repair not advised)	a) Tighten the fixing bolts and nuts and such other loose metallic parts. b) i) In the case such facilities are available, open the transformer and rectify any slackness by placing shim of insulated boards. If facilities are not available, take action as per (ii) below. ii) In the case of a big transformer, it is advised to contact the Manufacturer or Transformer Repairer or Expert Electrical Engineer.
2.	**High Temperature**	The temperature rise of the transformer during 10-24 hours of operation is observed. The input current and oil temperature are noted at intervals of half an hour and tabulated.	a) Transformer is overloaded. b) Transformer room is not properly ventilated. c) Dielectric strength of transformer oil low. d) Certain turns in the winding are short-circuited. The transformer has a major defect.	a) Reduce the load to the rated load. b) Improve the ventilation of the transformer to achieve effective air cooling. c) Filter transformer oil and improve dielectric strength to 40 kV minimum. d) Major repairs are necessary and should be taken up in consultation with an experienced Electrical Engineer and transformer repairer.

Sl. No.	Fault	Trouble Shooting Procedure	Cause	Remedy
		• The transformer becomes hot in a relatively short period, transformer oil escapes from the conservator, or there is even the appearance of gas. In the case of built-in Buchholz relay, accumulation of inflammable. Gas accompanied by the Alarm signal of the relay. • Abnormal heating of one terminal	e) Poor termination either inside or outside the transformer.	Take action for major repairs in consultation with an experienced Electrical Engineer and transformer repairer. a. External contacts should be checked up and put in order, especially in the aluminium bus bars. b. If heating persists, action for major repairs should be taken in consultation with an experienced Electrical Engineer.
3.	**Tripping of the circuit breaker or blowing of fuses.**	-	a) Short circuit in the windings. b) Damage in the insulation of the winding of one terminal.	Action for major repairs should be taken in consultation with an experienced Electrical Engineer and transformer repairer.
4.	**Buchholz relay contains only air. switch**	-	Due to leakage, the transformer has lost so much oil that even the conservator and	a) Locate the leakage, switch off the Transformer leakage socket, and weld the transformer tank or replace the packing.

Sl. No.	Fault	Trouble Shooting Procedure	Cause	Remedy
			Buchholz relay are drained off.	b) Fill with dry oil till the oil level appears on the oil level indicator. All terminals should be properly cleaned before switching on.
5.	**Frequent change of silica gel colour**	-	a) Breather leakage b) Breather oil level low c) Absorption of moisture completely	a) Replace packing. b) Check oil seal. Top up oil level. c) Moisture to be removed.
6.	**Oil leak at joints/bushing/drain valve**	-	a) Defective packing b) Loose tightening c) Uneven surface d) Bushing cracked e) Drain, valve not fully tight	a. Replace packing. b. Tighten properly. c. Check and correct it. d. Replace bushing along with a washer. e. Tighten valve and plug.
7.	**Low insulation resistance**	-	a) Moisture absorption by winding b) Contaminated oil c) Presence of sludge	a) Heat the windings by operating the transformer on no-load, and check whether insulation resistance improves. If no improvement is observed after operation for five to six hours, filter the oil. b) Replace with proper oil. c) Filter or replace the oil.
8.	**Water inside tank**		a) Defects of joints b) Moisture condensation c) Oil mixed with water when topping up	a) Rectify the defect. b) Drain water and dry the moisture from winding. c) Heat the winding on no-load. Recheck dielectric strength and filter if necessary.
9.	**Overheating of cable ends**		a. Loose connections	Check and tighten the ions.

Sl. No.	Fault	Trouble Shooting Procedure	Cause	Remedy
	and cable terminals			
10.	**Neutral ground conductor (earth strip) burnt.**		a) Loose connections b) Heavy fault current	Replace the grounding conductor.

Annexure 9.7: Trouble Shooting for Air Compressor

Problem	Cause	Solution
Compressor will not operate.	1. No electrical power 2. Dirty contacts	Turn on the power. Push the reset button. Tighten connections. Clean all the contacts.
	3. Low oil level	Check oil level. Replace oil if necessary.
	4. Pressure switch is not making contact	See pressure switch adjustment.
	5. Pressure in the tank is below the cut-in pressure	See pressure switch adjustment. Replace the pressure switch with one that has a lower cut-in PSI.
Excessive noise in operation.	1. Loose pulley, flywheel, belt, belt guard, cooler, clamps or accessories	Tighten any loose ends.
	2. Lack of oil in the crankcase	Check for possible damage to bearings. Replenish the oil level.
	3. Piston hitting the valve plate	Remove the compressor cylinder head and inspect for foreign matter on top of the piston. Add a new gasket and reassemble the head.
	4. Compressor floor mounting loose	Tighten the bolts on the air compressor. It may also be a good idea to replace vibration pads.
	5. Defective crankcase	Repair or replace.
	6. Excessive crank end play	Adjust and shim properly.
Knock - same cycle as R.P.M.	1. Main bearings	Replace bearings.
	2. Connecting rod bearings	Replace rod.
	3. Loose flywheel	Tighten.
Knock occurs while the compressor is loading.	1. Connecting rod bearings	Replace rod.
	2. Wrist pins, wrist pin bearings	Replace piston assembly.
	3. Loose connecting rod nut	Tighten.
Excessive oil consumption.	1. Restricted air intake	Clean or replace the air filter.
	2. Oil leaks	Tighten bolts or replace the gasket.
	3. Worn piston rings	Replace rings.

Problem	Cause	Solution
	4. Wrong oil viscosity.	Drain oil, and refill with oil of proper viscosity.
	5. Compressor tilted too much.	Level compressor. Vibration pads may help with this.
	6. Scored cylinder.	Replace cylinder.
Oil in discharge air.	1. Compressor air intake restricted.	Clean or replace air filters.
	2. Worn piston rings.	Replace rings.
	3. Excessive oil in the compressor.	Drain down to the full mark on the sight gauge.
	4. Wrong oil viscosity.	Check viscosity.
	5. Piston rings installed upside down.	Replace crankshaft.
Compressor vibrates.	1. Mounting bolts loose.	Tighten.
	2. Compressor not properly mounted.	Level compressor so that all feet touch the floor before tightening down.
	3. Pulley and flywheel misaligned.	Realign.
	4. Belts loose.	Tighten belts.
	5. Bent crankshaft.	Replace crankshaft.
Air blowing out of the inlet.	1. Broken first stage inlet valve.	Replace valve plate assembly.
Insufficient pressure at the point of use.	1. Leaks or restrictions.	Check for leaks or restrictions in hose or piping repair.
	2. Restricted air intake.	Clean or replace the air filter element.
	3. Slipping belts.	Tighten belts.
	4. Service hose too small.	Replace with a larger hose.
	5. Excessive air requirement.	Limit air usage to compressor capacity by using fewer or smaller tools.
The receiver does not hold pressure when the compressor is unloaded.	1. Faulty check valve.	Bleed tank! Disassemble, check valve assembly, and clean or replace faulty parts.
Excessive belt wear.	1. Pulley out of alignment.	Realign motor pulley with compressor flywheel.
	2. Belts too tight.	Adjust tension.
	3. Belts too loose.	Adjust tension.
	4. Pulley or flywheel wobble	Check for the worn crankshaft, keyway, or pulley bore resulting from running with loose pulleys. Check for the bent crankshaft.

Problem	Cause	Solution
	5. Nick in belt groove of pulley or flywheel	File smooth.
Excessive discharge air temperature.	1. Dirty cooling surfaces	Clean cooling surfaces of the cylinder, intercooler, and discharge tube.
	2. Poor ventilation	Improve ventilation or relocate compressor.
	3. Blown head gasket	Replace the head gasket.
	4. Restricted air intake	Clean or replace the air filter element.
	5. Worn valves	Replace valve plate assembly.
Air leaking from the inter-stage safety relief valve when the compressor is pumping.	1. Safety relief valve not functioning properly	Remove and install a new safety relief valve. If new safety valve leaks, remove the cylinder head and inspect and clean the reed valve assembly.
	2. Leaky gasket – High- pressure inlet valve	Replace gasket.
Receiver pressure builds up slowly.	1. Dirty air filter	Clean or replace filter element.
	2. Blown cylinder head gasket	Install new gasket.
	3. Worn or broken low- pressure intake or discharge valves	Install new valve plate.
	4. Air leaks	Tighten joints.
	5. Loose belts	Tighten or replace belts.
	6. Speed too slow	Check speed.
Receiver pressure builds up quickly on the compressor.	1. Excessive water in the receiver	Drain receiver/tank.
	2. Speed too fast	Check speed.
Reset mechanism cuts out repeatedly; fuses of proper size blow.	1. Motor overload	Shut down immediately to avoid damage.
	2. Malfunction or improperly adjusted	Adjust or replace.
	3. High ambient temperature	Provide ventilation.
Fuses blow repeatedly.	1. Wrong fuse size	Check to make sure that fuses are of proper ampere rating.
Compressor suddenly stops working	1. Bad unloader valve	Replace the unloader valve.
	2. Loss of power	Plug compressor into a new power source.
Pipe rattle	• Inadequately supported piping or loose pipe	• Support pipes or check pipe connections.

Problem	Cause	Solution
	connections • No muffler in the discharge line • Or muffler improperly located	• Install or move the muffler closer to the compressor.
Compressor will not load.	• Low oil pressure • Capacity control valve struck open • Unloader element struck	• Take actions as stipulated below for the problem: Oil pressure lower than normal or no oil pressure. • Repair or replace. • Repair.
Oil pressure lower than normal or no oil pressure.	• Low oil charge • Faulty oil gauge • Defective oil pressure regulator • Clogged oil suction strainer • Broken or worn oil pump • Worn compressor bearings	• Add oil. • Check and replace. • Repair or replace. • Clean. • Replace pump assembly. • Replace.

Annexure 11.1: Case Study – Water Loss Reduction in Bangalore City

Background

Bangalore, the information technology centre of India has seen a massive growth in its population in last three decades. The city needs 1620 MLD to serve its 12 million residents. This water demand is fulfilled through two sources. The city receives 1440 MLD water from River Cauvery and the rest of the demand is met through ground water from deep borewells installed by residents in their properties.

The city water supply system has a history of over 120 years. Bangalore Water Supply and Sewerage Board (BWSSB) constituted in the year 1964 had taken over the then existing system and has been active since in covering the length and breadth of the city with piped network to distribute treated surface water. BWSSB has created and managed one of the finest infrastructures in India for treatment, pumping and transfer of treated water from River Cauvery to Bangalore City. It currently manages over 8750 km water pipeline network serving over 10 lakh customers.

While there are varying estimates for the total water loss in the system between the source and customer tap, all suggest a loss between 35%–40%. Very old leaking pipelines in the core city areas and high density of connections laid out in congested narrow city lanes, pose tremendous challenge in reducing losses. The BWSSB administration realised much early, the importance of conserving water and has implemented major scheme for reducing water losses in the distribution system. BWSSB was among the first utilities in the country to introduce water metering. The organisation has robust water metering programme with efficient meter reading, billing system. It generates sizable revenue from volumetric water tariff in domestic and non-domestic categories, which also helps reduce consumption and wastage. With bulk water meters installed at various levels in the supply system, there is a reliable estimation of losses which help undertake control measures.

Water loss reduction measures

The first pilot project to reduce water losses was implemented between 2003–2006 in the city's central business district under Cauvery Stage 4 Phase I scheme financed by the Japanese International Co-operative Agency (JICA). The UFW loss reduction and control and water distribution system rehabilitation project covered 370 Kms pipeline network and roughly 32000 connections in 16 sq. km area. A template for systematic study, measurement, reduction, and control of water losses was established through this pilot project. First, the entire pipeline network was surveyed, traced, and mapped on a geographical information system. The data accuracy was improved through field works, testing and record updates as the work on UFW reduction progressed. Based on the mapped information, DMA were designed and constructed, a concept globally accepted and recommended to measure water losses and take up reduction measures in distribution network. Hydraulically discrete DMA boundaries allowed accurate measurement of flows into and out of the DMA, consumption within the DMA boundary to calculate UFW which is the difference between the water supplied and consumption. Water balance as per International Water Association (IWA) methodology and estimation of real and apparent losses was carried out to prioritise reduction measures in each DMA. Active leakage control with detection and repair of visible and invisible leaks, customer meter testing and replacement, leaky pipeline and house service connection replacement, detection and control of unauthorised consumption was undertaken while continuously monitoring reduction in leakage and UFW levels. The leakage level was reduced from 56% to 26% while the UFW was reduced from 64% to 38% in the pilot project area within a period of 40 months.

Important insighted were gained in the pilot project based on which BWSSB framed major policies. First was to replace all cast iron pipe of size below 100 mm and non- metallic pipes with new Ductile Iron pipes. The old cast iron pipes were found to be heavily clogged from inside due to deposits and corrosion and had badly leaking lead joints. Second, new age Medium Density Polyethylene (MDPE) pipes were introduced for replacement of galvanised iron (GI) house service connections. Third, all meter in service beyond seven years were decided to be replaced with standard Class B rating brass body multi-jet type meters.

Following success of the pilot project, BWSSB introduced three more projects between 2012–2014 for reducing UFW in the South, West and Central Zones. These were financed under Cauvery Stage 4 Phase II scheme financed by JICA. These projects covered 133 sq. km and about 300,000 connections in the core city zones. The water loss reduction scope and methodology were similar to the pilot project. The works in all these projects were completed by 2018, maintenance of DMAs and leakage reduction works by the respective contracting agencies has continued till 2022. The current average UFW level in these projects is 23% and reducing further. BWSSB has initiated similar UFW reduction project in part of Northeast Zone covering 25 sq. km where works are in progress.

BWSSB in 2015 took up helium tracer gas based hidden leak detection project in the East and Southeast zones. It covered 1750 kms network in 65 sq. km area. The unique technique detects leaks flowing underground which are very difficult detect and pinpoint. Such leaks go undetected and continue to flow for long years. The technology claims over 90% accuracy in finding and pinpointing hidden leaks. Other competitive technologies based on acoustics fail in low pressure, noisy conditions in water pipe networks as prevailing in Bangalore. BWSSB had very good success in resolving contamination complaints by tracing the exact source using helium leak detection method. The overall impact of just leak detection and repair works is estimated to be 20% reduction in UFW level.

UFW reduction and control is a continuous process. The city is seeing major advance in providing reliable daily water supply coverage to all areas. It is planned with a mix strategy of increasing supply through augmentation of treatment and transfer capacity on one hand and reducing losses in the system on the other.

Annexure 11.2: Various Case Studies related to NRW Reduction Spot Billing Initiative (Hyderabad, India)

In order to encourage meter readers to generate water bills on time, the **Hyderabad Metro Water Supply and Sewerage Board**, in Hyderabad (India), introduced a spot billing scheme for billing its water connections (Year 2001) and has outsourced the billing function to a private party that has relevant experience in such practices and, through handheld data logger machines, can generate bills on the spot and deliver them to customers as well. The scheme has been in operation for about 70% of the Board's service area.

Spot billing had been a success, with the billing cycle being reduced from three weeks to one day, resulting in increased cash flow.

Employee Incentives and Addressing Community Behaviour (Phnom Penh, Cambodia)

In Phnom Penh, the public utility was able to reduce NRW by 91% in 15 years through strong commitment and a comprehensive network replacement and physical loss reduction programme. On top of that, simple but unique measures were taken to reduce commercial losses. For example, if a meter reader of an area did not, or could not, find an illegal connection, but one of his colleagues did, the colleague received a reward, and the meter reader was penalised.

The public was also made aware of the problem of illegal connections. Those customers found to have illegal connections were heavily penalised, and anyone who reported an illegal connection was rewarded. Inspection teams were set up to search for, find, and eliminate illegal connections. As a result of these and other actions, the number of illegal connections discovered dropped from an average of one per day to less than five per year by 2002. At present, it is highly unusual to find even one illegal connection

Employee Incentives (Hyderabad, India)

The Hyderabad Metro Water Supply and Sewerage Board has been concentrating on incentivising its staff for ensuring timely collection of bills. One of the initiatives was collection drivers on meter readers, where meter readers were rewarded US$0.025 per bill for collections made manually. Meter readers were also incentivised for collecting bills from 'Never Paid Customers' through financial rewards of 3% of total collections made from these customers. The Board has about 40,000 customers who have never paid their water bill and who are located mostly in circles I and II in the walled city area. As of 2005, the Board has been able to collect about US$2.5 million across two years with collections from about 10,000 consumers.

Meter readers have also been set collection targets, based on current demand estimates and arrears. Meter readers are incentivised to meet these revenue targets since the chief minister of the state awards the best performing circle and division for revenue collection. To generate competition internally within the circle, the chief general manager of each individual circle ranks the divisions according to their achieved revenue realisations. Some chief general managers also monitor revenue collections for each O&M division under them on a daily basis. Indicators like daily revenue targets and the number of consumers to be contacted daily are monitored regularly. The Water Board set a collection target of US$0.4 million for O&M division VII for 2005. As of May 2005, the actual collections for the entire division were US$0.23 million, which then increased to US$0.29 million in June 2005 as a result of these initiatives.

Employee Incentives (Bangalore, India)

The BWSSB has implemented some measures for streamlining its billing practices. In a typical month, the first half of the month is reserved for billing practices with the balance month reserved for collection initiatives. There are approximately 250 meter readers, each responsible for 1,000–1,500 connections

Reading is to be done on a fixed day for every household, and if the meter reader is unable to read the meter, it is indicated on the bill and the household is charged on the basis of average consumption over the last six months. Billing on a prefixed date also ensures that the concerned household knows that it will receive its bill on that particular day. At the time of meter reading, the reader also checks whether the meter is in working condition or not, reporting the status on the water bill. Typically, readings get translated into a household water bill on the third day from the day the meter has been read.

Once bills are generated, meter readers at the Bangalore Water Board are expected to ensure that the consumers pay their bill on time. The divisional head (executive engineer) at each Bangalore Water Board division level also sets specific collection targets for meter readers, on the basis of current demand plus 10%–15% of arrears.

Constant monitoring by the divisional head ensures that meter readers meet their collection targets. The divisional heads also use the threat of transfer for ensuring that revenue performance is up to the mark.

While this practice has been found to be successful in incentivising meter readers for improving collections in the cities of Bangalore and Hyderabad, this is not necessarily a best practice that could be replicated elsewhere. Such practices could turn out to be dangerous for the utility or service provider since meter readers could be robbed after a day's collection.

Integrated Meter Management

In the past, the responsibilities for metering-related activities were scattered throughout the organisation of Maynilad Water Services Inc. As a result, metering efforts and resources (e.g., data loggers, service vehicles, and meters) were often uncoordinated and insufficient. With the establishment of the IMM department and its integration in the Central NRW Division, Maynilad now has a one-stop-shop for all metering issues. The IMM department is a young team of highly specialised engineers responsible for all metering related issues—from the smallest customer meters to the largest raw water bulk meters.

Connecting Poor Populations (Bangalore, India)

In Bangalore (in the state of Karnataka, India) the water utility, the BWSSB, mobilised low-income communities and successfully helped them connect to the network through innovative means such as subsidised connection fees, options for group connections, and simplified and easy methods for application for a new connection. The initiative was partnered with AusAID during 2000–2002; the project's Community Development Component examined and tested options for improving service delivery to urban poor populations in three pilot slums including Cement Huts, Sudhamanagar, and Chandranagar.

Nearly 850 connections (individual and shared) were installed during the pilot phase. After successful implementation of the pilots, the Board decided to replicate the results in other slums. Today about 6,000 connections across 46 slums in the city are served with water. They receive bills and make payments willingly for getting an improved and reliable service. By connecting all slums to piped water, the Board is reducing its nonrevenue water component and hopes to slowly phase out the 15,000+ public taps that operate within city limits.

One-Time Settlement Scheme (Hyderabad, India)

The Hyderabad Metro Water Supply and Sewerage Board devised an incentive scheme for its customers through its One-Time Settlement scheme. This applied to customers who had huge arrears in their bills. A close look at the billing statistics of the Board revealed that there were as many as 0.28 million customers who had not paid their water cess to the Board.

To encourage customers to settle their arrears, the Board launched the scheme in June 2004, giving a discount of 10% to those who would pay their water cess arrears upfront. Alternatively, an instalment facility of 10 instalments was made for those who could not make upfront payments of arrears all at one time. There was a huge response to the scheme with a record collection of US$4.71 million in June 2004, the highest-ever recorded in the history of the Board. The scheme, which was due to expire in August 2004, was later extended till September 2004. The collection in September 2004 was also high, totalling US$4.16 million and an all-time high of 0.16 million customers.

Credible Disconnection Policy (Manila, Bangkok, Bangalore, and Hyderabad)

Manila Water has a credible disconnection policy whereby customers who are in arrears for 60 days after a due date are given warning notices prior to disconnection. As of December 31, 2004, about 63,837 connections had been disconnected. Of these disconnections, about 70% were later reconnected.

Bangkok-based **Metropolitan Waterworks Authority** has a credible disconnection policy in place for unpaid bills. A customer is given 12 days to pay the bill, after which a duplicate copy is sent as a reminder. In case the bill still remains unpaid for the next 15 days, the inlet valve is sealed and a fine of US$3.35 is imposed. In case the bill is still unpaid for the next 15 days, the meter is taken off and a fine of 10% of the connection fee is imposed. In case of further non-payment for the next three months, the customer will have to apply for reconnection and pay a fine of 25% of the connection fee. For any time period beyond this, the case is considered as a new connection and the customer would need to pay fresh connection fees for taking a connection.

In Bangalore, the water utility, **BWSSB**, has a disconnection policy whereby connections are initially clamped off at the street level, after which legal notices are sent. In the event that no action is taken, the Board could resort to disconnection. While this policy does exist, the Board does admit that it is not used very often.

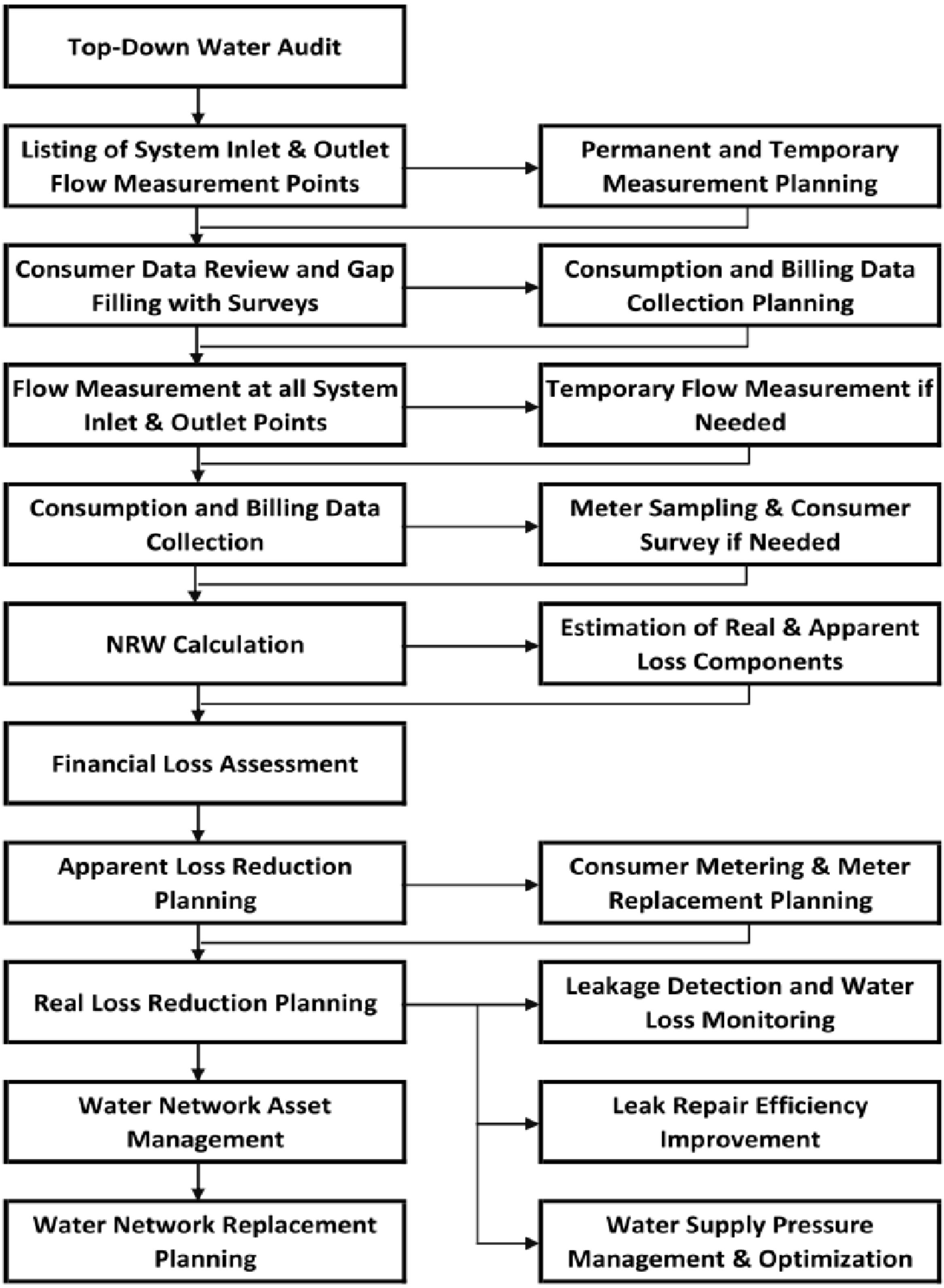
In Hyderabad, too, a disconnection policy for penalising customers who either default on payment or have tampered with their meters is in place. A fine of US$1.25 per month has been imposed on those who have faulty meters and who have failed to repair their meters. In case of continuing default, meter readers along with disconnection staff of the **Hyderabad**

Metro Water Supply and Sewerage Board are authorised to disconnect. They sometimes also clamp the connection at the street level, and in case this does not work, then resort to disconnection. However, the Board acknowledges that its disconnection policy is not used much.

Water Adalats

Water adalats (literally, courts) are used in Hyderabad and Bangalore to resolve long-standing issues and complaints related to service delivery. Consumers are usually informed about water adalats through all the major English and vernacular newspapers; they are required to register their complaints or cases in advance to facilitate collection of required information and documents from the concerned zone or circle of the water utility so as to ensure speedy complaint resolution.

Annexure 11.3: Flow Chart for Top-Down Water Audit



Annexure 12.1: Brief Terms of Reference for Energy Auditors

A comprehensive audit provides a detailed energy project implementation plan for a facility, since it evaluates all major energy using systems.

This type of audit offers the most accurate estimate of energy savings and cost. It considers the interactive effects of all projects, accounts for the energy use of all major equipment, and includes detailed energy cost saving calculations and project cost.

In a comprehensive audit, one of the key elements is the energy balance. This is based on an inventory of energy using systems, assumptions of current operating conditions and calculations of energy use. This estimated use is then compared to utility bill charges.
Detailed energy auditing is carried out in three phases: Phase I, II and III. Phase I – Pre-Audit Phase
Phase II – Audit Phase Phase III – Post Audit Phase

A Guide for Conducting Energy Audit at a Glance

Industry-to-industry, the methodology of energy audits needs to be flexible.

A comprehensive ten-step methodology for conduct of energy audit at field level is presented below. Energy manager and energy auditor may follow these steps to start with and add/change as per their needs and industry types.

Ten Steps Methodology for Detailed Energy Audit

Step No.	Plan of Action	Purpose / Results
Step 1	Phase I – Pre-Audit Phase • Plan and Organise • Walk through Audit • Informal interview with Energy Manager, Production/Plant Manager	• Resource planning, Establish/Organise Energy Audit Team • Organise Instruments and time frame • Macro Data Collection (suitable to type of industry) • Familiarisation of process/plant activities • First hand observation and Assessment of current level operation and practices
Step 2	• Conduct of Brief Meeting Awareness programme with all divisional heads and persons concerned (2–3 hrs.)	• Building up co-operation • Issue questionnaire for each department • Orientation, awareness creation
Step 3	Phase II – Audit Phase • Primary Data Gathering, Process Flow Diagram, and Energy Utility Diagram	• Historic data analysis, baseline data collection • Prepare process flowcharts • All service utilities service diagram (Example Single line power distribution diagram, water, and compressed air and steam distribution)

Step No.	Plan of Action	Purpose / Results
		• Design, operating data, and schedule of operation • Annual Energy Bill and energy consumption pattern (Refer manual, log sheet, name plate, interview)
Step 4	• Conduct survey and monitoring	• Measurements: Motor Survey, Insulation, and Lighting survey with portable instruments for collection of more and accurate data. Confirm and compare operating data with design data
Step 5	• Conduct of detailed • trials/experiments for selected energy guzzlers	• Trials/Experiments: - 24 hours power monitoring (Maximum Demand, PF, kWh, etc.) - Load variation trends in pumps, fan, compressors, etc. - Efficiency trials for (4–8 hours) - Efficiency trials, Equipment Performance experiments, etc.
Step 6	• Analysis of Energy Use	• Energy and Material balance and energy loss/waste analysis
Step 7	• Identification and development of energy conservation (ENCON) opportunities	• Identification and consolidation Energy Conservation (ENCON) measures • Conceive, develop, and refine ideas • Review the previous ideas suggested by unit personal • Review the previous ideas suggested by energy audit if any • Use brainstorming and value analysis techniques • Contact vendors for new/efficient technology
Step 8	• Cost benefit analysis	• Assess technical feasibility, economic viability and prioritisation of ENCON options for implementation • Select the most promising projects • Prioritise by low, medium, long term measures
Step 9	• Reporting and Presentation to the Top Management	• Documentation, Report Presentation to the Top Management
Step 10	<u>Phase III – Post Audit Phase</u> • Implementation and follow up	• Assist and Implement ENCON recommendation measures and monitor the performance - Action plan, schedule for implementation

Step No.	Plan of Action	Purpose / Results
		- Follow-up and periodic review

Phase I – Pre-Audit Phase Activities

A structured methodology to carry out an energy audit is necessary for efficient working. An initial study of the site should always be carried out, as the planning of the procedures necessary for an audit is most important.

Initial Site Visit and Preparation Required for Detailed Auditing

An initial site visit may take one day and gives the energy auditor/engineer an opportunity to meet the personnel concerned, to familiarise him with the site and to assess the procedures necessary to carry out the energy audit.

During the initial site visit, the energy auditor/engineer should carry out the following actions:

- Discuss with the site's senior management the aims of the energy audit.
- Discuss economic guidelines associated with the recommendations of the audit.
- Analyse the major energy consumption data with the relevant personnel.
- Obtain site drawings where available – building layout, steam distribution, compressed air distribution, electricity distribution, etc.
- Tour the site accompanied by engineering/production.

The main aims of this visit are:

- To finalise energy audit team.
- To identify the main energy consuming areas/plant items to be surveyed during the audit.
- To identify any existing instrumentation/additional metering required.
- To decide whether any meters will have to be installed prior to the audit, e.g., kWh, steam, oil, or gas meters.
- To identify the instrumentation required for carrying out the audit.
- To plan with time frame.
- To collect macro data on plant energy resources, major energy consuming centres.
- To create awareness through meetings/programme

Phase II – Detailed Energy Audit Activities

Depending on the nature and complexity of the site, a comprehensive audit can take from several weeks to several months to complete. Detailed studies to establish, and investigate, energy and material balances for specific plant departments or items of process equipment are carried out. Whenever possible, checks of plant operations are carried out over extended periods of time, at nights and at weekends as well as during normal daytime working hours, to ensure that nothing is overlooked.

The audit report will include a description of energy inputs and product outputs by major department or by major processing function and will evaluate the efficiency of each step of the manufacturing process. Means of improving these efficiencies will be listed, and at least a preliminary assessment of the cost of the improvements will be made to indicate the expected payback on any capital investment needed. The audit report should conclude with specific recommendations for detailed engineering studies and feasibility analyses, which must then be performed to justify the implementation of those conservation measures that require investments.

The information to be collected during the detailed audit includes:

1. Energy consumption by type of energy, by department, by major items of process equipment, by end-use
2. Material balance data (raw materials, intermediate and final products, recycled materials, use of scrap or waste products, production of by-products for re-use in other industries, etc.)
3. Energy cost and tariff data
4. Process and material flow diagrams
5. Generation and distribution of site services (e.g., compressed air, steam)
6. Sources of energy supply (e.g., electricity from the grid or self-generation)
7. Potential for fuel substitution, process modifications, and the use of co- generation systems (combined heat and power generation)
8. Energy Management procedures and energy awareness training programmes within the establishment

Existing baseline information and reports are useful to get consumption pattern, production cost and productivity levels in terms of product per raw material inputs. The audit team should collect the following baseline data:

– Technology, processes used and equipment details
– Capacity utilisation
– Amount and type of input materials used
– Water consumption
– Fuel Consumption
– Electrical energy consumption
– Steam consumption
– Other inputs such as compressed air, cooling water, etc.
– Quantity and type of wastes generated
– Percentage rejection/reprocessing
– Efficiencies/yield

Data Collection Hints

It is important to plan additional data gathering carefully. Here are some basic tips to avoid wasting time and effort:

- Measurement systems should be easy to use and provide the information to the accuracy that is needed, not the accuracy that is technically possible;
- Measurement equipment can be inexpensive (flow rates using a bucket and stopwatch);
- The quality of the data must be such that the correct conclusions are drawn (what grade

of product is on, is the production normal etc.);
- Define how frequent data collection should be to account for process variations;
- measurement exercises over abnormal workload periods (such as startup and shutdowns);
- Design values can be taken where measurements are difficult (cooling water through heat exchanger).

Draw process flow diagram and list process steps; identify waste streams and obvious energy wastage

An overview of unit operations, important process steps, areas of material and energy use and sources of waste generation should be gathered and should be represented in a flowchart as shown in the figure below. Existing drawings, records and shop floor walk through will help in making this flow chart. Simultaneously the team should identify the various inputs and output streams at each process step.

Identification of Energy Conservation Opportunities

Fuel substitution: Identifying the appropriate fuel for efficient energy conversion.

Energy generation: Identifying Efficiency opportunities in energy conversion equipment/utility such as captive power generation, optimal loading of DG sets, minimum excess air combustion with boilers/thermic fluid heating, optimising existing efficiencies, efficient energy conversion equipment, biomass gasifiers, cogeneration, high efficiency DG sets, etc.

Energy distribution: Identifying efficiency opportunities network such as transformers, cables, switchgears and power factor improvement in electrical systems and chilled water, cooling water, hot water, compressed air, etc.

Energy usage by processes: This is where the major opportunity for improvement and many of them are hidden. Process analysis is useful tool for process integration measures.

Technical and Economic feasibility

The technical feasibility should address the following issues:

- technology availability, space, skilled manpower, reliability, service, etc.;
- the impact of energy efficiency measure on safety, quality, production or process;
- the maintenance requirements and spares availability.

The economic viability often becomes the key parameter for the management acceptance. The economic analysis can be conducted by using a variety of methods. Example: Pay back method, Internal Rate of Return method, Net Present Value method etc. For low investment short duration measures, which have attractive economic viability, simplest of the methods, payback is usually sufficient. A sample worksheet for assessing economic feasibility is provided below:

Sample Worksheet for Economic Feasibility		
Name of Energy Efficiency Measure		
1. Investment	**2. Annual Operating Cost**	**3. Annual Savings**
a. Equipment's b. Civil Works c. Instrumentation	a. Cost of Capital b. Maintenance c. Manpower	a. Thermal Energy b. Electrical Energy c. Raw Material

d. Auxiliaries	d. Energy e. Depression	d. Waste Disposal
Net Savings / Year (Rs./year) = (Annual saving – annual operating costs)	Payback Period in Months = (Investment/net savings/year) × 12	

Classification of Energy Conservation Measures

Based on energy audit and analyses of the plant, a number of potential energy saving projects may be identified. These may be classified into three categories:

1. Low cost – high return;
2. Medium cost – medium return;
3. High cost – high return

Normally the low cost – high return projects receive priority. Other projects have to be analysed, engineered and budgeted for implementation in a phased manner. Projects relating to energy cascading and process changes almost always involve high costs coupled with high returns and may require careful scrutiny before funds can be committed. These projects are generally complex and may require long lead times before they can be implemented. Refer table given below for project priority guidelines.

Project Priority Guideline			
Priority	**Economic Feasibility**	**Technical Feasibility**	**Risk/Feasibility**
A - Good	Well Defined and attractive	Existing Technology adequate	No Risk/High Feasibility
B – May be	Well Defined and only marginally acceptable	Existing Technology may be updated, lack of confirmation	Minor operating risk/may be feasible
C – Held	Poorly Defined and marginally unacceptable	Existing Technology is inadequate	Doubtful
D - No	Clearly not Attractive	Need major Breakthrough	Not Feasible

Energy Audit Reporting Format

After successfully carried out energy audit energy manager/energy auditor should report to the top management for effective communication and implementation. A typical energy audit reporting contents and format are given below. The following format is applicable for most of the industries. However, the format can be suitably modified for specific requirement applicable for a particular type of industry.

Report On
DETAILED ENERGY AUDIT
TABLE OF CONTENTS

1. Introduction about the plant
   1.1 General Plant details and descriptions
   1.2 Energy Audit Team
   1.3 Component of Production cost (energy, chemicals, manpower, overhead, others)
   1.4 Major Energy use and areas
2. Production Process Description
   2.1 Brief description of process
   2.2 Process flow diagram and Major unit operations
   2.3 Major Inputs, Quantity and Costs
3. Energy and Utility System Description
   3.1 List of Utilities
   3.2 Brief description of each utility
      3.2.1 Electricity
      3.2.2 Water
4. Detailed Process flow diagram and Energy and Material balance
   4.1 Flow chart showing flow rate, temperature, pressure of all input-output streams
   4.2 Energy Balance
5. Energy efficiency in utility and process systems
   5.1 Specific Energy Consumption

Efficiency assessment

   5.2 Electric Motor Load analysis
   5.3 Lighting System
6. Energy Conservation Options and Recommendations
   6.1 List of options in terms of no cost/low cost, medium cost and high investment cost, Annual Energy and Cost Savings and payback
   6.2 Implementation plan for energy saving measures/projects

Annexures

A1. List of Energy Audit Worksheets
A2. List of Instruments
A3. List of Vendors and Other Technical Details

The following Worksheets (refer Table 3.2 and Table 3.3) can be used as guidance for energy audit assessment and reporting.

Summary of Energy Saving Recommendations

S. No.	Energy Saving Recommendations	Annual Energy (Fuel and Electricity) Savings (kWh/m or kl/m)	Annual Savings Rs. Lakhs	Capital Investment (Rs. Lakhs)	Simple Payback Period
1					
2					
3					
4					
Total					

Types and Priority of Energy Saving Measures				
	Type of Energy Saving Options	**Annual Electricity / Fuel Savings**	**Annual Savings**	**Priority**
		KWh or kl/m	**(Rs. Lakhs)**	
A	No Investment (Immediate) - Operational Improvement - Housekeeping			
B	Low Investment (Short to Medium Term) - Controls - Equipment Modification - Process change			
C	High Investment (Long Term) - Energy efficient Devices - Product modification - Technology Change			

BIBLIOGRAPHY

BIBLIOGRAPHY

[CHAPTER RELEVANT BIBLIOGRAPHY]

Chapter 1: Introduction

1) US EPA, (2013*), Water Audits and Water Loss Control for Public Water Systems, https://www.epa.gov/sites/production/files/2015-04/documents/ epa816f13002.pdf*

Chapter 2: Operational Strategy

1) Maharashtra Jeevan Pradhikaran (MJP), (2012), *Module 2: Operation and Maintenance of Water Supply System*, *https://www.pas.org.in/Portal/document/ResourcesFiles/pdfs/Module_2%20Operation_maintenance%20of%20water%20supply%20system.pdf*
2) National Disaster Management Guidelines, Government of India, (2010), *Plan to Counter the Threats to Municipal Water Supply and Water Reservoirs*, https://ndma.gov.in/sites/default/files/PDF/Reports/municipal_water_pdf.pdf
3) WHO, (2021), *Guidelines for Drinking-water Quality*, *https://www.who.int/publications/m/item/guidelines-for-drinking-water-quality- 4th-ed.-incorporating-the-1st-addendum-(chapters)*

Chapter 3: Sources of Water Supply

1) CGWB, (2009), *Revised Guidelines with Amendments for Artificial Recharge of Groundwater Through Dug Wells*, *http://cgwb.gov.in/documents/AR/Revised%20Guidelines%20for%20dug%20well%20recharge.pdf / https://admin.indiawaterportal.org/sites/default/files/iwp2/revised_guidelines_with_amendments_for_artificial_recharge_to_groundwater_dug_well_recharge_scheme_cgwb_2009_10.pdf*
2) CPCB, (2019), *Indicative Guidelines for Restoration of Water Bodies*, *https://cpcb.nic.in/wqm/Ind-Guidelines-RestWaterBodies.pdf*
3) CWC Basin Planning and Management Organisation, GoI, (2006), “Evaporation Control in Reservoirs”, *http://www.old.cwc.gov.in/main/downloads/Evaporation%20Control%20in%20reservoirs.pdf*
4) Ministry of Jal Shakti, Government of India, (2021), *Drinking Water Quality Monitoring & Surveillance Framework*, *https://jalshakti- ddws.gov.in/sites/default/files/WQMS-Framework.pdf*

Chapter 5: Water Treatment Plant

1) US EPA, (1984), *Corrosion Manual for Internal Corrosion of Water Distribution Systems*, *https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=10003FIW.TXT*

Chapter 6: Raw Water and Clear Water Reservoirs

1) IIT Kharagpur, *Module 4 Hydraulic Structures for Flow Diversion and Storage*, https://nptel.ac.in/courses/105105110
2) IS 3370: *Code of Practice — Concrete Structures for the Storage of Liquids*
3) U.S. Environmental Protection Agency, (2002), *Finished Water Storage Facilities*, https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100ZM9Y.txt
4) Nevada Division of Environmental Protection, (2021), *Operations & Maintenance Plan, Guidance and Template Manual*, https://ndep.nv.gov/uploads/documents/OM_Manual_Template_June_2021.d ocx
5) U.S. Environmental Protection Agency, (2011), *Advice Note No. 10: Service Reservoir Inspection, Cleaning, and Maintenance*, https://www.epa.ie/publications/compliance--enforcement/drinking- water/advice--guidance/Advice-Note-No10.pdf

Chapter 8: Drinking Water Quality Monitoring and Surveillance

1) Central Pollution Control Board. (2007). *Guidelines for Water Quality Monitoring*.
2) Ministry of Drinking Water and Sanitation. Government of India. (2013). *Uniform Drinking Water Quality Monitoring Protocol*.
3) Central Ground Water Board. (2014). *Concept Note on Geogenic Contamination of Groundwater in India*
4) Ministry of Jal Shakti. (2021). *Drinking Water Quality Monitoring & Surveillance Framework*
5) World Health Organization. (2017). *Guidelines for Drinking-water Quality*.
6) Proceedings of the Royal Society of Medicine. Vol. 55.

Chapter 9: Pumping Station and Machinery

1) Igor J. Karassik (2008), “Pump Handbook edited by Karassik”
2) Bureau of Energy Efficiency, Pumps and Pumping System, https://www.beeindia.gov.in/sites/default/files/3Ch6.pdf
3) RVPN, “Operation & Maintenance Manual for Sub Station Equipment and EHV Transmission Lines”, http://energy.rajasthan.gov.in/rvpnl

Chapter 10: Automation of Water Sypply System

1) CPHEEO, MoHUA. Advisory on Water Metres, Instrumentation and SCADA. June 2020

Chapter 11: Water Audit, Monitoring and Control of NRW

1) ADB, (2010), *The Issues and Challenges of Reducing Non-Revenue Water*, https://www.adb.org/publications/issues-and-challenges-reducing-non- revenue-water
2) GIZ, (2022), *Comparison of Suitable Leak Detection Methods*, https://climatesmartwater.org/library/comparison-of-suitable-leak-detection-methods/GIZ, (2022), *Smart Water Management*, https://climatesmartwater.org/library/2nd-edition-smart-water-management/

3) World Bank, (2008), *Performance improvement planning: developing effective billing and collection practices*, https://documents.worldbank.org/en/publication/documents-reports/documentdetail/713571468138288578/performance-improvement- planning-developing-effective-billing-and-collection-practices
4) U.S. EPA, (2013), *Water Audits and Water Loss Control for Public Water Systems*, https://www.epa.gov/sites/default/files/2015- 04/documents/epa816f13002.pdf
5) AWWA, (2016), *M36 Water Audits and Loss Control Programs*, https://engage.awwa.org/PersonifyEbusiness/Store/Product-Details/productId/51439782
6) BWSSB, (2016), *Active Leak Management – Best Practice Guide*
7) Water Loss – International Water Association (iwa-network.org)

Chapter 12: Energy Audit and Conservation of Energy

1) Book-3, 'Energy Efficiency in Electrical Utilities' of BEE (Preparation book for Energy Managers and Auditors).

Chapter 13: Safety Practices

1) World Health Organization. (2014). *Water Safety in Distribution Systems*
2) World Health Organization. (2016). *Quantitative Microbial Risk Assessment: Application for Water Safety Management*
3) World Health Organization. (2009). *Water Safety Plan Manual: Step-by-step Risk Management for Drinking-water Suppliers*

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