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CHAPTER 4: PLANNING AND DEVELOPMENT OF WATER SOURCES

4.1 Introduction

Water occurs in nature in all its three forms, the solid, liquid and gaseous, and in various degree of motions. Formation and movement of clouds, rain, snow fall, stream and groundwater flow are some of the examples of dynamic movement of water. These dynamic formations of water relate to earth in various kinds of natural sources of water as described below.

Water Resources Management (WRM) is defined by the World Bank (2019) as the "process of planning, developing, and managing water resources, in terms of both water quantity and quality, across all water uses, wherein planning and development of water source is crucial.

4.2 Types of Water Sources

The origin of all sources of water is rainfall. Water can be collected as it falls as rain before it reaches the ground; or as surface water when it flows over the grounds in rivers or streams; or as pooled/stored water in lakes, reservoirs or ponds; or as groundwater when it percolates into the ground and flows or collects as groundwater; or from the sea into which it finally flows. With the advent of modern treatment technologies, the recycled water can also be a potential source. The quality of the water varies according to the source as well as the medium through which it flows.

Monsoon precipitation is the lifeline of India. The isohyetal Map of India is shown in Figure 4.1. The country receives approximately 4,080 billion cubic meters (BCM) of average annual precipitation including snowfall, out of which 3,000 BCM is available during monsoon season. About 50% of the total precipitation flows to the rivers estimated as 1999.2 BCM. However, due to various constraints of topography and uneven distribution over space and time, only about 1128 BCM of the total annual water potential can be put to beneficial use. This can be achieved through 690 BCM of utilizable surface water and 438 BCM through groundwater. The average assessed per capita water availability in the year 2011 was 1588 m^3 which was reduced to 1486 m^3 in 2021 and is further expected to be reduced to 1191 m^3 by 2050.

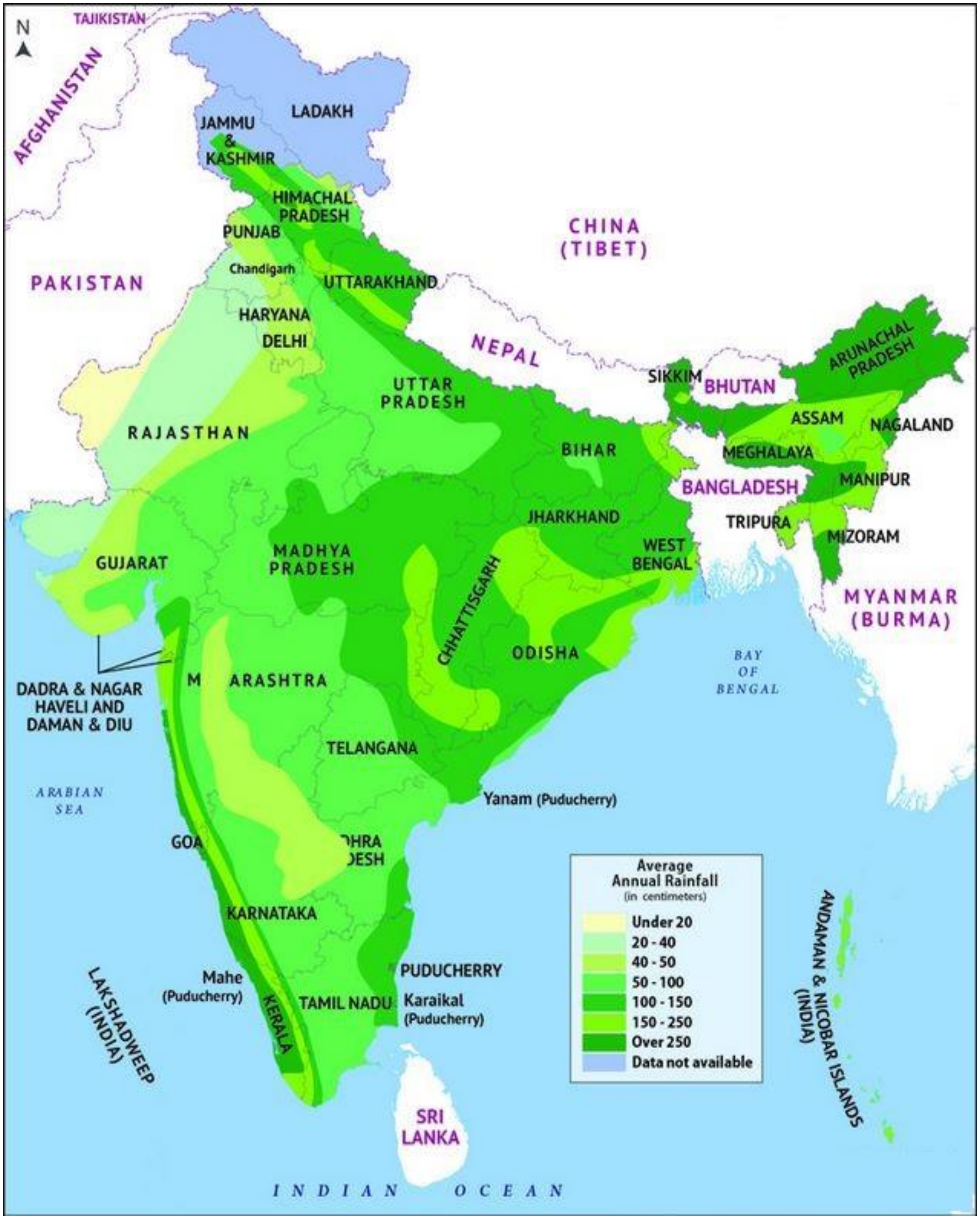

Figure 4.1: Isohyetal Map of India with average Annual rainfall in cm

4.2.1 Surface Water Sources

These include different water bodies like rivers, lakes/ponds, springs, tanks, reservoirs and sea water. India has been divided into 20 river basins as per report of Central Water

Commission (CWC; 2020). The mean annual flow in all the river basins in India is estimated as 1999.2 BCM. Out of this about 35%, i.e., 690 BCM can be put to beneficial uses. The Surface water is available in the following forms:

(a) **Natural Quiescent Waters as in Lakes, Ponds:** These waters would be more uniform in quality than water from flowing streams. Long storage permits sedimentation of suspended matter, bleaching of color and the removal of bacteria. Self- purification which is an inherent property of water to purify itself is usually less complete in smaller lakes than in larger ones. Deep lakes are also subject to periodic overturns which bring about a temporary stirring up of bottom sediment. The microscopic organisms may be heavy in such waters on occasions. If the catchment is protected and un-erodible, the stored water may not require any treatment other than disinfection.

(b) **Artificial Waters as in Impounding Reservoir:** Impounding reservoirs formed by hydraulic structures built across river valleys, are subject, more or less, to the same conditions as natural lakes and ponds. While top layers of water are prone to develop algae, bottom layers of water may be high in turbidity, carbon dioxide, iron, manganese and, on occasions, hydrogen sulphide. Soil stripping before impounding the water would reduce the organic load in the water.

(c) **Flowing Waters as in Rivers, other Natural courses and Irrigation Canals:** Waters from rivers, streams and canals are generally more variable in quality and less satisfactory than those from lakes and impounded reservoirs. The quality of the water depends upon the character and area of the watershed, its geology and topography, the extent and nature of development by man, seasonal variations and weather conditions. Streams from relatively sparsely inhabited watersheds would carry suspended impurities from eroded catchments, organic debris and mineral salts. Substantial variations in the quality of the water may also occur between the maximum and minimum flows. In populated regions, pollution by sewage and industrial wastes will be direct. The natural and man-made pollution results in producing colour, turbidity, tastes and odours, hardness, bacterial and other micro-organisms in the water supplies.

(d) **Springs**

Springs are active due to the emergence of groundwater on the surface. Till it emerges out on the surface as a spring, the groundwater carries minerals acquired from the subsoil layers, which may supply the nutrients to micro-organisms collected by spring, if it flows as a surface stream. Spring water from shallow strata is more likely to be affected by surface pollutions than deep-seated water. Springs may be either perennial or intermittent. The discharge of a spring depends on the nature and size of catchment, recharge and leakage through the sub-surface. Their usefulness as sources of water supply depends on the discharge and its variability during the year.

Various types of springs exist in different hydro-geological environments. These include Depression Springs, Fault Springs, Karst Springs, Hot Springs, Contact Springs, and Artesian Springs. Springs are the major source of drinking water for hilly areas.

The Water Cycle by which water moves between earth and atmosphere is as shown in Figure 4.2:

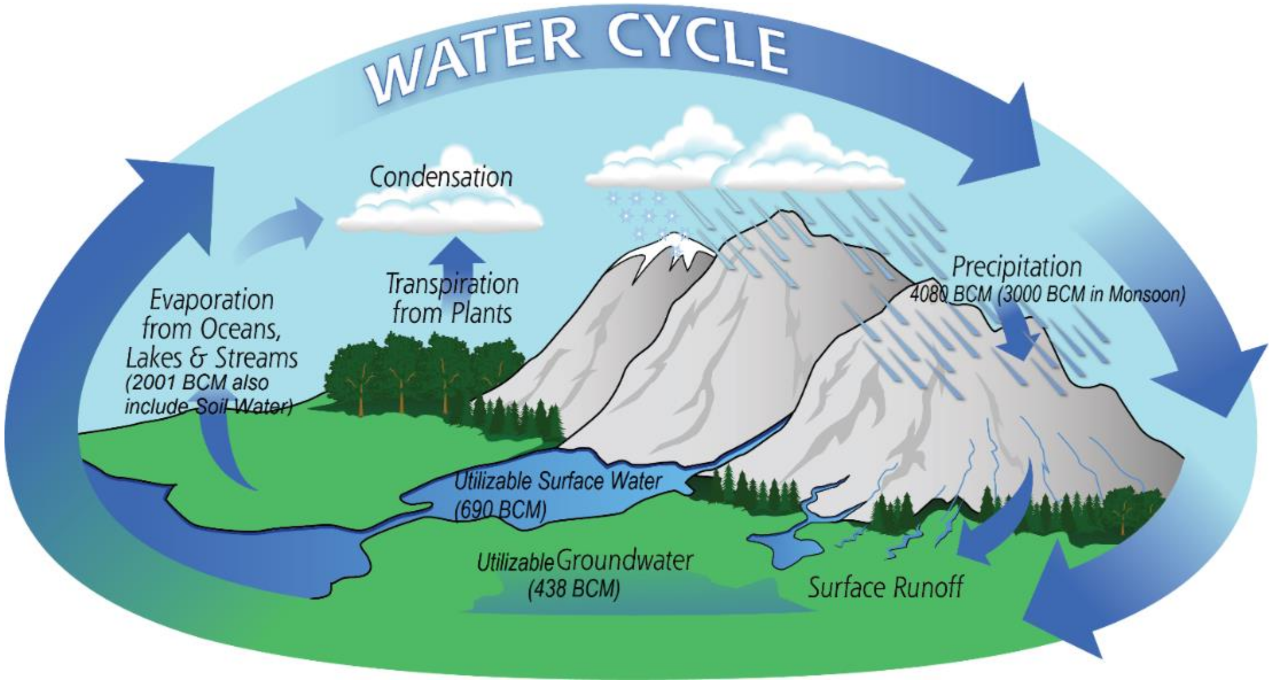

Figure 4.2: Water Cycle

Source: https://gpm.nasa.gov/education/water-cycle

4.2.2 Groundwater

Rainwater percolating into the ground and reaching permeable layers (aquifers) in the zone of saturation constitutes groundwater source. The upper level of zone of saturation is called "water-table". Groundwater is usually free from evaporation losses. Groundwater resources are less severely affected by vagaries of rainfall than surface water resources.

As per NITI Ayog, India is the largest groundwater user in the world, with an estimated usage of around 251 BCM per year more than a quarter of a global total. With more than 60% of the irrigated agriculture and 85 % of the drinking water supplies depend on it and growing industrial/urban usage, the groundwater is a vital resource.

As per the assessment (March 2022), the total annual groundwater recharge has been assessed as 437.60 BCM. Keeping an allocation for natural discharge, the annual extractable groundwater resource works out as 398.08 BCM. The total annual groundwater extraction (as on 2022) has been assessed as 239.16 BCM. The average stage of groundwater extraction for the country as a whole works out to be about 60.08%.

The extraction of groundwater for various uses in different parts of the country is not uniform. Out of the total 7089 assessment units (Blocks/Districts/Mandals/Talukas/Firkas) in the country, 1006 units in various States (14%) have been categorized as “Over Exploited”. A total of 260 (4%) assessment units have been categorized as “Critical”. There are 885 “Semi-Critical” units (12%) and 4780 (67%) assessment units have been categorized as “Safe”. Apart from this, there are 158 assessment units (2%), which have been categorized as “Saline” as major part of the groundwater in phreatic aquifers is brackish or saline.

Categorization based on status of groundwater quantity is defined by stage of groundwater extraction as given below:

Stage of Groundwater extraction	Category	Status of assessment units	
		Nos.	%
≤ 70%	Safe	4780	67
> 70% & ≤ 90%	Semi-Critical	885	12.5
< 90% & ≥ 100%	Critical	260	4
< 100%	Over-exploited	1006	14

Source: 2022-11-11- GWRA 2022.pdf

In comparison to 2020 assessment, the total annual groundwater recharge has increased from 436 to 437.6 BCM, where major increase is noticed in the States of Bihar, Telangana, Andhra Pradesh, Tamil Nadu, Arunachal Pradesh, Odisha and Gujarat. The groundwater extraction has marginally decreased from 244.92 to 239.16 BCM. The overall stage of groundwater extraction has marginally decreased from 61.6 % to 60.08 %.

The water as it seeps down, comes in contact with organic and inorganic substances during its passage through the ground and acquires chemical characteristics representative of the strata it passes through.

Generally, groundwater is clear and colorless but is harder than the surface water of the region in which it occurs. In limestone formations, groundwater is very hard, tends to form deposits in pipes and is relatively non-corrosive. In granite formations it is soft, low in dissolved minerals, relatively high in free carbon dioxide and is actively corrosive. Bacterially, groundwater is much better than surface water except where subsurface pollution exists.

Shallow Aquifer: The upper unconfined aquifers are branded as Shallow aquifer which bear at least 2 water bearing zones down to about 50 m to 70 m depth. Shallow aquifer is a source of dug wells & Shallow bore wells. Shallow groundwater is a condition where seasonal high groundwater table or saturated soil is less than 3 m from land surface. Shallow aquifers are easily rechargeable and relatively easily contaminated.

Deep Aquifer: Deep confined aquifers occur below shallow unconfined aquifers separated by impervious layers. Deep Confined aquifers are those located beyond 100 m depth below ground level. Deep aquifers bear relatively deeper water level. Deep aquifers also experience significant lag time in their response to climatic variations in comparison to Shallow aquifers. Deep aquifers are normally recharged through injection well bores commonly known as Aquifer Storage & Recovery wells (ASR).

Well Water: The proper siting and design of a well depends upon a region's geology, climate, distance to stream, and relation to area of recharge and discharge and the topography. To protect the water supply, wells should be located as far as possible away from potential sources of contamination.

4.2.3 Sea Water

Though this source is plentiful, it is difficult to economically extract and generate potable quality water because it contains 3.5% of salts in solution, which involves costly treatment. Offshore waters of the oceans and seas have a salt concentration of 33,000 to 37,000 mg/L of dissolved solids including 19,000 mg/L of chloride, 10,600 mg/L of sodium, 1,270 mg/L of magnesium, 880 mg/L of Sulphur, 400 mg/L of Calcium, 380 mg/L of Potassium, 65 mg/L of Bromine, 28 mg/L of Carbon, 13 mg/L of Strontium, 4.6 mg/L of Boron. Desalting or de-mineralizing processes involve separation of salt or water from saline waters. This is yet a costly process and has to be adopted in places where sea water is the only source available and potable water has to be obtained from it, such as in ships on the high seas or a place where an industry has to be set up and there is no other source of supply.

4.2.4 Wastewater Reclamation & Reuse

Considering the shortage of water in many urban / peri-urban areas, Government of India (GoI) is encouraging ULBs to utilize their treated sewage water for potable (indirect use) and non-potable applications, such as water for cooling, flushing, lawns, agriculture, horticulture, parks, fire-fighting and for certain industrial purposes and even for recharging groundwater after giving the necessary levels of treatment to suit the nature of use. The Atal Mission for Rejuvenation and Urban Transformation 2.0 (AMRUT 2.0) envisages major reforms for reducing non-revenue water to below 20%; recycle of treated used water to meet at least 20% of total city water demand and 40% for industrial water demand at State level.

4.3 National Water Policy (2012)

Ministry of Jal Shakti, Govt. of India formulated the National Water Policy (2012) to govern the Planning and Development of Water Sources and their optimum utilization. It has recognized the need for according the highest priority to the drinking water supply. That is why now-a-days all the water resources projects are planned, designed and constructed with domestic water supply component to meet the requirements of nearby villages, towns and cities.

Objective of National Water Policy is:

- To take cognizance of the existing situation
- To propose a framework for creation of a system of laws and institutions
- To prepare a plan of action with a unified national perspective
- The planning should be based on river basins and river sub-basins

The highlights of National Water Policy (2012) pertaining to Drinking Water Supply are as under:

- It states that the present scenario of water resources and their management in India has given rise to several concerns; one of them is that access to safe water for drinking and other domestic needs still continues to be a problem in many areas.
- Issues related to water governance have not been addressed adequately. Management of water resources has led to a critical situation in many parts of the country.
- Water is required for domestic purposes along with other uses. The utilization of all these diverse uses of water need to be optimized and an awareness of water as a scarce resource should be fostered.
- Safe water for drinking and sanitation should be considered as pre-emptive needs, followed by high priority allocation for other basic domestic needs including needs of animals etc. Available water should thus be allocated in a manner to promote its conservation and efficient use.
- There is need to remove the large disparity between the water supply in urban areas and in rural areas.
- Urban and rural domestic water supply should preferably be from surface water in conjunction with groundwater.
- Urban domestic water systems need to collect and publish water accounts and water audit reports indicating leakages and pilferages, which should be reduced taking into consideration the social issues.
- Water pricing ensures its efficient use and conservation. In order to meet equity, efficiency and economic principles, the water charges should preferably be determined on volumetric basis. Such charges should be reviewed periodically.

- Policy 2012 also envisages that there is need for comprehensive legislation for optimum development of interstate river valleys and to enable the establishment of basin authorities with appropriate powers to plan, manage and regulate the utilization of water resources in the basins.

4.4 India Water Resource Information System (WRIS)

India WRIS was initiated through a MoU on 3rd December, 2008, between Central Water Commission (CWC), MoWR (now Ministry of Jal Shakti) and the ISRO, Deptt. Of Space. India WRIS provides a single window solution for all water resources data and information on GIS framework. It allows user to access and analyse water data for planning & development of water resources in the context of Integrated Water Resource Management (IWRM). It is a web-based platform in public domain.

India–WRIS Web-GIS has 12 major info systems, 36 sub info-systems including 95 layers, classified under 5 major groups:

1) Watershed Atlas
2) Administrative layers
3) Water Resources projects
4) Thematic layers
5) Environmental Data

Major layers developed under India-WRIS are Basins, watershed, River, Water-body, urban & rural population extents, Dams, Barrage/Weir/Anicut, canals and command boundaries etc. All unclassified data of CWC and CGWB is available in the portal for free download. The information system has dedicated Sub-Info System of various components of surface water, groundwater, hydro-met observations, water quality, snow cover, inter-basin transfer links, socio-economic parameters as well as infrastructural and administrative layers.

Customized maps can be generated using “Create your WRIS Module “. India – WRIS Web-GIS has saving/printing capabilities:

WRIS Website:

- Surface water quality Sub-Info system
- Groundwater quality Sub-Info system
- HO Sub-Info system
- Telemetry Module
- Reservoir Module
- Snow Cover/ Glacial Sub-Info system

For detailed description about WRIS, reference can be made to https://indiawris.gov.in/wris/#/.

4.5 Water Resource Potential of River Basins

India is blessed with many rivers. Twelve of them are classified as major rivers whose total catchment area is 252.8 million hectares (MHa). Of the major rivers, the Ganga - Brahmaputra Meghana system is the biggest with a catchment area of about 110 MHa which is more than 43 percent of the catchment area of all the major rivers in the country. The other major rivers with catchment area more than 10 MHa are Indus (32.1 MHa), Godavari (31.3 MHa), Krishna, (25.9 MHa.) and Mahanadi (14.2 MHa). The catchment area of medium rivers is about 25 MHa and Subernarekha with 1.9 MHa catchment area is the largest river among the medium rivers in the country.

Besides major and medium river systems, the inland water resources include several reservoirs, tanks, ponds, lakes, derelict water and brackish water that cover about 17 MHa of area. About 50% of inland water resources are spread over the states of Andhra Pradesh, Gujarat, Karnataka, Odisha and West Bengal that cover about 7 MHa of area. River basin is recognized as a basic hydrologic unit for planning and development of water resources.

Government of India is contemplating creation of National Interlinking of Rivers Authority (NIRA), the status of which is outlined in the box below:

National River Linking Project (NRLP)

The NRLP program envisages the transfer of water from water excess basin to water-deficit basin by inter-linking 37 rivers of India by a network of almost 3000 storage dams. Perspective plan was prepared in August 1980 by Ministry of Irrigation (now Ministry of Jal Shakti). Under NRLP, the National Water Development Agency (NWDA) has identified 30 links (16 under peninsular components and 14 under Himalayan components) for preparation of Feasibility Reports. GoI is contemplating creation of National Interlinking of Rivers Authority (NIRA) for planning, investigation, financing and implementation of the river interlinking projects in the country and it will replace existing National Water Development Agency (NWDA).

Water Resources potential in river basins in India and utilizable surface water resources are shown in Table 4.1 and Figure 4.3. Water demand for various sectors from 2010 to 2050 is given in Table 4.2.

Figure 4.3: Various River Basins in India

(Source: India WRIS Database, National Water Informatics Centre, Ministry of Jal Shakti, Department of WR, RO & GR)

Table 4.1: Surface Water Resource Potential of River Basins of India (CWC, 2020)

S. No.	River Basin	Catchment area (Sq. Km)	Average Water Resources Potential (BCM)	Utilizable Water Resources (BCM)
1.	2.	3.	4.	5.
1	Indus	317708	45.53	46
2	Ganga-Brahmaputra Meghna			
	(a) Ganga	838803	509.92	250
	(b) Brahmaputra	193252	527.28	24
	(c) Barak and others	86335	86.67	----
3	Godavari	312150	117.74	76.3
4	Krishna	259439	89.04	58
5	Cauvery	85167	27.67	19
6	Subarnarekha	26804	15.05	6.8
7	Brahmani-Baitarni	53902	35.65	18.3
8	Mahanadi	144905	73	50
9	Pennar	54905	11.02	6.9
10	Mahi	39566	14.96	3.1
11	Sabarmati	31901	12.96	1.9
12	Narmada	96660	58.21	34.5
13	Tapi	65806	26.24	14.5
14	West Flowing Rivers from Tapi to Tadri	58360	118.35	11.9
15	West Flowing River from Tadri to Kanyakumari	54231	119.06	24.3
16	East Flowing Rivers Between Mahanadi and Pennar	82073	26.41	13.1
17	East Flowing Rivers Between Pennarand Kanyakumari	101657	26.74	16.5
18	West Flowing Rivers of Kutch and Saurashtra including Luni.	192112	26.93	15
19	Area of Inland Drainage in Rajasthan	144836	Neglect	------

S. No.	River Basin	Catchment area (Sq. Km)	Average Water Resources Potential (BCM)	Utilizable Water Resources (BCM)
20	Minor Rivers draining into Myanmar (Burma) and Bangladesh	31382	31.17	------
	Total	**3271953**	**1,999.2**	**690.1**

Table 4.2: Water Demand for Different Uses

S. No.	Total Water Requirement for Different Uses (in BCM) by Standing Sub-Committee of M/o Jal Shakti			
	Uses	**Year 2010**	**Year 2025**	**Year 2050**
1.	Irrigation	688	910	1072
2.	Municipal	56	73	102
3.	Industries	12	23	63
4.	Power (Energy)	5	15	130
5.	Others	52	72	80
	Total	**813**	**1093**	**1447**

Source: Water and Related Statistics 2021, Central Water Commission, Department of Water Resources, RD & GR, Ministry of Jal Shakti

Table 4.3: Demand and Supply Deficit Data

S. No.	Demand And Supply Deficit Data			
	Uses	**Supply 2020 (BCM)**	**Demand 2050 (BCM)**	**Deficit (BCM)**
1.	Irrigation	540	1072	532
2.	Municipal	45	102	57
3.	Industries	40	63	23
4.	Power (Energy)	25	130	105
5.	Others	10	80	70
	Total	**660**	**1447**	**787**

Source: Water Statistics, CWC 2020

Considering, the current supply capacity of 45 BCM for the municipal water supply use and the demand deficit in year 2050 will be reaching 57 BCM as shown in Table 4.3. This can be met by implementing reforms in water supply sector viz. recycling and reuse, NRW reduction, use of water efficient fixtures etc.

4.6 Aspects for Selection of Water Sources

The selection of water source is crucial in planning and designing the water supply system and following aspects for selection of surface water and groundwater sources need to be studied for selection of sustainable water source.

4.6.1 Surface Water

Hydrologic inputs play an important and effective role in the planning of Water Supply Projects. Hydrological studies are required at various stages of the project, such as (a) pre-feasibility stage, (b) stage of preparation of feasibility report, (c) planning and design (DPR) (d) project execution stage and (e) at project Operation and Maintenance stage.

(i) **Project Hydrology**: It encompasses three aspects as described below:

a) **Assessment of Water Availability:** The water availability is obtained from National Stream Flow by deducting the storage, where, national stream flow is measured by the rain gauges. The assessment of water availability of surface water resources in the river basins is extremely important in all the water resources development projects / Water Supply projects, because it caters not only the requirement of irrigated agriculture but also the needs of other uses like drinking water supply, industries, power etc. With growing population, the requirement of drinking water supply is becoming critical. Therefore, in all the Water Resource Development projects the provision is invariably kept for drinking water supply from the storage reservoir. In line with the above approach all the storage reservoir projects are planned and designed for 100% dependability to meet the drinking water supply requirement even by curtailing the other requirements if needed. However, in the case of irrigation and hydropower projects the dependability criteria may be 70% and 95% respectively.

b) **Estimation of Design Floods and High Flood Level (HFL):** Estimation of the design flood and HFL for the project is important from the angle of safety of the intake structures. Therefore, proper selection of a design flood value is very significant. A higher design flood value may result in increasing the cost of the intake structure while a low value of the design flood can cause risk to the intake structure and shortage of water intake flow during low water levels.

(ii) **Sedimentation of Reservoirs:** Due to rainfall, run-off and soil erosion in the catchments, reservoirs carry huge quantities of silt. The sedimentation study is carried out while planning water resources projects to estimate the loss of storage of the reservoir during its lifetime. Normally, the life of the reservoir is considered as 100 years as per guidelines (Working Group report and publication no. 19 of CBIP) framed by CWC and CBIP. For the outlet sill levels 100 years sediment load is considered and for carrying out the stimulation (testing performance of the scheme) studies 50 years sediment load is considered. Sedimentation near intake structures and intake channels is a very common but critical issue that has to be addressed in design. Sedimentation study of reservoir is carried out using *Area Reduction* methods as mentioned in CBIP manual.

Around 3700 dams in India will lose 26% of the total storage by 2050 due to accumulation of sediments which can undermine water security, irrigation and power generation as per study by United Nations. (Source: Appendix I/II; Compendium 1122020.pdf)

(iii) **Evaporation from reservoir:** Monthly evaporation from reservoirs based on pan evaporimeter data is required while conducting the reservoir stimulation studies for the project. The evaporation is very substantial in many shallow reservoirs which are acting as source and provision of additional reservation has to be kept in the reservoir storage for the summer period.

(iv) **Sanitary Surveillance:** This survey is a study of the environmental conditions that may affect its fitness as a source. The survey should be carried out 10 KM upstream and downstream of intake point. The scope of the sanitary survey should include a discerning study of the geological, geophysical, hydrological, climatic, industrial, commercial, agricultural, recreational and land development factors influencing the water drainage into the source and the surface and subsurface pollutions likely to affect it.

4.6.1.1 Assessment of the Yield and Development of the Source

I. General

A correct assessment of the capacity of the source (Impounding Reservoirs) investigated is necessary to decide on its dependability for the water supply project in view. The capacity of flowing streams and natural lakes is decided by the area and nature of the catchment, the amount of rainfall and allied factors.

The safe yield of surface sources is decided by its lowest daily dry weather flow (minimum flow in summer) and by the hydrological and hydrogeological features relevant to each case.

II. Factors in Estimation of Yield

The incidence and the intensity of rainfall, the run-off from a given catchment and the actual gauged flows in streams are the main factors in estimating the safe yield from any source. Reliable statistics of the rainfall over representative regions of the catchment area, recorded over a number of years, should be collected wherever available. In order to cover deficiencies in such data, it is desirable that rainfall recording stations are set up over all watersheds as part of a total water conservation program by the State Public Health Engineering Authority.

River gauging records should be collected and studied in regard to such sources under investigation. In respect of groundwater, aquifer geometries, boundaries and properties, groundwater levels, and surface-water ground-water relationships should be studied for the estimation of the resource.

Surface water yield: Water Yield is the estimation of fresh water input (for e.g. rain, snow and snowmelt) flowing into streams and rivers. Many factors affect water yield; including precipitation, temperature, watershed size and location, and primary water source (i.e., rainfall or snowmelt). Total surface water yield is calculated as sum of surface runoff, groundwater flow, tile-flow minus the transmission loss.

III. Methods for Assessment of Surface Flows

a) Assessing the availability of water at the site
When hydrological observation is carried out at the site of interest and data is available for a sufficiently long period (25 to 30 years or more), the quantum of water at the site can be determined. Current meters are used for velocity measurements which in turn is used for computing the flow of the water in the stream.

b) Assessing the peak discharge(flood) value
The methods generally adopted are as under:

(i) Unit hydrograph method* based on rainfall runoff studies;
(ii) Frequency analysis based on rainfall;
(iii) Envelope curves based on observed floods in similar catchments; and
(iv) Empirical formulae based on catchment characteristics.

CWC Manual on “Estimation of Design flood: Recommended Procedures” can be referred to.

4.6.2 Assessment of Groundwater Resources:

4.6.2.1 Hydraulics of Groundwater Flow

1. **General**
Groundwater moves from areas of high head to areas of low head due to gravity especially in unconfined aquifers conforming to slope of land. Geologic conditions in the sub-surface control the direction and rate of groundwater movement. Ground water flow is defined in meter/year. Streams flow freely while groundwater flows in tortuous path.

2. **Directions and Rate**
Groundwater flows in response to energy gradient. The amount of potential energy possessed by groundwater is measured by quantity termed as “Hydraulic head”. Hydraulic head is the elevation to which water rises in a well. Heads measured in wells tapping unconfined aquifer are used to construct water-table contour map. Total

head measured in wells tapping confined aquifer is used to construct potentio-metric-surface map. The rate of groundwater flow various directly with hydraulic gradient.

Groundwater in unconfined aquifer moves form topographically high areas (recharge) to topographically lower areas (discharge). Between recharge and discharge areas, groundwater flow is always in the direction of hydraulic gradient. For a local-scale flow system, the distance between recharge and discharge is relatively small and for regional scale it is much greater. Lakes, river and springs are useful in inferring water-table elevation where no wells exist.

3. Groundwater-Table Fluctuations

Groundwater table always fluctuates in response to recharge, stream stage and well pumping, The magnitude and rate of water level fluctuation in a well depend on whether aquifers are confined or unconfined, the amount and intensity of rainfall, pumping rate, soil characteristics and specific yield. Water levels fluctuate seasonally in response to climate change factors. Water levels generally decline throughout the summer period and recover during winter period.

4.6.2.2 Methods for Groundwater Prospecting/ Aquifer Systems

(a) Remote Sensing

The search for groundwater occurring in pores of the soil, regolith or bedrocks is greatly aided by remote sensing techniques. It should be understood at the beginning that remote sensing techniques complement and supplement the existing techniques of hydrogeological and geophysical techniques and are not a replacement for these techniques.

For convenience, we can divide the aquifers into two groups:

(i) Aquifers in alluvial areas and
(ii) Aquifers in hard rock areas

i. Aquifers in Alluvial Areas

Most well-sorted sands and gravels are fluvial deposits, either in the form of stream channel deposits and valley-fills or as alluvial fans. Table 4.4 lists the keys to detection of such aquifers on the satellite imagery. Although hydro-geologically significant landforms etc. can be delineated easily on Landsat images, more details are visible on aerial photographs. In favorable cases Satellite images can be used to select locations for test wells. In other areas locales can be marked for more detailed ground surveys or through examination of aerial photographs.

Table 4.4: Keys to Detection of Aquifers in Alluvial Areas on Satellite Images

SHAPE or FORM	
S. No.	**Description**
1	Stream valleys; particularly wide, meandering (low gradient) streams.

2	Underfit valleys:
3	Natural levees:
4	Meander loops
5	Meander Scars in lowland; oxbow lakes
6	Braided drainage-channel scars
7	Drainage line offsets; change in drainage pattern;
8	Arc deltas (coarsest materials) and other deltas
9	Cheniera; beach ridges; parabolic dunes
10	Alluvial fans, coalescing fans; bajadas
11	Aligned oblong areas of different natural vegetation representing landlocked bars, spits, dissected beaches, or other coarse and well-drained materials

ii. Aquifers in Hard Rock Areas

The groundwater abundance depends on rock type, amount and intensity of fracturing. The keys to detection of aquifers in hard rock areas are given in Table 4.5. The only space for storage and movement of groundwater in such areas is in fractures enlarged by brecciation, weathering, solution or corrosion.

Vertical fractures and lineaments represent favorable locations for water wells.

Table 4.5: Keys to Detection of Aquifers in Hard Rock Areas on Satellite Images

OUTCROPPING: ROCK TYPE	
Sl. No.	**Description**
1	Landforms; topographic relief
2	Outcrop patterns;
3	Shape of drainage basins
4	Drainage patterns, density frequency and texture
5	Fracture type and density.
6	Relative abundance, shape and distribution of lakes
7	Tones and textures (difficult to describe; best determined by study of known examples)
8	Types of native land cover

(b) GIS Method to Assess Groundwater Resources Potential

Most of the water used for domestic purposes comes from groundwater. Remote sensing, GIS field studies, Digital Elevation Models (DEM) can be fruitfully used in the assessment of groundwater resources.

Evaluating physical and environmental factors controlling Groundwater occurrence: The parametric influencing factors include:

- Geomorphology.

- Lithology of Rock formations.
- Land-use/Land cover
- Rainfall.
- Slope
- Soil
- Drainage Density
- Lineament and Rock fracture density.

Thematic layers on above mentioned parameters are generated and integrated through RS and GIS techniques. GIS based multi-criteria decision-making process as a spatial prediction tool can be utilized in exploring potential for groundwater resources of drainage areas. Geomorphology, geology, change, drainage density, slope, lineament density and land-use are influencing factors.

The Analytic Hierarchy Process (HAP) method is used to calculate the weightage of these criteria components. Groundwater potential index values are allocated to research locations and Groundwater Resources Potential Zone Maps (GWPZ) are developed as a result.

The Groundwater Potential Index (GWPI) values are classified as low to very good using multi-decision-making criteria and the Analytic-Hierarchy MCDM-AAP technique. GWPZ-maps are created as groundwater resource potential maps using this technology.

Groundwater rationalization factors like drainage and lineament density are thought to be more accurate forecasting tools. The findings of such research can be useful in groundwater exploration and development. It may be noteworthy to mention that drainage density in an area is directly connected to run-off and invisibly to permeability.

From GIS based groundwater prospection studies, it can be made out that groundwater availability mainly depends on integrating various data-layers of geology, geomorphology, slope drainage and lineament density, rainfall and land use.

I. Groundwater Resources Assessment

GEC-2015 Methodology recommends aquifer-wise estimation of Dynamic & Static groundwater resources. Groundwater resources are assessed to a depth of 100 m in hard rock areas and 300 m in soft rock areas. Methodology recommends resources estimation once in every three years. For detailed norms of estimation, the GEC-2015 Guideline can be referred.

State-wise Groundwater Resource Availability of India: The state-wise assessed groundwater resources of India (2022) are given in Table 4.6.

State-wise Depth to water Level and Distribution of Percentage of Wells for the Period of November-2021 in Unconfined Aquifer is given in Annexure 4.1

Table 4.6: State wise Groundwater Resources Availability in BCM (2022)

S. No.	States / Union Territories	Groundwater Recharge					Total Natural Discharges	Annual Extractable Groundwater Resource	Current Annual Groundwater				Annual GW Allocation for Domestic Use as on 2025	Net Ground Water Availability for future use	Stage of Groundwater Extraction (%)
		Monsoon Season		Non-monsoon Season		Total Annual Groundwater Recharge			Irrigation	Industrial	Domestic	Total			
		Recharge from rainfall	Recharge from other sources	Recharge from rainfall	Recharge from other sources										
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Andhra Pradesh	9.14	9.41	0.91	7.77	27.23	1.36	25.86	6.46	0.16	0.83	7.45	1.09	18.54	28.81
2	Arunachal Pradesh	1.96	0.94	1.06	0.56	4.52	0.41	4.07	0.02	0.01	0.01	0.03	0.01	4.03	0.79
3	Assam	17.92	1.15	6.52	0.94	26.53	2.56	21.4	2.06	0.01	0.58	2.65	0.62	18.71	12.38
4	Bihar	19.94	7.07	1.14	5	33.15	3.1	30.04	10.01	0.35	3.14	13.5	3.41	16.76	44.94
5	Chhattisgarh	8.08	1.8	0.15	2.01	12.04	1.04	11.01	4.62	0.11	0.73	5.46	0.83	5.56	49.58
6	Delhi	0.1388	0.0895	0.0094	0.1728	0.4105	0.0411	0.3695	0.0904	0.0007	0.2716	0.3627	0.2878	0.0288	98.1612
7	Goa	0.35	0.02	0	0.04	0.41	0.08	0.33	0.026	0.004	0.048	0.078	0.05	0.25	23.63
8	Gujarat	19	2.63	0	4.83	26.46	1.88	24.58	12.1	0.16	0.82	13.09	1.04	12.18	53.23
9	Haryana	3.15	2.79	0.70	2.83	9.48	0.87	8.61	10.30	0.60	0.65	11.54	0.66	1.04	134.14
10	Himachal Pradesh	0.6	0.14	0.14	0.15	1.03	0.09	0.94	0.18	0.05	0.12	0.35	0.12	0.59	37.56
11	Jharkhand	4.92	0.45	0.48	0.36	6.21	0.51	5.69	0.93	0.21	0.65	1.78	0.65	3.92	31.35
12	Karnataka	8.83	4.29	1.19	3.43	17.74	1.70	16.04	10.01	0.13	1.09	11.22	1.17	6.34	69.93
13	Kerala	4.25	0.15	0.47	0.87	5.74	0.54	5.19	1.17	0.01	1.55	2.73	2.2	2.18	52.56
14	Madhya Pradesh	26.87	1.56	0.11	6.69	35.23	2.66	32.58	17.39	0.17	1.69	19.25	1.88	14.21	59.1
15	Maharashtra	20.72	2.43	0.54	8.6	32.29	1.84	30.45	15.29	0.003	1.35	16.65	1.35	14.38	54.68
16	Manipur	0.4	0	0.11	0.01	0.52	0.05	0.47	0.02	0.0002	0.02	0.04	0.02	0.43	7.95
17	Meghalaya	1.29	0.01	0.42	0	1.72	0.17	1.51	0.003	0.0007	0.05	0.05	0.06	1.45	3.55
18	Mizoram	0.19	0	0.03	0	0.22	0.02	0.2	0.000	0.00	0.01	0.01	0.01	0.19	3.96
19	Nagaland	0.36	0.33	0.08	0.02	0.79	0.08	0.71	0.002	0.000020	0.02	0.02	0.02	0.69	2.89
20	Odisha	10.44	2.82	1.81	2.72	17.79	1.44	16.34	5.83	0.16	1.24	7.23	1.37	9.03	44.25
21	Punjab	4.67	9.09	0.72	4.46	18.94	1.87	17.07	26.69	0.16	1.17	28.02	1.19	1.57	165.99
22	Rajasthan	8.71	0.62	0.20	2.61	12.13	1.17	10.96	14.18	0.14	2.23	16.56	2.28	0.87	151.07
23	Sikkim	0.1712	0.0039	0.0956	0.0005	0.2712	0.0271	0.2441	0.0089	0.0022	0.0036	0.0147	0.0038	0.2291	6.04
24	Tamil Nadu	7.42	9.76	1.33	2.59	21.11	2.04	19.09	13.68	0.18	0.57	14.43	1.36	6.42	75.59
25	Telangana	7.19	6.66	0.98	6.44	21.27	2.02	19.25	7.257	0.154	0.596	8	3.82	11.23	41.6
26	Tripura	0.81	0.06	0.22	0.22	1.31	0.25	1.06	0.02	0.0007	0.08	0.10	0.09	0.96	9.70
27	Uttar Pradesh	35.44	13.96	0.82	21.23	71.45	6.13	65.3	40.72	0.41	5.01	46.14	5.48	19.99	70.66
28	Uttarakhand	1.28	0.31	0.1	0.32	2.01	0.16	1.86	0.63	0.12	0.15	0.89	0.15	0.96	48.04
29	West Bengal	15.46	1.65	3.04	3.46	23.61	2.19	21.42	8.38	0.14	1.54	10.07	1.76	11.29	47.01
30	Andaman and Nicobar	0.2979	0.0002	0.3203	0.0001	0.6185	0.0618	0.5566	0.0001	0.001	0.0065	0.0075	0.0069	0.5486	1.35
31	Chandigarh	0.01	0.01	0.00	0.03	0.05	0.01	0.05	0.01	0.002	0.03	0.04	0.03	0.01	80.99
32	Dadra & Nagar Haveli	0.06	0.01	0.003	0.02	0.09	0.01	0.08	0.01	0.09	0.01	0.11	0.02	0.01	133.2
	Daman & Diu	0.037	0.001	0.000	0.001	0.038	0.002	0.036	0.003	0.055	0.000	0.057	0.016	0.000	157.927
33	Jammu and Kashmir	1.16	1.94	1.15	0.64	4.90	0.46	4.44	0.31	0.05	0.71	1.07	0.73	3.35	24.18
34	Ladakh	0.01	0.05	0.02	0	0.08	0.01	0.07	0.00037	0.000200	0.03	0.03	0.03	0.04	41.36
35	Lakshadweep	0.01	0	0	0	0.01	0.01	0.01	0	0.00	0	0	0	0	61.6
36	Puducherry	0.06	0.09	0.01	0.04	0.21	0.02	0.19	0.08	0.01	0.05	0.13	0.05	0.05	69.17
	Grand Total	**241.35**	**82.30**	**24.88**	**89.07**	**437.60**	**36.85**	**398.08**	**208.49**	**3.64**	**27.05**	**239.16**	**33.86**	**188.03**	**60.08**

Total Annual Recharge estimated is 437.60 BCM and current total extraction for irrigation, industrial and domestic use comprises of 239.16 BCM.

The estimates are briefly outlined as below:

- Total estimated annual groundwater recharge = 437.60 BCM
- Total annual extractable groundwater resources = 398.08 BCM
- Current annual groundwater extraction for irrigation = 208.49 BCM
- Current annual groundwater extraction for industrial use = 3.64 BCM
- Current annual groundwater extraction for domestic use = 27.05 BCM
- Annual groundwater allocation for domestic use as on 2025 = 33.86 BCM
- Net groundwater availability for future use = 188.03 BCM
- Stage of groundwater extraction (%) = 60.08

Categorization of Assessment Units

Various groundwater assessment units are categorized as groundwater over-exploited, critical, semi-critical and safe category areas. The status of categorization of assessment units (Blocks/Talukas etc.) as on 2022 is given in Table 4.7.

Table 4.7: Categorization of Blocks/Talukas/Mandals in India (2022)

S. No.	State/Union Territories	Total No. of Assesse	Safe		Semi-Critical		Critical		Over-Exploited		Saline	
	States		Nos.	%	Nos.	%	Nos.	%	Nos	%	Nos.	%
1	Andhra Pradesh	667	598	89.7	19	2.8	5	0.7	6	0.9	39	5.85
2	Arunachal Pradesh	11	11	100.00								
3	Assam	28	27	96.43	1	3.57						
4	Bihar	535	469	87.66	46	8.60	12	2.24	8	1.50		
5	Chhattisgarh	146	116	79.45	24	16.44	6	4.11				
6	Delhi	34	4	11.76	8	23.53	7	20.5	15	44.12		
7	Goa	12	12	100.0								
8	Gujarat	252	189	75.00	20	7.94	7	2.78	23	9.13	13	5.16
9	Haryana	143	36	25.17	9	6.29	10	6.99	88	61.54		
10	Himachal Pradesh	10	10	100.00								
11	Jharkhand	263	241	91.63	11	4.18	6	2.28	5	1.90		
12	Karnataka	234	139	59.40	35	14.96	11	4.70	49	20.94		

S. No.	State/Union Territories	Total No. of Assesse	Safe		Semi-Critical		Critical		Over-Exploited		Saline	
	States		**Nos.**	**%**	**Nos.**	**%**	**Nos.**	**%**	**Nos**	**%**	**Nos.**	**%**
13	Kerala	152	122	80.26	27	17.76	3	1.97				
14	Madhya Pradesh	317	226	71.29	60	18.93	5	1.58	26	8.20		
15	Maharashtra	353	272	77.05	62	17.56	7	1.98	11	3.12	1	0.28
16	Manipur	9	9	100.0								
17	Meghalaya	12	12	100.0								
18	Mizoram	26	26	100.0								
19	Nagaland	11	11	100.0								
20	Odisha	314	300	95.54	8	2.55					6	1.91
21	Punjab	153	17	11.11	15	9.80	4	2.61	117	76.47		
22	Rajasthan	302	38	12.58	20	6.62	22	7.28	219	72.52	3	0.99
23	Sikkim	6	6	100.0								
24	Tamil Nadu	1166	463	39.71	231	19.81	78	6.69	360	30.87	34	2.92
25	Telangana	594	494	83.00	80	13.60	7	1.20	13	2.20		
26	Tripura	59	59	100.0								
27	Uttar Pradesh	836	557	66.63	169	20.22	47	5.62	63	7.54		
28	Uttarakhand	18	14	77.78	4	22.22						
29	West Bengal	345	232	67.25	31	8.99	22	6.38			60	17.39
30	Andaman and Nicobar	36	35	97.22							1	2.78
31	Chandigarh	1			1	100.0						
32	Dadra & Nagar Haveli	1							1	100.00		
33	Daman & Diu	2							2	100.0		
34	Jammu and Kashmir	20	19	95.00	1	5.00						
35	Ladakh	8	7	87.50	1	12.50						
36	Lakshadweep	9	7	77.78	2	22.22						
37	Puducherry	4	2	50.00			1	25.0			1	25.00
	Grand Total	**7089**	**4780**	**67.43**	**885**	**12.48**	**260**	**3.67**	**1006**	**14.19**	**158**	**2.23**

S. No.	State/Union Territories	Total No. of Assesse	Safe		Semi-Critical		Critical		Over-Exploited		Saline	
	States		Nos.	%	Nos.	%	Nos.	%	Nos	%	Nos.	%

Note:
Blocks- Bihar, Chhatisgarh, Haryana, Jharkhand, Kerala, Madhya Pradesh, Manipur, Mizoram, Odisha, Punjab, Rajasthan, Tripura, Uttar Pradesh, Uttarakhand, West Bengal **Taluks-** Goa, Gujarat, Karnataka, Maharashtra
Mandals- Andhra Pradesh, Telangana
District- Arunachal Pradesh, Assam, Meghalaya, Nagaland, Sikkim, Dadra & Nagar Haveli, Daman & Diu, Jammu & Kashmir
Valley- Himachal Pradesh, Ladakh
Islands- Andaman & Nicobar, Lakshadweep
Firka- Tamil Nadu
Region- Puducherry
UT- Chandigarh
Tehsil- Delhi

II. Groundwater Quality Monitoring

Groundwater quality is being monitored by Central groundwater board once a year through a network of 15,000 observation wells located all over the country and is aimed at generating background data of different chemical constituents in groundwater on a regional scale.

Main groundwater quality problems in India are given in Table 4.8:

Table 4.8: Groundwater Quality Problems in India

Quality Problem	Permissible Limit	States
Inland salinity	EC value of groundwater is greater than 1000 mili-Siemens/cm (Unit based on the name of the scientist) at 25ºC making water non-potable.	Inland groundwater salinity is present in arid & semi-arid regions of Rajasthan, Punjab, Haryana, Gujarat, Uttar Pradesh, Delhi, Andhra Pradesh, Maharashtra, Karnataka and Tamil Nadu. In some areas of Rajasthan and Gujarat, groundwater salinity is so high that the well waters are directly being used for salt manufacturing by solar evaporation.

Quality Problem	Permissible Limit	States
Fluoride	Level beyond permissible limit (>1.5mg/L)	221 districts covering 19 states of Andhra Pradesh, Assam, Bihar, Chhattisgarh, Delhi, Gujarat, J&K, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Odisha, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal
Arsenic	Level beyond permissible limit of 0.05 mg/L	86 districts covering 10 states of Assam, Bihar, Jharkhand, Chhattisgarh, Haryana, Karnataka, Manipur, Punjab, Uttar Pradesh and West Bengal
Iron	High concentration of iron (>1.0mg/L)	22 states of Andhra Pradesh, Assam, Bihar, Chhattisgarh, Goa, Gujarat, Haryana, J&K, Jharkhand, Kerala, Karnataka, Madhya Pradesh, Maharashtra, Manipur, Meghalaya, Odisha, Punjab, Rajasthan, Tamil Nadu, Tripura, Uttar Pradesh, West Bengal & UT of Andaman & Nicobar
Nitrate	Level beyond the permissible limit of 45mg/L	423 districts in 23 states & UTs and mostly from the states of Madhya Pradesh and Uttar Pradesh

III. Regulation and Control of Development and Management of Groundwater

A Central Groundwater Authority (CGWA) has been constituted under section 3(3) of the Environment (Protection) Act 1986 to regulate and control development and management of groundwater resources in the country. Similarly, each state should assign a regulator to regulate and control development and management of groundwater resources in the state. Powers and functions basically include regulation and control, management and development of groundwater and to issue necessary regulatory directions for the purpose.

Some states have come out with their own groundwater abstraction guidelines and have followed the structure of the groundwater model bill 1970/2005. Wherever states/UTs guidelines are inconsistent with CGWA guidelines, the provision of CGWA guideline will prevail as per CGWA, Ministry of Jal Shakti Notification dated 2020. Sates/ UTS are at liberty to suggest additional conditions/criteria based on local hydrogeological situations which shall be reviewed by CGWA/Ministry of Jal Shakti, GoI, before acceptance.

Ministry of Jal Shakti, (CGWA) Notification, dated 24th September, 2020

In pursuance of the directions of Hon'ble National Green Tribunal (NGT), the Department of Water Resources, River Development & Ganga Rejuvenation has notified guidelines to regulate and control groundwater extraction in the country in supersession to Ministry notification vide S O-6140(E), dated the 12th December, 2018. Guidelines shall continue to be regulated by Central Groundwater Authority (CGWA) by way of issuing "No Objection Certificate" for groundwater extraction to Industries, Infrastructure projects & Mining projects etc unless specifically exempted.

Groundwater extraction guidelines have been prepared to regulate groundwater extraction & conserve scares groundwater resources to have sustainable management of water resources in the country.

The entire process of grant of "No Objection Certificate" shall be online through a web-based application system. Application for issue of NOC is given Annexure 4.2.

IV. Aquifer mapping

Aquifer mapping is a scientific technique that uses a combination of geology, geophysical, hydrogeologic, and chemical quality data to determine the aquifer's long-term viability.

The requirement for aquifer mapping originates from the general need for scientific planning in groundwater development under various hydrogeological conditions, as well as the evolution of management strategies for better groundwater governance. Several developed countries have also used the standard UNESCO Legend of Chart-making to map their groundwater systems. A manual on aquifer mapping using international legend has also been published by the CGWB (MoJS).

The first map of India's hydrogeology, titled "Geohydrological Map of India," was released in 1969 by GSI at a scale of 1: 2 million. Following that, CGWB released a wall map –Hydrogeological Map on 1: 2 Million Scale and a 1: 5 Million Scale Hydrogeological Map of India, 1976. CGWB, under the Ministry of Jal Shakti of the Government of India, recently created an Aquifer Map of India on a 1: 250,000 Scale featuring 14 Principal aquifer systems and 42 Major aquifer systems.

V. Aquifer mapping Program

Aquifer mapping Programs are described as under:

A. National Project on Aquifer Management (NAQUIM)

CGWB has implemented National Aquifer Mapping and Management Programs (NAQUIM) which envisages mapping of aquifers (water bearing formations), their characterization and development of Aquifer Management plans to facilitate sustainable management of groundwater resource. NAQUIM was initiated in 2012 as part of “Groundwater Management & Regulation” scheme to delineate and characterize the aquifers and develop plans for sustainable groundwater management in the country. The state-wise information is shared with state/UTs. Out of 33 lakh sq.km geographical area of the country, a mappable area of 25 lakh sq.km has been identified by CGWB to be covered under the programs. So far 15.57 lakh sq.km has been covered in 36 different States & UTs. The entire program can be viewed referring to website, www.cgwb.gov.in).

Objective of programs: The objective of programs include:

- Delineation and characterization of aquifers in three dimensions.
- Identification and quantification of issues.
- Development of management plans to ensure the sustainability of groundwater resources.

The Management plans for each aquifer area are being prepared suggesting various interventions to optimize groundwater withdrawal and identifying aquifer with potable groundwater for drinking purposes in quality affected areas. The management plan also includes identification of feasible areas for artificial recharge of groundwater, which can help in arresting declining water levels besides demand side management options including crop diversification and increasing water use efficiency etc.

Outcome of Aquifer Infiltration Management System include:

1. Maps prepared under NAQUIM program have been shared with state governments through State Groundwater Coordination Committees headed by Principal Secretaries of concerned states. The Maps & Management plans are helping the state governments in water management and in better decision making.
2. Aquifer Mapping programs have provided detailed information on the aquifer dispositions and their characteristics which are necessary inputs for groundwater management.
3. As a part of NAQUIM program, the region-specific groundwater management plans have been prepared which suggest appropriate demand and supply side management interventions to improve sustainability of groundwater resources.

B. Hydro-Geomorphological Maps (Groundwater Prospect Maps)

Integration of geospatial techniques (Remote Sensing and GIS) for mapping groundwater prospection maps is an important tool in source location, monitoring and conserving groundwater. These include:

- Rock lithology/ geology
- Land use/Land cover
- Drainage density and drainage frequency
- Lineament and Fracture density
- Slope (%)

Factor evaluation for groundwater recharge mainly includes drainage density which is directly proportional to watershed run-off and lineament density that is directly proportional to infiltration for use in mapping groundwater potential zones.

Preparation and use of Hydro-geomorphological maps (HGMs) are considered essential using RS_GIS data in facilitating State Govts., using such maps for identifying and siting correct locations for sustainable and productive water wells as well groundwater recharging sites.

NRSA, the ISRO (Hyderabad) is responsible for preparation of Groundwater Prospect Maps called “HGMs”. HGMS have been prepared and supplied to various states for use in planned development of urban and rural drinking water sources. A User Manual: “Groundwater prospect Map” has also been prepared by NRSC/ ISRO for Ministry of Drinking water and sanitation for use of field level implementing agencies, planners and monitoring agencies in managing groundwater-based drinking water sources.

C. International Technology on Aquifer Mapping

1. **Mapping Groundwater using Airborne Geophysical System (SKYTEM):** SKYTEM is an innovative and technically advanced Airborne Geophysical System to map buried aquifers and is acceptable globally as best technique for mapping aquifer water resources. The technology is capable of mapping the top 500 m of earth materials in 3 dimensions.
2. **Groundwater Exploration and Mapping (GEM) System:** The next generation exploration mapping system and optimization is the game changing in subsurface intelligence gathering and simulation tool developed by Hydro Nova to explore, measure and map groundwater resources. The system integrates a wide range of latest groundwater observation and detection techniques including Geo-Spatial radar, airborne, seismic, hydro-geophysics as well as exploration drilling and down-hole imaging providing an unparalled geographic coverage and geologic versatility.

3. **Satellite based weekly Global Map:** NASA researchers have developed new satellite based global maps of soil-moisture and groundwater wetness conditions. Maps enable visualization of weekly snapshots of soil moisture/groundwater to get complete forecasts of draught situations.
4. **High Resolution Aquifer Mapping and Management:** CSIR Center launches Heli-borne surveying technology, a latest technology for groundwater mapping in arid regions.

4.6.3 Coastal Aquifer Systems:

The groundwater system that tress-passes land-sea boundaries is known as coastal aquifers. Coastal aquifers are sources of fresh water for those who live near the coast. For coastal villages, groundwater is the only source of drinking water, as well as the primary source of water for kettle-hole ponds.

Rainfall is the primary source of fresh water in the coastal aquifers system. All of the water that enters the aquifer system as recharge eventually makes its way to the sea. The hydrogeological balance between fresh groundwater and surrounding dense saline groundwater controls the position and movement of the boundary between fresh and saline groundwater.

4.6.3.1 Groundwater Table in Coastal Aquifer

The height of water table varies throughout the coastal-aquifer system, where recharge and pumping conditions and hydrogeological framework affect the height and configuration of water table. Schematic diagram of groundwater flow in unconfined coastal aquifers system and groundwater flow patterns in coastal areas is shown in Figure 4.4 and Figure 4.5 respectively:

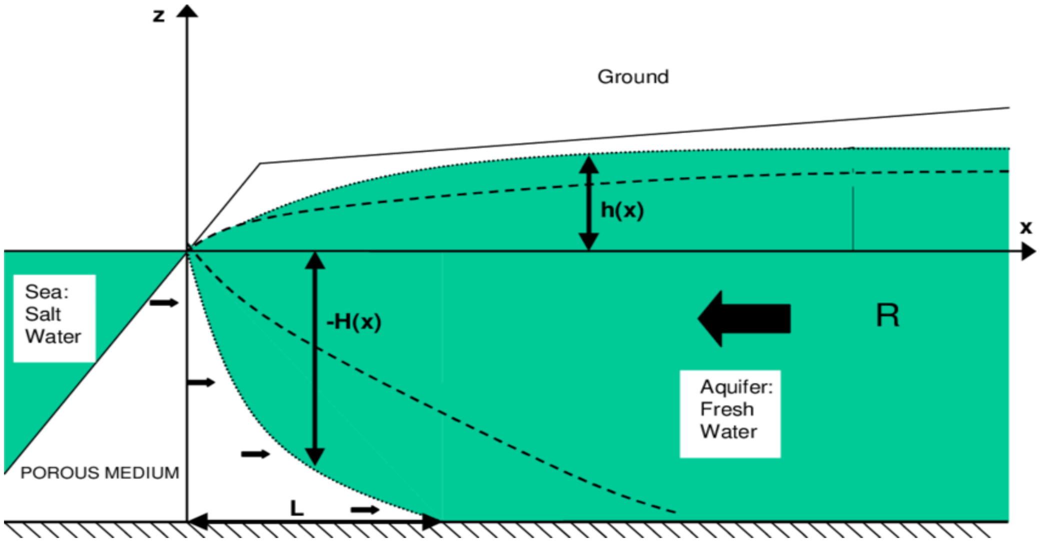

Figure 4.4: Groundwater Flow in Unconfined Coastal Aquifers System

(Source: Encyclopaedia of Ocean Scenarios (Second Edition) 2009

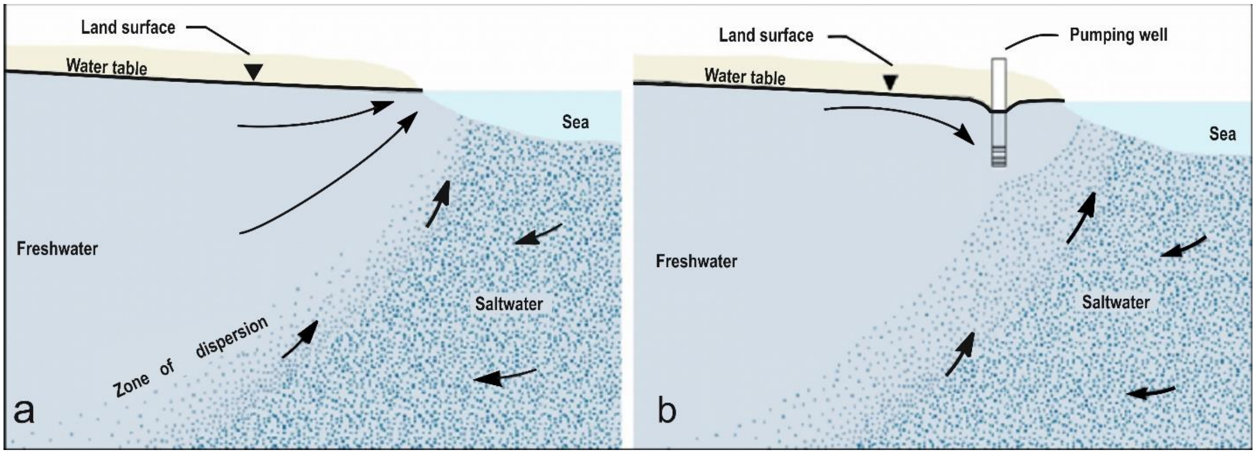

Figure 4.5: Groundwater Flow Patterns in Coastal Areas

(Source: Mary P. Anderson et. al.: Applied Groundwater Modelling (Second Edition) 2015

Managing Coastal Aquifer System

The looming problem of saline intrusion and groundwater levels in coastal aquifers must be adequately handled through regular monitoring. The management efforts may include:

(i) Constant & regular monitoring of well pumping movement of fresh and saline water interface.

(ii) Determining the cause of brackishness in aquifers using “Isotopic studies”.

(iii) Monitoring total influence on coastal aquifers.

(iv) Improving reduction on over-extraction of groundwater from coastal aquifers through CGWA advised regulatory measures.

4.6.3.2 Groundwater Quality in Coastal Aquifers

The coastline of India covers 9 States and 1 Union Territory. The status of groundwater quality in coastal aquifers is described as follows. The status and factors affecting the quality of groundwater in coastal aquifers is outlined.

i. Quality along West Coastal Areas

(a) Kerala: In Kerala coastal plain, electrical conductivity of shallow groundwater is in the range of 10 to 700 µS/cm. Flouride content of shallower groundwater is generally less than 0.5 mg/L. Deeper Varkala aquifer yields fresh water with chloride content of 10 and 200 mg/L with higher values occurring around Allepy. Also, the Iron content is in the range of 0.1 to 14.0 mg/L. The fluoride content of deeper aquifers is within the range of 0.3 to 2.6 mg/L. The nitrate content in Kuttanad region is within the range of 5 to 17 mg/L. The water of Vaikam aquifers, south of Kuttanad is of Calcium Carbonate type, whereas in the northern parts, it is of Sodium Chloride type. Brackish Water of Vaikam Aquifers has 700 mg/L of chloride and high iodide of about 300 times that of freshwater-seawater mixture.

(b) Karnataka and Goa: In coastal plains of Karnataka, water in shallow aquifers, in general, is fresh with electrical conductivity less than 1000 µS/cm, except in localized portions in and around Hangarkatta in Kundapura block of Udipi district where electrical conductivity and chloride value of sea water are recorded as 4230 µS/cm and 980 mg/L respectively.

(c) Maharashtra: In coastal districts of Maharashtra, groundwater is alkaline in nature. The groundwater is not highly mineralized. Spatial distribution of electrical conductivity values of groundwater are in the range of 250 to 750 µS/cm between Raigad-Thane belt, whereas, it is generally in the range of less than 250 µS/cm in coastal stretch between Raigad and Sindhudurg area. The chloride level of groundwater between Raigad and Sindudurg coastal belt is less than 100 mg/L. The fluoride level of groundwater is generally below 1.5 mg/L in all aquifers in the coastal tract.

(d) Gujarat: The Bhawnagar–Una section along Saurashtra coast is effected by sea water ingress and inherit salinity while Madhavpur-Maliya section has the effects of all factors like inherit salinity, sea water ingress, tidal inundation, marshy and seepages and saline alluvium. In coastal part of mainland Gujrat, groundwater is effected by salinity over a limited area. In Kutch area, the groundwater salinity due to ingress is restricted to narrow coastal strip of low-lying Bani plains. Electrical

Conductivity of water from deep confined aquifers of 100-200 m depth is less than 1000 µS/cm in Basalt, and more than 1500 µS/cm in alluvial/sandstone aquifers.

ii. Quality along East Coastal Areas

(a) Tamil Nadu: Insitu groundwater salinity problem has been recorded in the following areas:

- Minjur area, north of Chennai city, Chennai district (Saline water intrusion problem)
- Thiruvanmiyur-Kovalam tract, southern part of Chennai city (Sea water intrusion reported)
- Cuddalore coast: Sea water intrusion and insitu salinity reported
- Ramanathapuram, Nagapattinam, Thanjavur and Tuticorin district (insitu salinity problem)
- Kuttam-Radhapuram area, Tuticorin district (sea water intrusion reported)

In coastal tract of Tamil Nadu and Pondicherry, the location of fresh saline groundwater interface has varied with time due to exploitation of groundwater. In Minjur area (north of Chennai City) the interface was about 3.5 km inland in 1972. Which has presently moved to about 15 km inland.

(b) Andhra Pradesh: The saline groundwater at moderately deeper levels has been observed due to resident saline sea water. In east Godavari part of coastal area, some improvements in quality of groundwater is reported due to flushing of insitu saline water with continuous irrigation by Godavari canal water. Andhra Pradesh coast was subjected to manure transgression and regression in the past.

(c) Odisha: An area of 8575 sq.km of the coastal districts of Balasore, Bhadrak, Jajpur, Kendrapara, Jagatsinghpuri, Cuttack, Puri and Khurda suffers from groundwater salinity. Saline groundwater in the coastal tract has a width of 15 km in the extreme north east around Karangasul, 1.5 to 5.0 km in the northern part between Balasore and Kalyani sector and maximum of 75 km in the central part of Mahanadi Delta. The salinity of groundwater is prominent in the deltas of Mahanadi-Brahman, Subharnrekha and Bhurabalang and most prominent salinity groundwater hazard is present in the central part of the coastal tract.Freshwater aquifer overlying the saline water zones occur in Cuttack and Puri districts in parts of Kendrapara, Jagatsinghpuri and Jajpur Districts. The conditions of saline water zones overlying freshwater aquifers exist prominently in Balasore, Bhadrak, Kendrapara, Jagatsinghpuri and Jajpur.Presence of saline water throughout down to explored depth of 600 m is conspicuous in Puri district and in pockets of Kendrapara and Jagatsinghpuri districts. The salinity is also conspicuous in northern part along Karangasul/Chandaneshwar to Chandipur. In Cuttack district, 45 to 55 m thick freshwater aquifers occurring within 90 to 100 m depth is underlain by saline water zone beyond 300 m depth. In Puri district major part of coastal alluvium suffers from salinity hazard. In Cuttack- Jagatsinghpuri- Kendrapara and Jajpur tract, large areas falling in Rajkanika- Aul- Rajnagar-Pattamadai, Kujang, Mahakalpur, Patkura and Ersama block aquifers down to 60 to 320 m depth are saline to brackish in nature and fresh water aquifers occur below this depth.

(d) West Bengal: Groundwater quality issues of West Bengal include:

- Salinity Hazards
- Arsenic Water pollution
- Industrial pollution
- High Iron in Groundwater

Brackish to saline and freshwater bearing aquifers have been developed in different depth zones in Kolkata Municipal Corporation area, South 24 Parganas and in parts of North 24 Parganas, Haora and Purba Medinipur districts. Kolkata Municipal Corporation Area: Due to lowering of piezometric surface possibility of ingress of brakish Groundwater into freshwater in KMC area exists. Monitoring of piezometers is underway by CGWB. In order to combat salinity problem of Hoogly river water due to tidal effects, fresh groundwater is being withdrawn from deep tubewells located between Mahishadal and Chaitanyapur and is being supplied after mixing with treated surface water.The occurrence of Arsenic in groundwater above the permissible limit (more than 0.05 mg/L) has been reported to occur in shallow aquifers in parts of 24 Parganas, North 24 Parganas and Haora Districts. High Iron content above permissible limits is found in groundwater in shallow aquifers in South 24 Parganas and Haora districts.

4.6.3.3 Saline Intrusion

Salt Water intrusion is the movement of saline water into fresh water aquifer which results in contamination of drinking water resources. It is indicated by the process of higher concentration of chloride and electric conductivity of groundwater in the area. It is of major concern in coastal aquifers. It is the induced flow of sea water into fresh water aquifer. Salt-water encroaches aquifers when fresh groundwater levels decrease relative to sea-level, allowing higher sea water to flow towards the fresh water inland. Also, when large quantities of groundwater are withdrawn in coastal aquifers, the salt water migration takes place landward.

A. High Risk Intrusion Areas

These include areas:

- Close to the sea-coast
- Where the slope is low to moderate.

- Areas with limited source for groundwater recharge.
- Areas having high density wells and high rate of pumping for wells.
- Areas where static groundwater level is below sea level.

B. Prevention of Intrusion

Following management practices over areas of high risk of salt water intrusion are needed to be practiced.

- Avoiding drilling in locations immediately close to the coast e.g., within 50m of coastline.
- Avoiding drilling deep in areas in close proximity to coast.
- Avoiding hydro-fracturing in areas close to coast while developing hard rock wells.
- Closing of unusable wells.

C. Controlling saline-water Ingression

Salt-water intrusion can be controlled by maintaining water balance between water extracted and quality of water recharged into aquifer and creating fresh water mound near sea as well as adopting rain water harvesting and recharging. Groundwater aquifer along coast should not be over-pumped and pumping depth be reduced. The best way to control and prevent intrusion is continuously monitoring the depth of water table and water quality of coastal aquifers.

4.7 Pollution Control of Source

4.7.1 Preventing Pollution of Surface Water Sources

Pollution has the potential to harm both the aquatic ecosystem and human health. Pollution has different effects on streams and rivers depending on the type of pollutants.

Potential causes of pollution can be:

- Intrusion of sea-water into streams
- Sanitation including sewerage, sewage treatment and solid waste management
- Disorderly maintenance of sewer out-flow
- Management of erosion and sediment control and
- Regulatory measures to control water pollution
- Information, Education and Communication (IEC) activities
- Proper management of the leachates from the solid waste dump sites
- Untreated effluent from sugarcane & other industries.

Control of pollution requires appropriate infrastructure and management plans.

4.7.2 Preventing Pollution of Groundwater Sources

Water pollution sources and prevention measures are described as below:

(i) **Groundwater Contamination:** It is a major problem in the country particularly in industrial wells. It is more difficult problem to correct groundwater contamination than surface water contamination. Groundwater is vulnerable both to contamination and unmanaged exploitation. Agriculture, and urbanization as well as unmanaged groundwater exploitation lead to degradation of groundwater quality. Also pumping of groundwater result in water table depletion, land subsidence, saline water intrusion and intrusion of poor-quality water from streams. It is because of these problems and issues, the contamination, prevention and corrective measures are needed.

(ii) **Contamination Sources:** Contamination or polluting sources are classified as "point source" (e.g., Underground storage tank and "non-point source" (such as agricultural): Contaminating system and sources are outlined as below in Table 4.9.

Table 4.9: Contaminating Sources

System		Contaminating/leak sources
1. Septic Tank system	:	Commonly used for disposal of water
2. Agricultural Activities	:	Use of chemicals and fertilizes
3. Solid Waste Disposal	:	Seeps from landfills
4. Underground storage tank	:	Leaks from underground tanks
5. Spills (Overflows)	:	Spills and leaks at industrial site, military bases are points, gas line station, High ways
6. Mining	:	Coal and metal mining operation areas
7. Salt contamination	:	Due to pumping of groundwater in coastal aquifer regions
8. Underground injection	:	Threat to groundwater for disposal and injection wells
9. Abandoned wells	:	Uncapped and unsealed abandoned wells
10. Surface-water contamination of Groundwater	:	Due to withdrawal of groundwater near a contaminated river that drains surface water into aquifer and contaminate it

4.7.3 Protection of Groundwater:

Groundwater pollution by human activity normally cannot be totally eliminated but can be minimized.

i. **Preventive Option:** The best option is prevention which includes determining potential sources of pollution and effectively controlling these. Framers, Homo owners, well-drillers well developers, operators of waste-disposal facilities, gas station attendants, fertilizer dealers and manufactures can help curb pollutants/contamination.

ii. **Control of groundwater pollution:** It should begin with preventive actions instead of clean-up measures. Preventive strategies that can be used include the following:
- Zoning
- Land use planning
- Watershed protection
- Observing rules for waste discharge
- Based on hydrogeological, socio-economic and environmental influences on system.

Protection strategies are to emphasize public knowledge and well monitoring, enforcement and good understanding of hydrogeology of areas.

iii. **Developing Aquifers Protection Plan:** Several strategies are required for a successful groundwater protection plan and several strategies need to be developed at local level and at Central level/National level. Local rules can establish protection areas for vulnerable/over-exploited aquifers with the need to protecting towns water supply source-plan or well-head protection plan. Prevention is far less costly than restoring the polluted groundwater. Protection plan should include well-monitoring, network programming and enforcement approach. In the preparation of pollution protection plan, following maps and plans are always an inescapable necessity. These include:

- Aquifer sensitivity maps.
- Groundwater level contour maps showing direction and rate of groundwater movement.
- Inventorying wells data.
- Measuring non-pumping water level in all wells.
- Estimating aquifer parameters using well log and aquifer pump-test data (APT)
- Collecting and analyzing the water samples for wells/tube wells.
- Aquifer Vulnerability Maps.
- Assigning responsibilities for implementing the plan-by local citizens groups / organizations.

4.8 Conservation and Restoration of Water Bodies

India is covered by various types of water bodies which include Lakes, Wetland, Ponds etc. Urban Lakes/ water bodies are important factors in landscape. Lakes have traditionally been serving as source of drinking water, household uses, fishing, and for agriculture, religious and cultural purposes.

Lakes are intrinsic part of ecosystem. Because of their relevance to social benefits, they need to be restored, conserved, managed and maintained. Every lake has catchment, the area from which water drains into it. Run-off water along with pollutants enter the lakes from these areas.

In view of above, the Urban Water Bodies have to be in the focus and realms of planning and decision-making processes since such water resources, if protected and managed properly, will surely produce great potential to augment water supply at least for non-potable requirements of ever-increasing urban population.

Conservation Measures by ULBs: Steps include:

(i) Water bodies should be included in Municipal Land use records.
(ii) The Lake shore line should be properly fenced to safe guard against encroachment.
(iii) Water bodies should be protected with well-designed inlet and outlet structures.
(iv) Protecting Urban Water Bodies from out fall of domestic and industrial sewage based on CPCB guidelines.
(v) De-silting and cleaning of Water bodies be done on regular basis including treatment of their catchments.
(vi) Water quality of water bodies may be monitored on monthly and annual basis by concerned ULBs.
(vii) A Water Conservation Authority should be set up at State level to sustain Water Bodies by rejuvenating them at eco-system-based approach.
(viii) Water bodies/pond bodies should be part of storm water management plan of each city.

4.9 Development of Surface Sources

4.9.1 Intakes

An Intake is a device or structure placed in a surface or groundwater source for withdrawal of water from the source and its discharge into an intake conduit through which it will flow into the water works system. Types of intake structures consist of intake towers, intake barge or jetty, submerged intakes, intake pipes or conduits, intake wells, movable intakes, and shore intakes. Intake structures over the inlet ends of intake conduits are necessary to protect against wave action, floods, navigation, ice, pollution, debris and other interference with the proper functioning of the intake.

Intake towers are used for large waterworks drawing water from lakes, reservoirs and rivers in which there is either or both a wide fluctuation in water level or the desire to draw water at a depth that will give water of the best quality to avoid clogging or for other reasons. A schematic of an Intake Structure (Intake Well) is as shown in Figure 4.6.

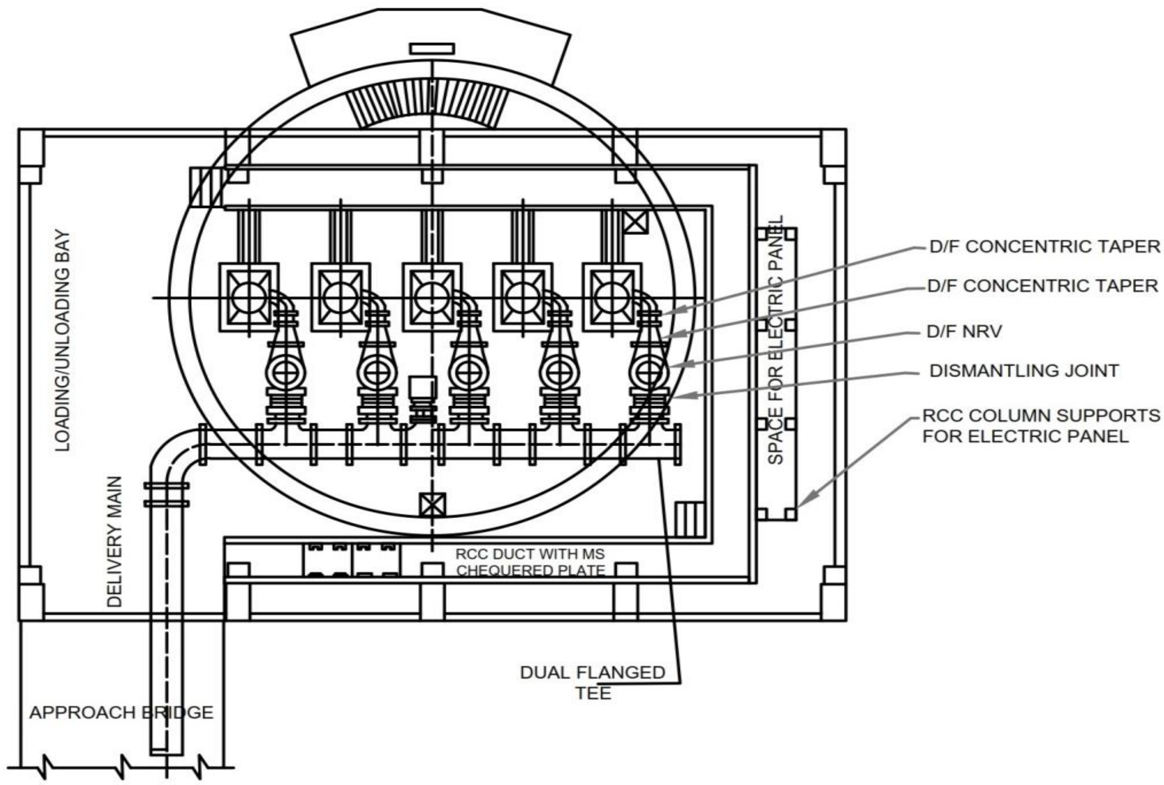

Figure 4.6: Intake Well

Main Sources of Water Intake:

Three main sources of water intake are:

- Surface Water (a lake, river or reservoir)
- Groundwater (an Aquifer)
- Recycled Water (Reused Water)
  The design norms are explained in Part A: Chapter 2 Planning and Investigations.

4.9.1.1 Intake Locating Factors

The following factors should be considered for locating the intake:

(i) The location where the best quality of water is available
(ii) The location shall not be provided at the meandering of the river or stream. Absence of currents that will threaten the safety of the intake
(iii) Above Highest Flood Level (HFL)
(iv) All season road should be constructed for accessibility

An intake in an impounding reservoir should be placed in the deepest part of the reservoir and it should be above the level of maximum accumulated sediments. The deepest portion is ordinarily near the dam, to take full advantage of the reservoir capacity available. The intake can be planned in the divide wall of the dam if the dam is not commissioned. Provision for trash arresters (Rose Pieces) at different depths to take advantage of better water quality should be made.

4.9.1.2 Type of Intakes

1. Impounding reservoir and Lake intake
2. River intake
3. Canal intake
4. Fixed Jetty intake
5. Intake Chamber with removable screens.
6. River Bottom intake
7. Floating intake

4.9.1.3 Functions of Intake Structures

Basic Functions are:

- To ensure getting required water.
- To check trash and debris entry along with water and drain.
- To secure entry of water with minimum disturbance.
- To reduce sediment entry

Description of Intakes

i. Impounding Reservoir and lake intake

Intake structure is required to withdraw water from surface sources like river, lake or reservoir. In reservoir it is often built as an integral part of the dam and in others as shore line structures. Typical intakes are well type circular RCC structures with submerged port holes fitted with screens at different levels in staggered manner on the circumference of the well. Location, height and selection of holes are related to the characteristic of water, depth of water etc. A control room is constructed on the top of the well to control the mechanism fitted therein to operate the closing and opening of the port holes fitted at different levels. Such intake towers are commonly built for lakes and reservoirs with fluctuating water levels and variation in quality of water with depth.

ii. River intake

River intakes are constructed upstream from point of discharge of community sewage and industrial wastewater. They should be so placed within the river channel as to take advantage of deep water, a stable bottom and better water quality. Streams in which water level during dry months depletes below the normal level of withdrawal a weir may be constructed to raise the level of water.

iii. Canal intake

Canal intake generally consists of masonry or concrete intake chamber of rectangular shape admitting water through coarse screen. A fine screen should be provided over bell mouth entry of the outlet pipe. In case normal flow of canal is not affected, the intake chamber may be constructed inside the canal bank. Preferably lining should be provided to the canal near the intake chamber.

iv. Fixed Jetty intake

The structure is of RCC cast in situ bored piles with M.S. liner of design length and thickness (Figure 4.7). The piles are tied with longitudinal and lateral tie beams over which working floor of structure is constructed. There is free passage of water at the inlet of the suction pipes of V.T. pumps which is subjected to invasion by unwanted floating objects. So, the inlet bell mouth is provided with screen of adequate design to prevent entry of unwanted objects.

Figure 4.7: Fixed Jetty Intake

(Source: https://www.gbcinfrastructure.in/complete-raw-water-intake-plants-projects/)

v. Intake Chamber with removable screens.

This is of RCC construction over the bed of river / lake where suction pipe is placed within the RCC chamber below LWL. Mild Steel Bar rack is fitted by the upstream side of the chamber followed by removable screen. The screen is useful in preventing entry of unwanted floating objects in surface water. Water is taken out using a suction pipe fitted with an inverted bell mouth. Periodical cleaning of bar rack and removable screen is necessary to keep the intake structure functions adequate for drawl of design quantity of water (Figure 4.8).

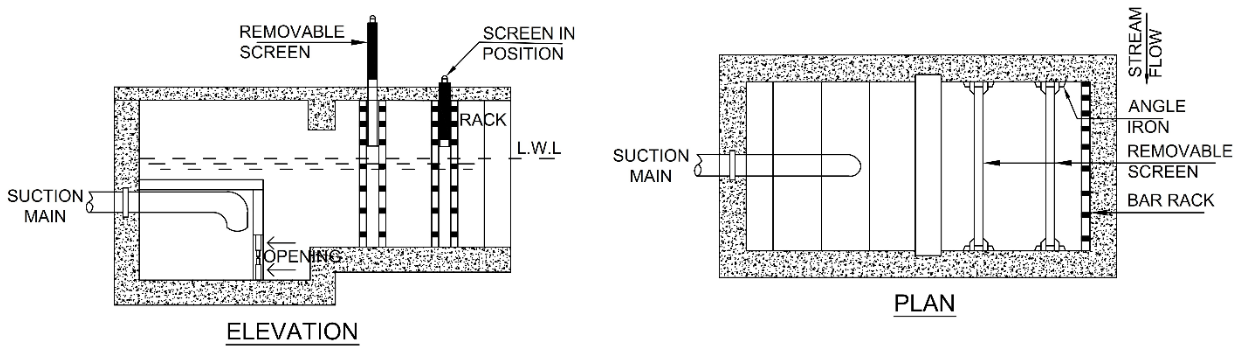

Figure 4.8: Intake with Removable Screen

(Source: http://www.vmmcl.com/projects_intake_structures_palanpur.aspx)

vi. River Bottom intake

River bottom intakes for drinking-water system are used in stream and river, where bed sediment content and bed load are low. Water is extracted through screen over a channel using submersible pump as shown in Figure 4.9. This type is recommended for taking emergency measures for restoration of water during the floods.

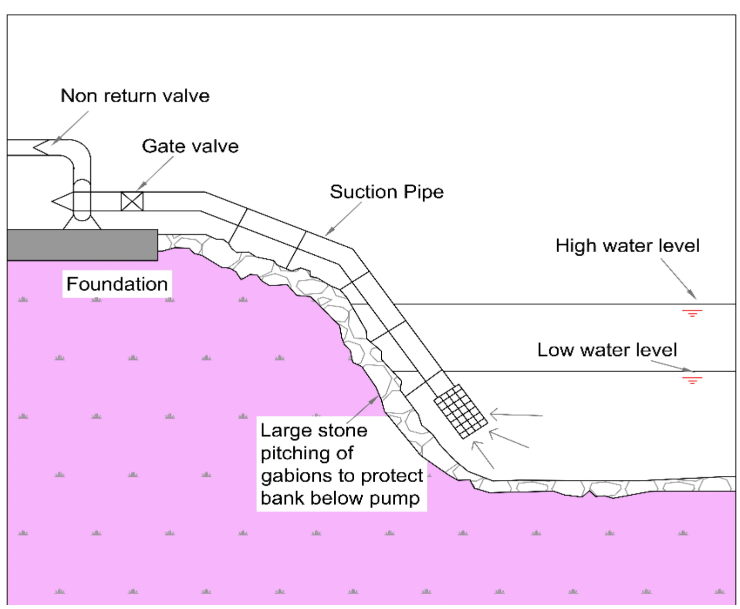

Figure 4.9: River Bottom Intake

(Source: https://repository.lboro.ac.uk/collections/Intakes_rivers_and_weirs/4500617)

vii. Floating Intake:

A floating water intake unit is an investment-friendly solution where, there are very large distance changes in the coastal line/ river bank with the vertical water level variation. To ensure continuity in the water receiving unit, it is necessary to reach the deep points of the water basin. This necessitates the use of piled bridges and lift pumps in conjunction with conventional intake well. Floating intake, can be built using amphibious floating concrete modules/ pontoon that can be placed both on land and on water.

These are for drinking water system that allows water to be abstracted from near the surface of river or duke and avoiding the heavier silt-load. Floating intake system is shown in the Figure 4.10.

The floating intake unit is constructed by placing the floating pump station in a desired area of water and connecting the pipe leading to it by a floating bridge or a floating way line. As an alternative to free surface water intake structures, with this method filtration and sedimentation costs will be significantly reduced as quality of water taken from more stable region and upper elevation is less turbid and transparent.

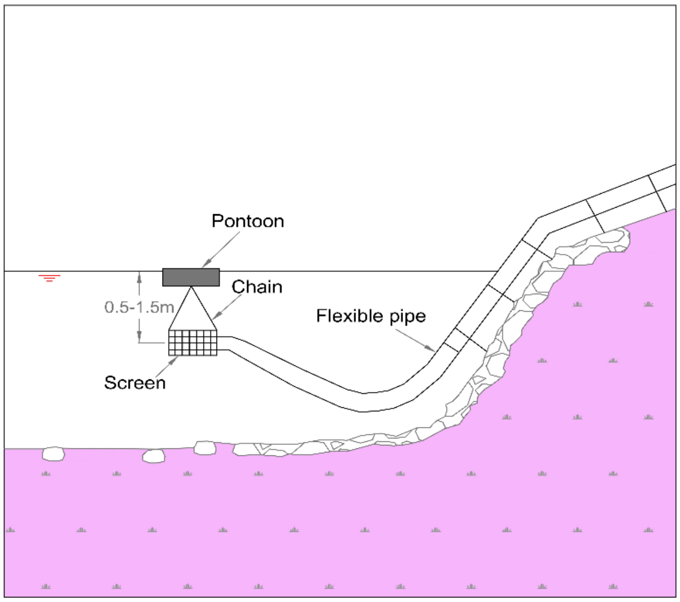

Figure 4.10: Floating Intake

(Source: https://repository.lboro.ac.uk/collections/Intakes_rivers_and_weirs/4500617)

4.9.1.4 Design Considerations

The intake structures design should provide for withdrawal of water from more than one level to cope up with seasonal variations of depth of water.

Undermining of foundations due to water currents or overturning pressures, due to deposits of silt against one side of an intake structure, are to be avoided.

The entrance of large objects into the intake pipe is prevented by coarse screen or by obstructions offered by small openings in the crib work placed around the intake pipe. Fine screens for the exclusion of small ash and other small objects should be placed at an accessible point. The area of the openings in the intake crib should be sufficient to prevent an excessive velocity to avoid carrying settleable matter into the intake pipe.

The conduit for conveying water from the intake should lead to a Jack well. For conduits laid under water, standard cast iron or suitable pipe may be used. Larger conduits may be of steel or concrete. A tunnel, although more expensive, makes the safest conduit.

The capacity of the conduit (joining Intake Well to Jack Well) and the depth of the Jack well should be such that the intake ports to the suction pipes of pumps will not draw air. A velocity of 60 to 90 cm/s in the intake conduit with a lower velocity through the ports will give satisfactory performance. The horizontal cross-sectional area of the jack well should be three to five times the vertical cross-sectional area of the intake conduit. The diameter of the jack well should be selected such that it can accommodate the required pumps along with stand by pumps even for the ultimate stage (30 years after base year).

The intake conduit should be laid on a continuously rising or falling grade to avoid accumulation of air or gas pockets of which would otherwise restrict the capacity of the conduit.

Excessive Sand Problem: In some of the rivers sand is transmitted even to the units of treatment plant making its operation difficult. A suitable sand removable mechanism (Detritous Tank or Plain Sedimentation Tank) shall be designed to overcome such problem.

4.9.2 Impounding Reservoirs

Impounding reservoir is a basin constructed across the river/stream to store water during excess stream flow and to supply water when the flow of the stream is insufficient to meet the demand for water. For water supply purposes the reservoir should be full when the rate of stream flow begins to become less than the rate of demand for water. The impounding reservoir can be in the form of dams, KT weirs, Balancing Tanks, etc.

Generally, Dams constructed by the irrigation department are considered as a source of drinking water supply projects. However, irrigation department constructs dam for which benefit cost ratio is more than one. If this ratio is unsuitable for irrigation purpose, then such left over locations can be considered for non-irrigation purposes such as drinking water and industrial use. As drinking water is the most important for sustenance of life the National Water Policy as considered as top priority. Hence, when there is no alternative source of water, the utility can think of constructing their own impounding storage reservoir at the sites where irrigation department is not contemplating the construction of irrigation dams. Even many power generation plants and industries have constructed their own dams for storing of water for their needs.

(a) Choice of Reservoir Site

The suitability of a site must be judged from the following stand points:

(i) Quantity of water available.
(ii) Quality of source.
(iii) Possibility of the construction of a reasonably water tight reservoir.
(iv) Distance of the source from the consumer.
(v) Elevation of the supply.

(b) Physical Considerations

The estimation of the quantity of water of desired quality and a proper location for siting the impounding structure are of primary concern for any water supply scheme. This consists essentially of relating the capacity of the reservoir (and therefore the height of the dam) to the distribution of run-off from the catchment area (i.e., the variations in a steam flow) during a dry period.

(c) Geological Considerations

The decision as to the practicability of dam construction on a particularly favoured site is one which rests largely on geological considerations; viz, the geology of the catchment area, of the reservoir area and of the dam itself. The geological maps should be used to study the nature of the catchment area, the reservoir area and the dam site.

(d) Site Exploration

The geological investigation should extend to the exploration of the foundations to determine their ability to carry the structure. This will involve the sinking of numerous trial holes or borings in addition to those sunk along the centre line of the dam.

(e) Computation of Storage

Storage can be computed using available scientific methods.

(f) Reservoir Management

i. Silting: Loss of capacity due to the deposition of silt in a reservoir may occur and the usefulness of the reservoir will diminish in few years. It may be minimized by proper site selection, erosion control like afforestation, reservoir operation and de-silting works.

Soil erosion and control are closely related to the silting of reservoirs since without erosion there would be no silting. Erosion prevention methods recommended for soil conservation include proper crop rotation, ploughing on contours, terracing, strip cropping, protected drainage channels, check dams, reforestation, fire control and grazing control.

Hence it is necessary to provide for silting capacity for all impounding reservoirs, based on studies or data pertaining to similar catchments.

ii. **Evaporation:** Evaporation is of importance in determining the storage requirements and estimating losses from impounding reservoirs, and other open reservoirs. Evaporation from water surface is influenced by temperature, barometric pressure, mean wind velocity, vapour pressure of saturated vapour and vapour pressure of saturated air and dissolved salt content of water. The evaporation loss in storage tanks in India amounts to 2-2.5 m/year.

iii. **Seepage:** Seepage occurs wherever the sides and bottom of the reservoir are sufficiently permeable to permit entrance of water and its discharge through the ground beneath the surrounding hills. Apart from making them impermeable to the extent possible economically, erosion control measures such as proper crop rotation, contour ploughing, terracing, strip cropping, reforestation or afforestation, cultivation of permanent pastures and the prevention of gully formation through the construction of check dams could also be useful on a long-term basis.

iv. **Algal Problems:** Reservoir management comprises of reducing the algal problems and the growth of water hyacinth. Small inflows of water rich in organic matter should be bypassed wherever possible instead of allowing them to infect the main body of the water. The water weeds in the reservoir should be controlled by suitable methods such as dragging and under-water cutting. Algicidal measures as described in Chapter 9: Disinfection may be adopted to control algae in reservoirs.

4.10 Development of Subsurface Sources

The subsurface sources include springs, wells and galleries. The wells may be shallow or deep. Shallow wells may be of dug well type, sunk or built, of the bored type or of the driven type. They are of utility in abstracting limited quantity of water from shallow pervious layers, overlying the first impermeable layer.

Deep wells are wells taken into pervious layers below the first impermeable stratum. They can be of the sunk well type or the bored or drilled type. They are of utility in abstracting comparatively larger supplies from different pervious layers below the first impervious layer. Because of the longer travel of groundwater to reach pervious layers below the top impermeable layers, deep wells yield a safer supply than shallow wells.

4.10.1 Spring-shed Management

Springs with significant flow of water (over 20m^3/ h) have usually being developed long ago and are currently used for either irrigated agriculture or human needs, but smaller flows are often over looked as potential sources of water for live-stock consumption mostly in arid and semi-arid regions where a small water flow quickly evaporates if not properly collected and conveyed.

A spring discharge of less than 0.5 m^3/h does not usually show any flow. Water disappears by evaporation and evapotranspiration in the middle of the vegetation which naturally develops around the spring. If properly collected and distributed, the same water could meet the requirements of cattles.

Discharge Measurements: A simple and accurate way to determine flow-volume of small water supplies 90º V notch. A 'V notch' for determining up to 10 m^3/h can be made from a piece of flat metal measuring 40x25 cm for which a triangular notch with a right angle is cut out. The graduation is to be written on the side of the opening. The position of Graduation (m^3/h) should be as given in Table 4.10:

Table 4.10: Graduation Discharges

Graduation Discharge (m^3/h)	Vertical distance in mm from the bottom of the notch to the Graduation
0.5	19
1	34
2	43
3	52.5
4	59
5	65
10	85

4.10.2 Classification of Wells

The wells are classified according to construction as follows:

(a) Dug wells;
(b) Sunk wells;
(c) Driven wells; and
(d) Bored wells.
(e) Artesian Wells

(a) Dug Wells

The depth and diameter of drinking wells are decided with reference to the area of seepage to be exposed for intercepting the required yield from the sub-soil layers. Unsafe quality of water may result if care is not taken in the well construction.

The bottom of the well should be at a level sufficiently below the lowest probable summer water table allowing also for an optimum drawdown when water is drawn from the well.

(b) Sunk Wells

Sunk wells depend for their success on the water bearing formations which should be of adequate extent and porosity. The sunk well is only the inter-position of a masonry barrel into such a deposit so as to intercept, as large a quantity of water, as is possible.

Construction Methods

The minimum depth of a well is determined by the depth necessary to reach and penetrate, for an optimum distance, the water bearing stratum allowing a margin for dry seasons for storage and for such draw-down as may be necessary to secure the required yield. The method of construction employed depends on the size and depth of the well, characteristics of material to be excavated and quantity of water to be encountered.

(c) Driven Wells

Construction

The shallow tube well, also called a driven well, is sunk in various ways depending upon its size, depth of well and nature of material encountered. The closed end of a driven well comprises a tube of 40 to 100 mm in diameter, closed and pointed at one end and perforated for some distance therefrom.

Such a driven well is adopted for use in soft ground or sand upto a depth of about 25 m and in places where the water is thinly distributed. It is especially useful in prospecting at shallow depths and for temporary supplies. It is useful as a community water stand post in rural area.

(d) Bore Wells

Bore wells are tubular wells drilled into permeable layers to facilitate abstraction of groundwater through suitable strainers inserted into the well extending over the required range or ranges of the-water bearing strata.

Bored wells, useful for obtaining water from shallow as well as deep aquifers, are constructed employing open end tubes, which are sunk by removing the material from the interior, by different methods.

For bored wells, the hydraulic rotary method and the percussion method of drilling such wells through hand soils are popular. For soft soils, the hydraulic jet method, the reverse rotary recirculation method and the sludger method are commonly used.

(i) Well Drilling Methods

Driven wells are constructed by pushing pipe into shallow sand and gravel aquifer to a depth of 6 to 20 m. Most modern wells are drilled by cable-toil Restoring-drill equipment.

(ii) Direct Rotary Method

With the hydraulic direct rotary method, drilling is accomplished by rotating suitable tools that cut, chip and abrade the rock formations into small particles.

Water wells drilled by the hydraulic rotary method generally are cased after reaching the required depth, the complete string of casing being set in one continuous operation.

The hydraulic rotary drilling generally requires large quantity of water which may have to be brought from long distances, if not locally available.

(iii) Percussion Method

In the percussion method of drilling, the hole is bored by the percussion and cutting action of a drilling bit that is alternately raised and dropped. The drill bit, a club like, chisel-edge tool, breaks the formation into small fragments; and the reciprocating motion of the drilling tools mixes the loosened material into a sludge that is removed from the hole at intervals by a bailer or a sand pump.

(iv) Hydraulic Jet Method

This is the best and most efficient method for small diameter bores in soft soils. Water is pumped into the boring pipe fitted with a cutter at the bottom and escapes out through the annular space between the pipe and the bored hole. When the desired depth is reached, the pipes are withdrawn and the well tube with the strainer is lowered by the same process using a plug cutter with the plug removed instead of the ordinary steel cutter.

(v) Reverse Rotary Method

In this method the water is pumped out of the bore through the pipe and fed back into the annular space between the bore and the central pipe. No casing is required in this method which is used only in clayey soils with little or no sand. This method is suitable for large diameter bores upto a depth of 150 m.

After the required depth is reached, the pipe with the cutter is taken out of the bore and the well pipe with the strainer is then lowered into the hole. The annular space between the bore and the well screen is then shrouded with pea gravel.

(vi) Sludger Method

In this method the boring pipe with the cutter attached is raised and lowered by lever action and the bore filled with water from a sump nearby. This method is suitable for depths upto about 5O metres. This method is suitable for small diameter wells in soft soils and medium hard soils.

(vii) Casing of Bore Wells

Wells in soft soils must be cased throughout. When bored in rock, it is necessary to case the well atleast through the soft upper strata to prevent caving. Casing is also desirable for the purpose of excluding surface water and it should extend well into the solid stratum below. Where artesian conditions exist and the water will eventually stand higher in the well than the adjacent groundwater, the casing must extend into and make a tight joint with the impervious stratum; otherwise, water will escape into the ground above.

(viii) Well Strainer and Gravel Pack

The openings in well strainers are constructed in such a fashion as to keep unwanted sand out of the well while admitting water with the least possible friction. In fine uniform strata, the openings must be small enough to prevent the entrance of the constituent grains. Where the aquifer consists of particles that vary widely in size, however, the capacity of the well is improved by using strainer openings through which the liner particles are pulled into the well, while the coarser ones are left behind with increased void space. A graded filter is thereby created around, with the aid of back-flushing operations or by high rates of pumping.

(ix) Yield Test for wells

The wells after their construction are tested for their yield, specific capacity and aquifer parameters as per details given in Annexure 4.3.

(e) Artesian Water & Artesian Wells

Artesian aquifer is confined aquifer containing groundwater under positive pressure. Artesian aquifer has trapped water surrounded by layers of impervious rocks which apply positive pressure to water contained within aquifer. Artesian well is the name derived for a well from which water flows automatically under pressure & well is called a “Auto-flowing” well which does not require a pump to yield water. An artesian well along with shallow and deep well are shown in Figure 4.11.

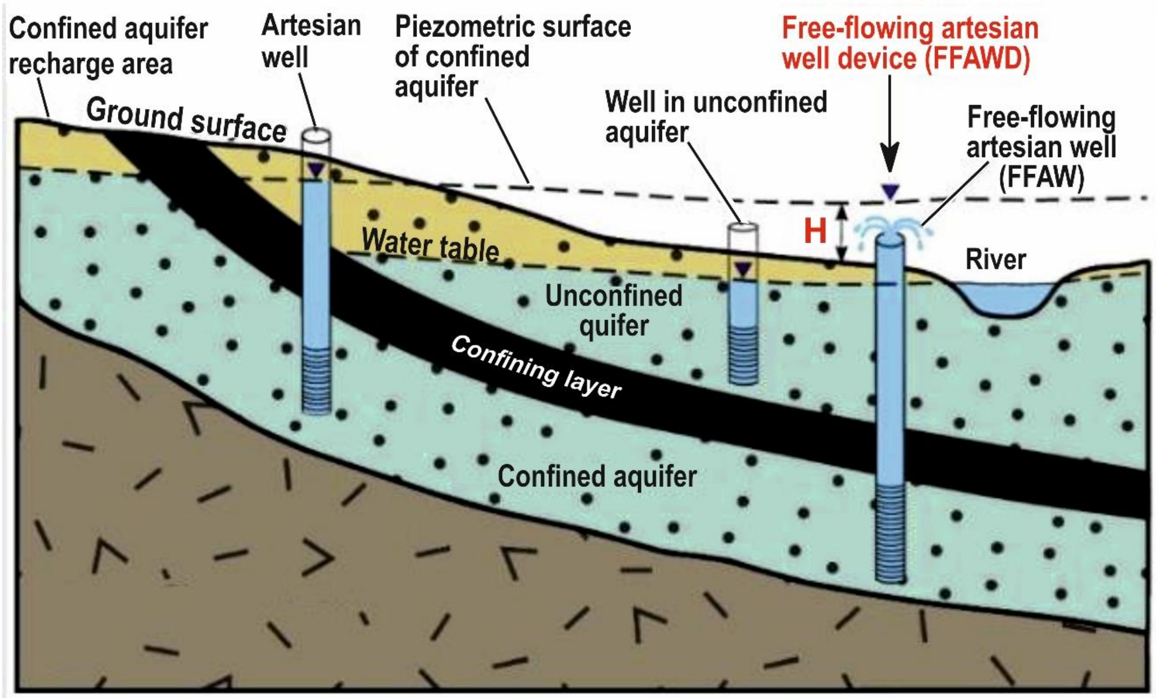

Figure 4.11: Artesian Well

Indian Artesian belt of great significance stretches along foot hills of Himalayan Regions, commonly known as Bhabbar-Tarai belt, and are located in various states as follows:

(i) Artesian wells of Uttarakhand located in Tarai area. Udham Singh Nagar district is famous for Auto-Flow Wells.
(ii) Tarai-belt of Jammu Province where sping-line exist at the contact of Bhubar & Tarai formation.
(iii) Artesian well water in Malabar Coastal plain & Alleppy.
(iv) Artesian water in Malabar coastal plain of southern Kerala.
(v) Artesian wells; Great Rann of Kachchh, Gujarat.

Artesian Wells works on the principal of Pascal's low where a liquid at high pressure in one well will increase the height of liquid in another well.

4.10.3 Infiltration Galleries

(a) Wells Vs. Galleries

These are horizontal drains made from open jointed or perforated pipes that are located below the groundwater table. Infiltration galleries offer an improvement over a system of wells. A gallery laid at an optimum depth in a shallow aquifer serves to extract the sub-soil flow along its entire length, with a comparatively lower head of depression. Moreover, in the case of a multiple system of infiltration wells, the frictional losses contributed by the several connecting pipes diminish the draw-down in the farther wells to that extent and the utility of a well becomes less and less in the total grid.

(b) General Layout

Essentially, a gallery is a porous barrel inserted within the permeable layer, either axially along or across the groundwater flow. A collecting well at the shore end of the gallery serves as the sump from where the infiltrated supply is pumped out. The collecting well is the point at which the maximum head of depression is imposed under pumping operation, the depression head being diffused throughout the length of the gallery to induce flow from the farthest reach.

The exact alignment of a gallery must be decided with reference to the actual texture of the sub-soil layers, after necessary prior investigations to map out the entire sub-soil. A gallery could be laid axially along a river or across a river. In both the cases, the head of depression induced is the factor influencing the abstraction of the sub-surface flow into the gallery liner; and the zone of influence exerted along the entire length of the gallery line will have the same variations irrespective of the direction of the gallery.

(c) Structure of a Gallery

The normal cross-section of a gallery comprises loosely jointed or porous pipe or rows of pipes, enveloped by filter media of graded sizes, making up a total depth of about 2 ½ m and a width of 2 ½ m or above, depending on the number of pipes used for collection of the infiltrated water.

The gallery has necessarily to be located sufficiently below the lowest groundwater level in an aquifer, under optimum conditions of pumping during adverse seasons.

The galleries consist of either a single or double row of stoneware or concrete pipes loose jointed with cement lock filters. Perforated PVC pipes can also be used. The pipes are laid usually horizontally or to a gradient if aligned in the direction of flow. The coarse aggregate envelope in the pipe material is in three layers, followed by coarse and medium sand layers, as detailed below;

Filtering medium near pipe line - 18 mm broken stone.

2nd layer -38 to 19 mm broken stone.

3rd layer -12 to 6 mm broken stone.

4thlayer - Coarse sand passing through a sieve of 3.35 mm size and retained on a sieve 1.70 mm size.

5th layer - Fine sand retained on 70-micron sieve and passing through 1.70 mm sieve.

The particle size distribution between each successive layer should preferably be based on a multiple of four. Precast perforated concrete barrels are also used as collecting pipes with the enveloping media on the three sides.

(d) Constructional Features

The constructional features during the execution of such galleries are of importance. Trenches are dug with adequate shoring or piling facilities right down to the required level decided upon for the invert of the gallery, which would normally be placed several metres below the sub-soil water level, a greater depth indicating a greater potential for the yield from the gallery. The gallery can be laid under water, if dewatering the trench completely for the purpose is not feasible or economical. Manholes should be provided at intervals of about 75 m for inspection. These are sunk into the bed before the gallery is laid and the floor of these wells are taken a little below the invert level of the gallery pipe. The manholes are covered with R.C.C. slab with water-tight manhole frame and cover.

(e) Check-dams

Under certain conditions, the provision of a sub-soil barrage or check darn across a river just downstream of a gallery system, helps in inundating the river-bed area over the gallery and providing permanent saturation of the sub-soil layers contributing to the yield through the gallery. The barrage is usually keyed into the river-bed on an impermeable layer and into the banks for it to function successfully. Incidentally, it would also save the gallery system against damages by scour during floods.

4.10.4 Radial Collector Wells

A well that has central caisson with horizontal perforated pipes existing radially into an aquifer is a Ranney well. It is also called a Radial collector well.

i. Constructional Details:

(a) De-sanding Operation while Driving Radials

An important operation in the driving of the drains is the operation of de-sanding of drain tubes of 200 mm to 300 mm diameter which will remain inside the sand bed being driven to a certain distance. An inner tube is then introduced into the drain which is used for sending a blast of compressed air for loosening and separating the fine particles of the alluvium at the head of the drain. When the compressed air is turned off, the pressure of the water, due to the head of the water table, enables the fine particles into the interior of the well to be carried until clear water without any fine particles is obtained.

(b) Suitability of Radial Collector Wells (RC-well) in Shallow Aquifers

Although boreholes are efficient method of groundwater extraction, but under special circumstances, collector wells are more suitable than dug well or borewell for groundwater extraction. This is where aquifer is thin and shallow of moderate permeability. Such conditions for example exist in Yamuna flood plain area in NCT Delhi. The large effective radius of shaft plus radials in a collector well make it a hydrogeological efficient method of maximizing daily yields. Shallow alluvial collector wells can be constructed in such hydro-geological environment where shallow aquifer of high permeability exist such as the flood plain aquifer system of rivers.

An RC well extracts groundwater with less drawdown at the well casing than what usually occurs at a traditional vertical well extracting water at same pumping rate.

(c) Features of a Radial Collector Well

These include:

- The horizontal perforated collector pipe which enables a large area of an aquifer to be exploited.
- The removal of fine sand and gravel in the path of the collector pipe, so that the artificial aquifer of much higher permeability is established.
- After construction, the collector pipe serves as a sub-drain in a filter surrounded by a circle of coarse gravels of very large diameter.

ii. Design Details of a Radial Collector Well:

A collector well consists of a cylindrical well of reinforced concrete say 4 to 5 m in diameter, going into the aquifer to as great a depth of the sub-strata as possible, i.e., upto an impermeable stratum. Normally the saturated aquifer should not be less than 7 m above the top of the radial pipes. From the bottom of the well, slotted steel pipes, normally of 200 mm to 300 mm diameter on the inside and going upto 30-35 metres in length are driven horizontally. The length is determined by the composition and yield from the aquifer. The drain tubes are made up of short length of pipes each 2.4 m in length which are welded to each other electrically one after the other.

These steel pipes are driven horizontally into the aquifer by means of suitable twin jacks placed in the well and crossing the steining of the well, through the special openings or port holes. At the same time, de-sanding operation is carried out through the head of the drain pipes. This operation is very important and results in the removal of all the fine particles in the alluvium thus increasing the draw-off. A radial well schematic diagram is placed at Figure 4.12.

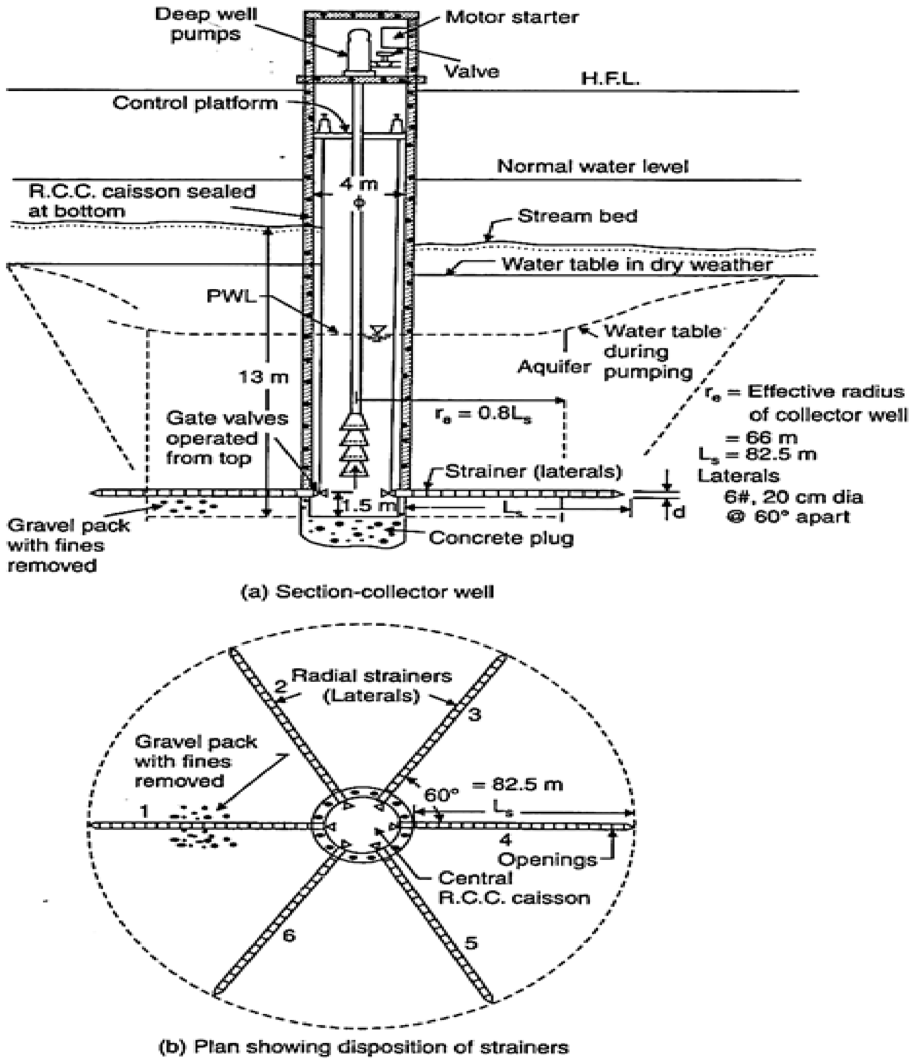

Figure 4.12: Radial Water Collector

(Source: https://in.pinterest.com/pin/323062973266073040/)

4.10.5 Filter Basins

When there is a perennial flow in a river and the sub-soil met with is hard rock below an average depth of 1.5 to 3 m, filter basins are constructed to take advantage of the perennial flow, assuming a filter rate similar to that of a slow sand filter. Sand in this area is removed and under-drains, usually loose-jointed stoneware pipes or perforated PVC pipes, are laid and covered with sand. The water from the under-drains will be led to a collecting well by C.I. or R.C.C. pipes. The collecting well which is also used as pump house is located on the bank of the river.

4.10.6 Syphon Wells

When the depth of saturated aquifer is 20 – 30 m and the conventional wells and galleries cannot be laid to take full advantage of such depths, certain alternate devices have to be tried. A syphon well will be most suitable in this case. A syphon well consists of a masonry well, 4-5 m diameter, sunk to a shallow depth and sealed at the bottom.

4.10.7 Determination of the Specific Capacity of a Well

The specific capacity of a well is the discharge per metre of drawdown at the well. In the case of artesian wells it is usually assumed that the specific capacity is constant within the working limits of the drawdown. The specific capacity decreases with duration of pumping, increase in drawdown and the life of well. High specific capacity can be ensured by proper selection of screens and gravel and thorough development.

(a) Measurement of Drawdown

The actual drawdown in wells under pumping is ascertained in several ways. In the case of shallow tube wells, dug or sunk wells, the more common method is to drop a weighted string up to the water level, before and during pumping and computing the difference. In the case of deep tube wells, a satisfactory procedure is to adopt the air pressure method.

The specific capacity may be determined either by the discharge method or by the recuperation method.

(b) Discharge Method

Using a pump discharging at a constant rate, the water level is lowered in a well and at intervals of time Δt, the water levels are noted.

The discharge equation for this method will be:

$$Q\Delta T = A\Delta h + Kh\Delta t. \qquad (4.2)$$

Where,

Q = steady rate of pumping;
A = area of section of well;
K = specific capacity of the well;
h = average drawdown during the interval Δt
Δt = interval of time; and
Δh = depression during the interval Δt.

In the above equation, Q, A and Δt are known, Δh is observed, h is measured and K can be calculated for each set of observation.

The selection of the pump capacity should be such that a desirable depression is obtained finally. The time interval Δt should be such that the depressions during the time interval are neither too great nor too small.

When the water level is maintained constantly after a particular drawdown, the equation becomes:

$$Q\Delta t = Kh\Delta t \qquad (4.3)$$

Or

$Q = Kh$, i.e., the rate of pumping equals the yield for that particular drawdown and sp. cap. = Q/h

A practical way to confidently predict yields and drawdowns for larger dia. gravel packed permanent production wells is to construct two 65 mm dia. test-wells, 0.6 m apart, pumping one well with a centrifugal pump (about 30 KL/min. capacity) and measuring the drawdown in the other. The resulting discharge divided by the drawdown in the well 0.6 m away is the expected specific capacity of 1.2 m gravel packed well to be drilled at the site.

4.10.8 Maximum Safe Yield and Critical Yield

If the well is not developed to the full capacity of the aquifer, the maximum yield is limited by the maximum permissible drawdown at the well and by the size and the method of construction of the well. In the case of shallow tubular wells, the maximum permissible draw-down may be limited by the suction lift of the pumps or by the depth of the wells. In the case of masonry sunk wells as well as tube wells, the drawdown can be further restricted with a view to preventing sand blows which may disturb the aquifer unduly. Sand blows which help to remove the fines and help in the training of the yield are, however, desirable. The maximum quantity that can be drawn may be fixed with reference to the diameter of the well and the hydraulic subsidence value of the largest site of the particles proposed to be removed during the training of the yield to get the best results. This may be termed the critical yield.

4.10.9 Spacing of Wells

The amount of water which can be obtained from a system of wells depends upon the extent by which the water level can be lowered along the line of wells. The maximum amount of water obtained from a given system of wells would be when they are spaced enough apart so that their circles of influence will not over-lap. If wells are deep and therefore, expensive, they should be spaced to interfere comparatively to a lesser extent than the shallow wells which could be spaced closer. The extent of mutual interference can be judged by pumping tests on trial wells, or on those first sunk, the wells being operated at different rates and in various combinations.

4.10.10 Design of Water Well (Bored Well)

The main objectives of the bore well design is as follows:

1. The highest yield with minimum draw down consistent with aquifer capability
2. Good quality of water with proper protection from contamination
3. Water that remains sand free
4. Well should have long life (25 years or more)
5. Low initial cost

a. Well Structure

The well structure consists of two main elements- casing and Intake zone.

b. Design Procedure

Selecting the casing diameter and material

Casing diameter of the well is important because it will significantly affect the cost of the structure. Therefore, following considerations should be given while selecting the casing pipe:

1. The casing must be large enough to accommodate with enough clearance for installation of pump, passage of drilling tools and development equipment.
2. The diameter of casing must be sufficient to assure that the up-hole velocity is 1.5m/sec or less.
3. The casing diameter should be kept 50mm larger than the pump bowls.
4. The casing should have smooth exterior to minimize resistance against the formation due to friction.
5. The casing should have sufficient wall thickness to resist the stresses from the placement and subsequent production.
6. The casing must be capable to withstand the corrosive groundwater.
7. In deep wells that have both static and high pumping water levels, the casing diameter can be reduced at a depth below the lowest pump setting to reduce material cost.

The following Table 4.11 gives the recommended diameter of well casing for various pumping rates:

Table 4.11: Recommended Diameter for Well Casing

S. No.	Expected well yield L/min	Internal Diameter of well casing (cm)		Nominal size of pump bowel (cm)
		Minimum	Maximum	
1	400	12.5	15	10
2	400 - 600	15	20	12.5
3	600 – 1400	20	25	15

4	1400 - 2200	25	30	20
5	2200 - 3000	30	35	25
6	3000 - 4500	35	40	30
7	4500 - 6000	40	50	35
8	6000 - 10000	50	60	40

Source: Ragunath, 2007

The Table 4.12 shows the Recommended Minimum Diameter for Well Casings and Screen.

Table 4.12: Recommended Minimum Diameter for Well Casings and Screen

S. No.	Well Yield (m^3)/day	Normal Pump Chamber Casing Diameter (cm)	Surface Casing Diameter (cm)		Normal Screen Diameter(cm)
			Naturally Developed Wells	Gravel Placed Wells	
1	<270	15	25	45	5
2	27-680	20	30	50	10
3	680-1,900	25	35	55	15
4	1,900-4,400	30	40	60	20
5	4,400-7,600	95	45	65	25
6	7,600-14,000	40	50	70	30
7	14,000-19,000	50	60	80	35
8	19,000-27,000	60	70	90	40

(Source: US Bureau of Reclamation, 1977)

i. **Design for sanitary protection**

All drinking water wells supplying potable water should be provided with continuous sanitary protection. Contaminated from surface drainage or low quality of water can move downward through the annulus between the casing and bore hole wall. The annulus around the casing must be sealed either by placing a cement grout in the annulus. Sometimes bentonite is used in place of cement.

ii. **Disinfection of Wells and Pipelines**

New wells as well as those after repairs have to be disinfected by heavy dose of chlorine. The doses applied are generally of the order of 40 to 50 mg/L of available chlorine and bleaching powder is usually employed. For pipelines, when a section of water main is laid or repaired it is impossible to avoid contamination of the inner surface therefore disinfection is needed. The further details about disinfection of wells and pipelines are provided in Annexure 4.4.

4.11 Groundwater Recharging Methodologies

4.11.1 Conventional Recharging Methods

Groundwater recharging methods are broadly classified into four categories of techniques. These are as given Table 4.13 below:

Table 4.13: Groundwater Recharging Techniques

(i)	Direct surface techniques • Flooding • Percolation ponds/basins • Ditch and Furrow system • Over-irrigation
(ii)	Direct sub-surface techniques • Injection wells • Recharge pits/shafts • Dug well Recharge • Bore-hole flooding • Cavity fillings
(iii)	Combined Surface and Sub-surface techniques • Basin or Percolation tanks with pit-shaft or bore-wells.
(iv)	Indirect Techniques • Induced Recharge from surface water sources. • Aquifer modification

In addition to above, the following groundwater conservation structures also help arresting of sub-surface flows:

(i) Groundwater Dams or Sub-surface Dykes
(ii) Hydro-fracturing and blasting in Hard Rock areas.
(iii) Cement sealing of fractures through specially constructed bore wells to consuming sub-surface flow and augmenting bore-well yield.

4.11.2 Managed Aquifer Recharge (MAR) Innovations

Adoption of innovative MAR approaches to pursing sustainable water management is an inescapable necessity of time particularly when changing climates are impacting water & water infrastructure system. Achieving sustainable & secured urban water supply & services would need to use holistic IUWM framework. The suggestive MAR innovations include Aquifer storage & Recharging System (ASR), River & Lake-Bank Filtration System (RBF/LBF) with storage goal and potable water use. Also, MAR System such as Modular Rain Tank System, In-stream modifications & recharge, conventional RWH System with non-storage goals can be used to support non-potable urban water supply uses. Role of stake holders & water managers is imperative to sustainable urban water management.

1. **Urban Aquifers & MAR Systems:** The depth, limit & extent as well as Empty-storage space of both Alluvial & Hard rock aquifers are pre-requisite to planning MAR systems. Aquifer sensitivity maps, maps of potential contaminant sources and maps showing direction and rate of movement of groundwater flow are of paramount importance to develop aquifer recharging plans. There has to be compatibility between source recharge water and native groundwater under recharge. Due to complex nature of aquifer systems, the complexity of hydrogeologic-framework is also required to be investigated in detail prior to recommending the design, suitability and feasibility of MAR methods and recharging structures.

2. **Source Water for Recharging:** Managed recharge to aquifers can be used to store water from various sources such as urban storm water from roofs of houses and buildings, pavements and roads which shed water from their embankments. Source water also includes water from rivers & lakes, ponds, treated waste water and desalinized sea-water. Recycled urban storm water can be stored in aquifer underlying parks &gardens, sports complexes and fly-overs for non-potable uses.

   Urban water systems are faced with impacts of climate change, rapid urban population growth, population migration from rural to urban centres as well as deteriorating age-old water infrastructure. The need to manage urban water supply has therefore been an urgent necessity and inescapable necessity of time. The integrated urban water management (IUWM) seeks to integrate planning, management and, community participation to building climate –resilient city and township water supply and sanitation system. IUWM is holistic management of urban water supply, sanitation, storm water & wastewater to yielding sustainable socio-economic & environmental objectives. Various IUWM application tools can help water utilities manage the threat & menace of climate change.

3. **Priority MAR Methods:** The Empty storage capacity of urban Aquifers classify themselves into priority category areas (viz. priority I & priority II Category Area) to the recharging of groundwater.

   Priority I category MAR project will involve high value use areas as potable supply water & priority II as lesser value use areas for non-potable water use such as for horticulture & watering of parks & gardens. It is imperative to list out the priority I & II MAR Projects. These are given in Table 4.14 below

Table 4.14: MAR Priority Projects

I	Priority I MAR Project (For potable water use)	:	Recharge System • ASR & ASTR Well System.

			• River Bank Filtration (RBF) & Lake Basin Filtration (LBF) System
II	Priority II MAR Projects (For Non-potable water use)	:	• Check dams, Gabbion & Nalabunds. • City Roads, Sports complex, Fly overs • Shafts & Trench driver bore wells. • Pond basins.

4.12 Integrated Water Resources Management (IWRM):

The challenges facing today's major cities are daunting, and water management is one of the most serious concerns. Potable water from pure sources is rare, other sources of water must be treated at high cost, and the volume of used water is growing. City dwellers in many areas of the Country lack good-quality water and fall ill due to waterborne illnesses. As cities seek new sources of water from upstream and discharge their effluent downstream, surrounding residents suffer the effects. The hydrologic cycle and aquatic systems, including vital ecosystem services, are disrupted.

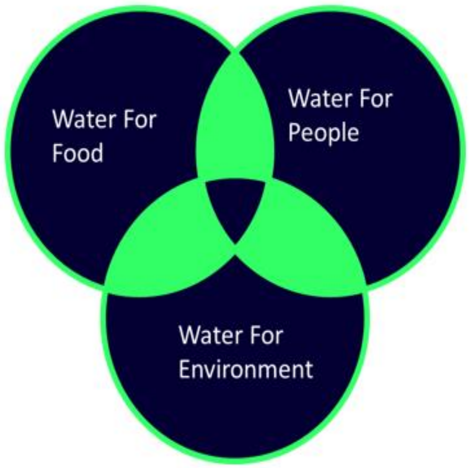

Figure 4.13: Definition Sketch of IWRM
(Source: IWRM, 2005)

Water is a primary requirement for survival, yet its effective management in terms of diversion, transport, storage, and recycling is one of the most elusive targets. An efficient water Supply, sanitation, and allied services have tremendous socio-economic and health benefits, a fact that has been reiterated by United Nations' Sustainable Development Goal (U.N. SDG) number 6. Level of water availability, quality of piped water and used water treatment, reuse and recycle levels are often considered proxy indicators for the level of development of a nation. Government schemes to provide clean, safe water and necessary sanitation facilities to every citizen in India, have served to reinforce our national commitment for better water services. However, a great deal of preparedness is necessary from the grassroots level to enable superior water resource management. India has a two-tier governance system for management of its water resources- the first tier consists of the Central Governmental agencies which deal with policy matters on inter-state rivers, flood management and international water issues, while the second level consists of State water/water resource authorities/ULBs, which are responsible for management of water resources, water supply and sanitation services in the respective states.

India's intermittent water supply can only provide water for more than a few hours to the 49 Indian cities with a population of more than one million. Water is usually pumped to large distances and high elevations, greatly increasing the associated energy costs. While surface water is the primary source in most locations, there is significant dependence on groundwater in regions where surface water sources do not provide reliable supply across the year. In the absence of appropriate recharge measures results in depleting groundwater resources, which in turn leads to saltwater intrusion in coastal aquifers, and other problems associated with deterioration of groundwater quality. According to the guidelines issued by the CPHEEO, 150 lpcd (litres per capita per day) for mega cities, and 135 lpcd (IS 1172:1993, 1993) is considered as allowable for consumption at locations (towns/cities) where there is access to public underground sewerage system. In the absence of such systems, the value is 70 lpcd (Central Public Health and Environmental Engineering Organization (CPHEEO), 1999). Ever-growing urban populations have intensely stressed available water resources for any city or town. Water demand is one of the major uncertainties for operation and management of a Water Distribution System (WDS), which varies seasonally and regionally.

The per capita availability of water in India is less than 1,000 m^3/capita/year based on the estimated utilizable water resources of 1,123 BCM (Ministry of Water Resources (MoWR), 2012), about 1,588 m^3/capita/year (Office of the Registrar General India, 2011) which makes us among one of the most water stressed countries in the world. The population in India has increased by about 181.5 Million from 2001 to 2011(Office of the Registrar General India, 2011), and the similar rate of increase is expected in the near future as well. With this rate of population increase, stress on water resources is inevitable. It is suggested that by 2030, India will face water scarcity amounting to 50% of its water demand, or 75 BCM (billion cubic metres) (United Nations' Children Fund (UNICEF), 2013).

The National Water Policy (Ministry of Water Resources (MoWR), 2012) recommends priority of water allocation to be retained for drinking and sanitation followed by agriculture and supporting livelihood for the poor. The policy emphasises on avoiding wastage on unnecessary uses and utilising water judiciously.

Providing adequate quantity and safe quality of drinking water are key priorities of most Indian States, and there are numerous challenges that inhibit accomplishing such objectives. Water quantity estimations are performed by assessing supply and demand levels. Supply-side management involves infrastructure optimisation, preventive maintenance, minimisation of losses, metering of connections etc. Demand management, on the other hand, involves social awareness, effective usage of supplied water, pricing, billing and minimization of losses or Unaccounted For Water (UFW) (Mohan Kumar et al., 2013). Parity between demand and supply levels is necessary for efficient distribution and reducing residence time of water within the Water Distribution System (WDS), which is required to preserve the integrity of the water quality. Water pricing and household metering has been seen to reduce additional demands (Ruijs and Zimmermann, 2008).

Even urban water demand increases due to growing populations, water supplies may become scarce as precipitation patterns, river flows, and groundwater tables change (UN-Habitat, 2011). Some sources may become unsuitable for certain uses (e.g., salinity may limit water for agricultural use), and the cost of water treatment may rise (e.g., eutrophication may require additional treatment of domestic water). For some fast-growing desert and semi-desert megacities, water scarcity may be severe. Climate change is likely to affect water supply technologies, primarily through flood damage, increasing treatment requirements and reducing availability and operational capacity. Extended dry periods will increase the vulnerability of shallow groundwater systems, roof rainwater harvesting, and surface waters.

Climate change also poses significant threats to the reliability and resilience of our water sources. Clearly, sustainable water resources management calls for an integrated approach and constant monitoring and re-adjustment of all its components.

It is prudent to note that the IUWRM is a subset to IWRM which is more aligned towards water management on broader and larger catchment scale. IUWRM is more aligned towards managing the water resources on a sustainable basis in an urban setting. In the following discussions, IWRM is used more to represent IUWRM.

4.12.1 Rationale of IWRM

In the past, water supply, sanitation, used water treatment, stormwater drainage, and solid waste management have been planned and delivered largely as isolated services. Conventional Urban Water Management seeks to ensure access to water and sanitation infrastructure and services. Conventional urban water management strategies, however, have strained to meet demand for drinking water, sanitation, used water treatment, and other water-related services. Some cities already face acute water shortages and deteriorating water quality.

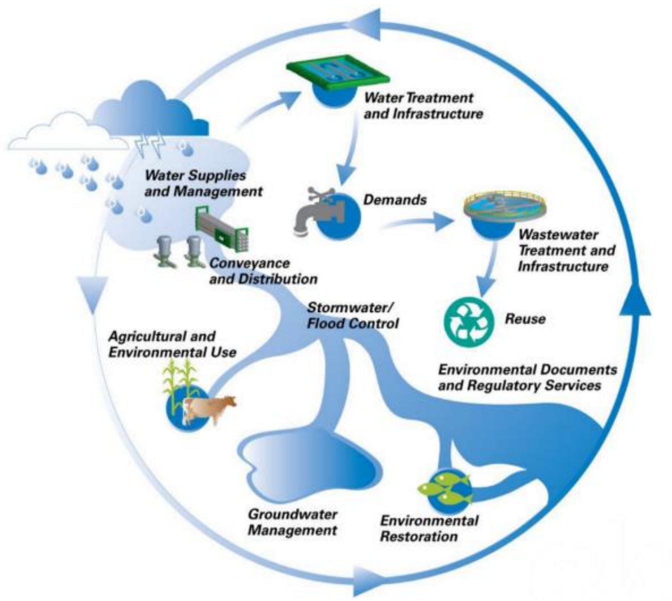

Figure 4.14: The Principles of IWRM
(Source: www.google.co.in/natural + resources)

It must also manage rainwater, used water, stormwater drainage, and runoff pollution, while controlling waterborne diseases and epidemics, mitigating floods, droughts, and landslides, and preventing resource degradation. Even though conventional urban water-management strategies have been unable to respond to existing demands, more will be asked of urban water management in the future. Given the challenges posed by urban growth and climate change, conventional urban water-management practice appears outdated.

A range of authorities, each guided by distinct policies and pieces of legislation, continue to oversee water subsectors at the city level. The traditional urban water-management model has failed to distinguish between different water qualities and identify uses for them. As a result, high-quality water has been diverted to indiscriminate urban water needs (Van der Steen, 2006). This issue is not confined to city boundaries: basin-level management often neglects to acknowledge the cross-scale interdependencies in freshwater, used water, flood control, and stormwater. Water is extracted from upstream sources and delivered to urban areas, where it is used and polluted, then re-channelled – often untreated – downstream.

Water issues often remain disconnected from broader urban planning processes. This problem is particularly evident in developing countries, where modern urban development, associated with the design of physical human settlements and land-use zoning schemes, still hold sway (UN-Habitat, 2009).

IWRM includes assessments to determine the quantity and quality of a water resource, estimate current and future demands, and anticipate the effects of climate change. It recognises the importance of water-use efficiency and economic efficiency, without which water operations cannot be sustainable. It also recognises that different kinds of water can be used for different purposes: freshwater sources (surface water, groundwater, rainwater) and desalinated water may supply domestic use, for example, and used water (black and grey water) can be treated appropriately to satisfy the demands of agriculture, industry and the environment. With efficient new desalination technologies, saltwater has become an accessible water source.

Therefore, integrated urban water resource management (IWRM) promises a better approach than the current system, in which water supply, sanitation, stormwater and used water are managed by isolated entities, and all four are separated from land-use planning and economic development. IUWM calls for the alignment of urban development and basin management to achieve sustainable economic, social, and environmental goals

The traditional fragmented sectoral approach and that of the cross sectoral integrated approach are respectively shown in Figure 4.14 and Figure 4.15.

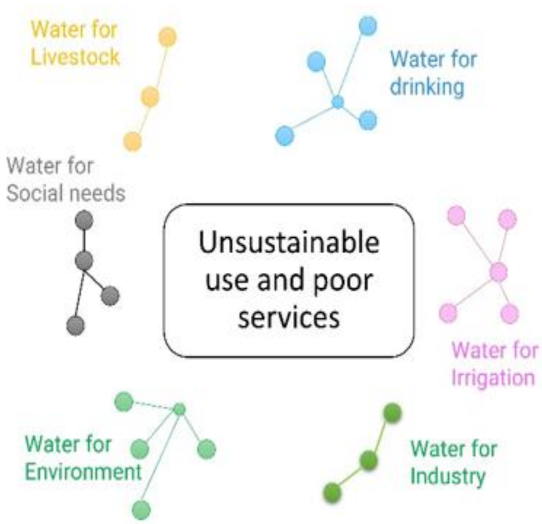

Figure 4.15: Traditional Fragmented Sectoral Approach

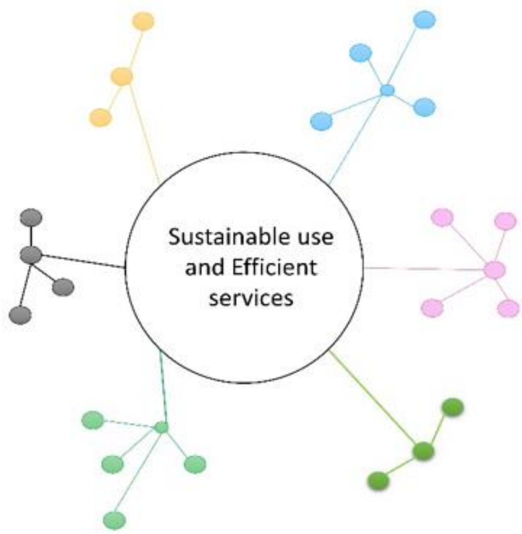

Figure 4.16: Cross-Sectoral Integrated Approach

Demerit of the traditional fragmented sectoral approach is that it can create problems and pushing the system to unsustainable use and poor services. For example. City administration makes drinking water reservation in the live storage of the dam. But sometimes, if dam authority releases excess water for irrigation, then there will be chaotic conditions, lot of tankers will have to be used. Moreover, if dead water from dam is utilized it will pose problems of taste, colour and odour and there will be unrest in city customers.

Similarly, putting domestic sewage or releasing industrial pollutions will pose health problems. In IWRM since there is cross-sectoral integrated approach, such situations are avoided and system runs efficiently. Thus, IWRM is a process which helps to deal with water issues in a cost-effective and sustainable way.

4.12.2 Objectives and principles of IWRM

Objective of an IWRM Plan is to promote development that coordinates management of water, land and related resources so as to maximise the resultant economic and social welfare. One of the major aspects considered in development of this approach includes identification and development of an optimized solution that is based on techno-economic evaluation of various available water sources or combinations thereof.

The goals of urban water resource management are to ensure access to water and sanitation infrastructure and services; manage rainwater, used water, stormwater drainage, and runoff pollution; control waterborne diseases and epidemics; and reduce the risk of water-related hazards, including floods, droughts, and landslides. All the while, water management practices must prevent resource degradation.

Under IWRM Plan, Triple-Bottom-Line (TBL) Principles has been used to help identify the most preferred water infrastructure solution.

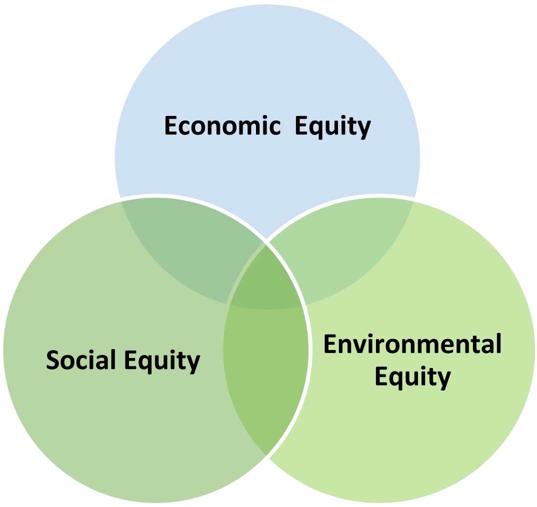

Figure 4.17: The Triple Bottom Line Principle

The most preferred solution is to be an optimal mix of social, environmental and economic benefits as well as being practical and recognizes that ideal and perfect solutions seldom exist in the real-world as shown in Figure 4.17.

Integrated urban water management (IWRM) offers a set of principles that underpin better coordinated, responsive, and sustainable resource management practice. It is an approach that integrates water sources, water use sectors, water services, and water management scales:

- It recognises alternative water sources.
- It differentiates the qualities and potential uses of water sources.
- It views water storage, distribution, treatment, recycling, and disposal as part of the same resource management cycle.
- It seeks to protect, conserve and exploit water at its source.
- It accounts for nonurban users that are dependent on the same water source.
- It aligns formal institutions (organisations, legislation, and policies) and informal practices (norms and conventions) that govern water in and for cities.
- It recognises the relationships among water resources, land use, and energy.
- It simultaneously pursues economic efficiency, social equity, and environmental sustainability.
- It encourages participation by all stakeholders.

Under IWRM, supply management and demand management are complementary elements of a single process. There is no one-size-fits-all model nor is any single method sufficient. Rather, the mix of approaches reflects local socio-cultural and economic conditions.

4.12.3 Development of IWRM Plan

Global Water Partnership (GWP) as part of the Dublin-Rio statement of 1992 defines "Integrated water resources management is based on the equitable and efficient management and sustainable use of water and recognises that water is an integral part of the ecosystem, a natural resource, and a social and economic good, whose quantity and quality determine the nature of its utilisation.". An IWRM Plan adopts sustainable, resilient and cyclical water resources utilisation in an urban setting. In essence, it reflects the 'Whole to Part' approach in managing water on a city or urban centre level, where the water demand emanates from multiple users, and water supply comprises of different sources from single or multiple watersheds. Efficient and equitable distribution of water; collection, treatment, and safe disposal and/or reutilisation of used water; creating financial sustainability and concerted stakeholder engagement forms the core of an IWRM Plan.

4.12.4 Vision and Scope of IWRM Plan

IWRM is the only feasible way forward to ensure water security for Indian cities. This integrated approach requires collaboration with multiple stakeholders from diverse backgrounds- ranging from hydrology, hydraulics, chemists, microbiologists, management, data sciences to social sciences among others. Some of the key considerations while building IWRM systems are summarized as below:

- IWRM solutions should be uniquely tailored for each catchment and city. One must remember that IWRM solutions are not a one-size-fits-all, but should be customized for the local hydrology, climate, geology, water use patterns, demographics and other relevant factors. For example, separate IWRM plans should be developed for Mega, Tier I and Tier II cities, to effectively reflect local conditions, treatment capabilities and environmental requirements
- Multiple sources of water should be delineated by cities, which have satisfactory levels of quality and reliability, now and in the future
- These sources must be protected from external contamination to avoid excessive treatment costs at subsequent stages
- Water distribution systems should be carefully planned, with extensive monitoring to improve control over the quantity and quality of water at various stages from catchment-to-consumer. Data-driven analyses should be used to model system behaviour and predict future performance for various scenarios of uncertainty.
- Used water should be viewed as a resource, and recycled into the system to augment water availability. Cities should aim for innovative uses of secondary or tertiary treated water in order to minimize the burden on freshwater resources
- Water balance studies need to be conducted at a city-scale, to account for all sources, demands and recovery channels
- Tertiary treated water can be used to create natural river systems, groundwater recharge systems or can be additionally treated and blended with freshwater resources to make it fit for potable and other purposes
- Any IWRM project should account for various scenarios of urbanization, population growth and climate change, and be prepared with suitable responses

Development of an Integrated Urban Water Resources Management Plan requires a multi – disciplinary, holistic and systematic approach. It should promote practices that are focussed towards delivering solutions that will create a desirable future for people, business and the environment in the Project Area, and forms the basis for developing a healthy state of dynamic balance between human, natural and economic and environmental/ ecological systems.

4.12.5 Approach

The overall project approach for delivering a sustainable IWRM Plan is built on three fundamental objectives as follows:

- To develop an optimised solution, based on techno-economic evaluation of alternatives to effectively utilise all the available water resources in a sustainable manner to address the water demands as development grows in the future.

- To develop a robust suitable Operating Model and large data management tools that are highly efficient in optimising the operations of water infrastructure in an effective and accurate manner, and will also act as a dynamic decision support tool for managing magnitude / multitude of scenarios.
- To develop a sustainable Integrated Urban Water Resources Management Plan that incorporates a strategic prioritization of planned projects.
- To achieve the above-mentioned objectives the project activities are distributed in three consecutive stages as shown in Figure 4.18.

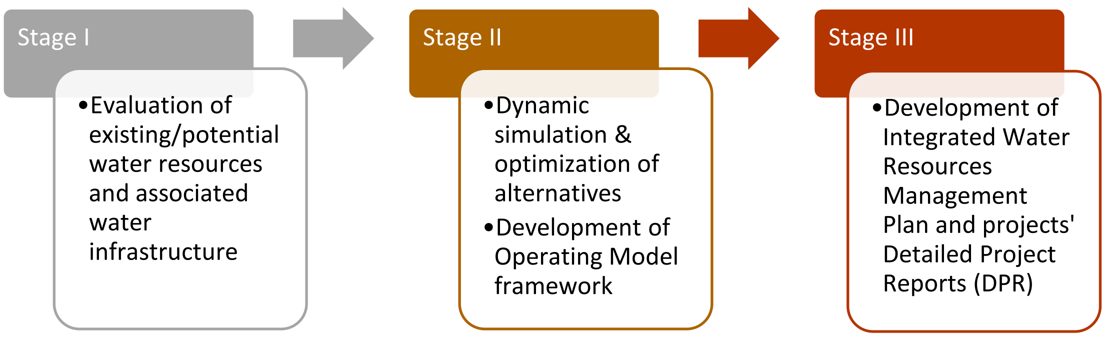

Figure 4.18: Staging of Project Activities

The guidance for developing an IWRM following the stages presented in Figure 4.18 are briefly explained below.

4.12.6 Stage I – Evaluation of Existing Water Resources and Associated Infrastructure

4.12.6.1 Overview of Existing Resources

A holistic water source identification should be performed to develop a diverse water portfolio. Identification of sources can be done based on Multi Criteria Analyses, where selection each source is assessed based on it societal, environmental, economic and technical impact. It is important that all available water sources, such as surface water, ground water, harnessed rainwater, used water, recycled water, inter basin water transfer, seawater, non-Revenue water etc. are identified and evaluated before finalising the water portfolio.

While the available quantity and quality of the source water is of primary importance, the reliability of the source should be keenly analysed too. Reliability refers to the dependability of the source to provide the requisite quantity and quality of water across various seasons in a year, and also several years down the line as urban water demands grow. Ideally an urban settlement should have not just one, but multiple reliable sources (both surface water and groundwater) to provide water under various scenarios of climate change and land use-land cover change and/ or exigencies like droughts. While calculating the water demands of an urban area, care should be taken to make allocations for recreation, environment and ecology, and urban river rejuvenation besides the usual water demands for human and economic development.

Perform quantitative and qualitative assessment for all potential sources of water in the form of 'Strengths Weaknesses Opportunities Threats' (SWOT) Analysis. The SWOT analysis will form the basis for identifying the aspects that needs to be addressed prior to development of an IWRM Plan.

The details of various potential sources are as under.

- Surface water
- Groundwater
  - Groundwater depths
  - Hydro-Geochemistry/Groundwater Quality
- Treated used water and recycled water
- Rainwater (rooftop and/or at catchment level)[1]
- Storm water
- Seawater desalination
- Water demand management
  - Non-Revenue Water (NRW) reduction,

a. Surface Water Resources

The initial step towards ensuring safe drinking water supply is protecting the surface water source from contamination via (untreated) domestic, agricultural, industrial sewage. According to the World Water Assessment Programme (WWAP), 70% of the untreated domestic and industrial waste is dumped into water bodies, which renders the source unusable or leads to very high treatment costs. Increasing pollution and rapid depletion of surface water sources often increases the dependence on groundwater sources for supply.

Availability of the reliable source through the project period is most important parameter that need to be considered. Allocation of surface waters to drinking and other purposes from water resources department of the state, which handles all water requirements is the key factor.

[1] Urban flooding is a critical component of stormwater management, and is explained under the Appendix to this document.

Surface water sources may contain high levels of faecal coliform, indicating the necessity for thorough disinfection. Treatment technologies should be ascertained not only based on current pollutant profiles, but also by anticipating the occurrence of emerging contaminants such as pharmaceutical and personal care products (PPPs), pesticides and endocrine disrupting compounds (EDCs), micro-plastics etc.

b. Ground Water Resources

These groundwater sources have been seen to contain high levels of nitrate, arsenic and fluoride. Wells, which are commonly used for extraction of groundwater resources, are vulnerable to contamination from surrounding areas, as are the surrounding aquifers if polluted waters are allowed to seep into the ground. Indiscriminate groundwater withdrawal in coastal regions exacerbates saltwater intrusion, further deteriorating the quality of groundwater resources in the area. Clearly, the need for robust source protection measures cannot be undermined. Investments in source protection translate directly into savings in treatment costs and source replacement costs. Further, it should be noted that the suitability of a source to provide drinking water to a community should be ascertained not only on the basis of its yield/ water availability but also on its quality, which directly impacts public health.

For groundwater development status, below in Table 4.15**Error! Reference source not found.** presents the guideline that can be adopted. Ground water status mapped by CGWB / State Ground Water Department could be the starting point for such analysis. Other survey data obtained by educational, research or private organizations can also be used.

Table 4.15: Groundwater Balance

<table>
<tr><th colspan="3">Groundwater Resource Balance</th></tr>
<tr><td rowspan="5">Annual Replenishable Groundwater Resource</td><td rowspan="2">Monsoon Season</td><td>Recharge from Rainfall</td></tr>
<tr><td>Recharge from other source</td></tr>
<tr><td rowspan="2">Non-Monsoon Season</td><td>Recharge from Rainfall</td></tr>
<tr><td>Recharge from other source</td></tr>
<tr><td colspan="2">Total</td></tr>
<tr><td colspan="3">Extraction During Non-Monsoon Season (Loss)</td></tr>
<tr><td colspan="3">Net Annual Groundwater Availability</td></tr>
<tr><td colspan="2" rowspan="2">Annual Groundwater Draft (Demand)</td><td>Urban Irrigation</td></tr>
<tr><td>Domestic & Industrial Users</td></tr>
</table>

Groundwater Resource Balance	
	Total
Groundwater Deficit Volume	
Stage of Groundwater Development (%)	

c. Treated used water and reuse water.

Typically, the treated used water is either directly or indirectly discharged into river or disposed on open land. Only a small portion of the treated used water that is currently being generated by various Used Water Treatment Plants (UWTP) is used for non-potable needs. Need-based treatment for the consumer refers to a level of treatment required to satisfy water quality for intended use. For example, if water is intended to be used for flushing or gardening, it does not have to be treated to drinking water standards. This approach not only ensures a net saving in treatment costs, but also reduces the burden on high-quality drinking water.

Recycling and reuse close the loop between water supply and used water disposal. Integration of these two water management functions requires forward-looking planning, a supportive institutional setting, coordination of infrastructure and facilities, public health protection, used water treatment technology and siting appropriate to end uses, treatment process reliability, water utility management, and public acceptance and participation.

As many cities now focusing on circular utilisation of treated used water and recycled water, depending on the end uses (indirect potable or direct non-potable) water quality plays an extremely important role. Such an approach is also linked with Need Based Treatment, wherein the product water is treated at different level based on end user requirement (irrigation, land-based disposal, disposal to water body, industrial uses).

d. Rain water

Rainwater harvesting can help address water scarcity at the household level and may be easy and cost-effective to implement. Flow- or roof-water harvesting provides a direct water supply and can recharge groundwater, while reducing flooding. Such measures may be an immediate solution to accompany long-term infrastructure improvements in water supply and drainage

e. Storm water

Storm water can mitigate intense rainfall events and enhance local water sources. Cities that suffer from flooding have several options for urban stormwater management, such as using retention ponds, permeable areas, infiltration trenches and natural systems to slow the water down

f. Sea Water Desalination

Desalination systems could be adopted to supplement water availability in coastal areas, to reduce the stress on freshwater resources. In cities that have exhausted most of their renewable water resources, desalinated water meets both potable and industrial demand. The cost of producing desalinated water was estimated about Rs. 48.80 per cubic meter (levelled tariff) which is being paid by Govt. of Tamil Nadu and Chennai Metro Water Supply and Sewerage Board to a Private company for a period of 25 years starting from the year 2009-10 (100 MLD Desalination Plant set up at Minjur, Chennai on DBOOT Basis).

g. Non-Revenue Water

Non-revenue Water (NRW) is an issue with almost all water supply utilities in India. It includes physical and commercial losses and free authorized water for which payment is not collected. The average NRW in India is about 38%, just above the global average range of 30% to 35% reported by the World Bank. The control of NRW will conserve the fresh water resources and prevent the augmentation of water resources and postpone the investment.

4.12.6.2 Source Water Quality

Extensive catchment-to-catchment-via-consumer (C2C via C) monitoring should be carried out by water supply authorities / boards. The concept of C2C via C refers to monitoring of water at every step of its transmission: from the source to consumer (as drinking water) and subsequently from consumer back to a source (as treated, partially treated / untreated used water). C2C via C monitoring enables water boards to keep track of the quantity and quality of water being generated, used, re-used and eventually sent back to the catchment. Reliable flow, pressure and water quality sensors, placed at optimal locations along the water supply system can be beneficial to detect both pressure and discharge/flow rates, leaks, water quality anomalies, contamination events etc. Also, historic databases generated, can be used for better system monitoring, control and behaviour prediction. Internet of Things (IoT)-based sensor measurements should be carefully validated and curated, and their accuracy should be cross-checked through regular calibration before further analysis. This should be a continuous process.

While the chief goal of water distribution in a city is to achieve a per capita target of supplied water, it is equally important to prioritize water quality during planning. The quality of water supplied has a direct bearing on human health and well-being. Improved quality of supplied water will not only reduce occurrences of various water-borne diseases, but also reduce the dependence on home-treatment units (such as RO units) or bottled water. Ensuring the supplied water meets the recommended standards, both spatially (across all locations in a city, State or country), diurnally and temporally (all seasons of a year, both during monsoon and low-flow periods in a river) is a crucial step towards IWRM. Some important water quality aspects have been discussed below. This should not be treated as an exhaustive list, but rather an indicator for priority areas to be explored.

I. Source and Well-Head Protection

Wells, which are commonly used for extraction of groundwater resources, are also vulnerable to contamination from surrounding areas, as are the surrounding aquifers if polluted waters are allowed to seep into the ground. These groundwater sources have been seen to contain high levels of nitrate, arsenic and fluoride. Indiscriminate groundwater withdrawal in coastal regions exacerbates saltwater intrusion, further deteriorating the quality of groundwater resources in the area. Clearly, the need for robust source protection measures cannot be undermined. Investments in source protection translate directly into savings in treatment costs and source replacement costs. Further, it should be noted that the suitability of a source to provide drinking water to a community should be ascertained not only on the basis of its yield/ water availability but also on its quality, which directly impacts public health.

II. Need-based Water Treatment

As the water quality from surface- and groundwater sources varies considerably, need-based water treatment processes should be adopted for removal of pollutants. Need-based treatment for the supplier refers to targeting the commonly occurring pollutant groups in particular source of water. This kind of treatment relies on prior knowledge of the common pollutants found in a source. For example, groundwater sources are found to contain higher levels of arsenic or fluoride. Additional arsenic/ fluoride treatment units must be installed along with the conventional treatment system, keeping in mind that the waste sludges thus generated should be disposed safely.

III. Integrity of Water Within the Distribution System

Even after treatment, there are several factors within the WDS, that lead to deterioration of water quality. Aging pipelines, pipe-breaks or leaks make a WDS vulnerable to contamination. The water supplied through distribution networks provides a favourable environment for bacteriological growth due to corrosion, sediment accumulation, , long residence times, the presence of nutrients etc. Such detrimental effects undermine the quality of water post the water treatment plant. WDS integrity is, thus, of primary concern to ensure maintenance of satisfactory water quality during distribution. Water quality monitoring and contamination event detection systems throughout the WDS pose a technical challenge to every water utility, but are essential for ensuring safe drinking water supply in addition to ensuring WDS integrity. Regular maintenance and cleaning protocols can help prevent unexpected deterioration in water quality. Transmission mains should also be subject to such protocols, to ensure that all pipelines preserve the quality of the treated water as much as possible.

Disinfection By-Products (DBPs) are formed by the interaction of Natural Organic Matter (NOM) present within the WDS with the residual chlorine in water. Common DBPs are trihalomethanes (THMs), haloacetic acids (HAAs) etc. Considering the potential carcinogenic effects of DBPs on humans, DBP control should be a priority for water boards. Alternative treatment processes like UV radiation and ozonation etc. show promise in tackling DBP formation. These treatment technologies are associated with significantly higher treatment costs. A thorough cost-benefit analysis, which would enable selection of such alternate treatment methods, to ultimately meet the goal of improved water quality is required.

Chlorine dosages in water treatment plants are ascertained to ensure the presence of an optimal residual chlorine concentration within the distribution system. Generally, a lower limit and upper limit (0.2 mg/l and 0.5 mg/l) is provided for these residual concentrations, such that the chlorine concentration is sufficient to account for bulk and wall reactions but not high enough for the formation of Disinfection By-Products (DBPs) which are carcinogenic in nature. However, in large distribution networks (with high water age) or old pipelines (with extensive bio-film deposits) the residual chlorine concentration falls below the desired limit, jeopardizing the quality of the supplied water. Booster doses may be necessary at intermediate locations in the distribution system to maintain optimal residual chlorine concentrations.

IV. Water Safety

Any failure to ensure a safe drinking water supply is a significant public health risk, which leads to higher healthcare costs and lower economic productivity. To avoid such failures, the World Health Organization's (WHO) Guidelines for Drinking Water Quality (GDWQ) lays out a detailed Water Safety Plan (WSP). This Plan provides comprehensive management strategies to prevent disease outbreak by protecting catchment-to-consumer water flow from contamination, by optimizing treatment plant performance, preventing contamination during storage, distribution and handling of the treated drinking water. Error! Reference source not found. provides a pictorial representation of the safe drinking water supply framework, which includes WSP.

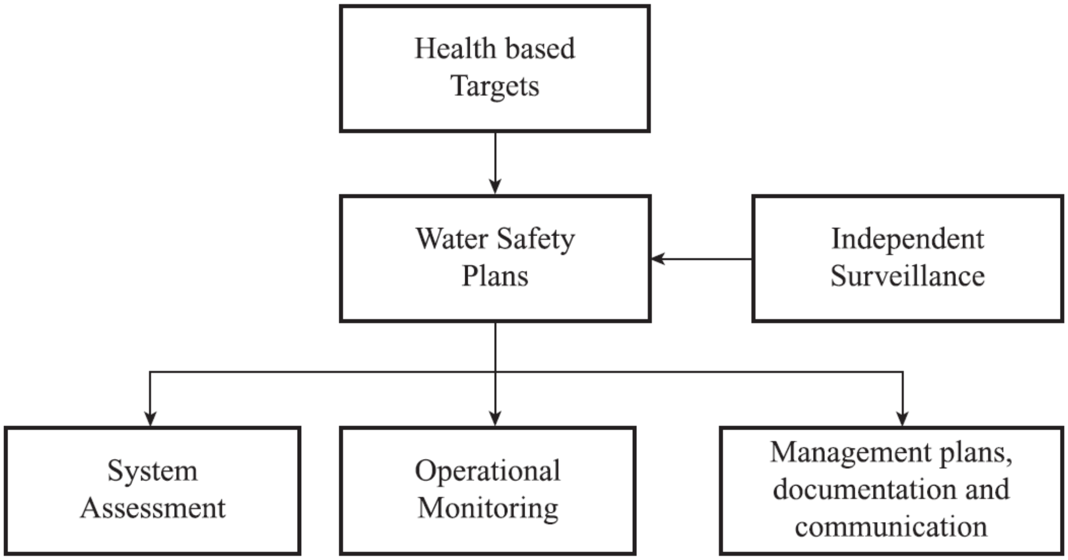

Figure 4.19: Holistic framework (including Water Safety Plan) for ensuring safe drinking water supply (adapted from Mohan Kumar et. al., 2013)

Post 9/11, the global water community has become increasingly aware of the threats of bio-terrorism and cyber-attacks through water systems. Increased automation in control and distribution opens up urban water systems to such external threats, several of which were previously unheard of. Such situations bring up challenging questions on the optimal placement of water quality sensors within a WDS, to minimize the risk and time of exposure to any accidental/ intentional contamination. Ostfeld et.al, (Ostfeld et al., 2008) lay out several algorithms to determine optimal sensor placement to minimize public health risks. Cyber-security protocols should also be updated continuously, to prevent unscrupulous elements from gaining control of urban WDSs.

V. Used water Treatment, Reuse and Recycling

Used water treatment is a very important component of IWRM. A good water supply system should be complemented with a robust used water collection and treatment system. Sustainable water use can be achieved only if cities in India resort to minimal (or near-zero) water wastage systems. Many present-day systems are a “disposal-based linear systems,” where untreated sewage is disposed into surface or groundwater resources, rendering them polluted. As opposed to that, a closed-loop treatment system is recommended, which promotes used water reuse, recycling and recharge. Benefits of safely recovering and reusing used water include a reduction in effluents to water bodies, and the opportunity to enriching soil with valuable organic matter. The nutrients in reclaimed water can replace equal amounts of fertilizers during the early to midseason crop-growing period (Mohan Kumar et al., 2011). Level of necessary treatment of used water depends on its intended use: secondary treatment may be sufficient if the reclaimed water is to be used for agricultural or cooling purposes, while tertiary treatment is recommended for sanitary or gardening use of the recycled water. In many highly populated cities such as Tokyo (Japan) and Seoul (South Korea) there are in-plot treatment systems which reclaim the used water from houses and use it for toilet and urinal flushing purposes. This mode of water/ used water usage is generally termed as dual water supply. Some countries depend on treated used water for irrigation purposes as well. There have been demonstrated economic benefits of using used water for irrigating non-edible crops like mulberry floriculture. Treated used water has also been used for recharge of groundwater aquifers with adequate safeguards. Usually used water treatment involves collecting the used water in a central, segregated location (the used water treatment plant) and subjecting the used water to various treatment processes. Decentralized systems are also a feasible alternative at certain locations, although the environmental impacts should be thoroughly assessed.

VI. Creating New Source of Water

Based on a city's requirement, tertiary-treated water can be provided with an additional treatment step to elevate its quality to drinking water standards. Allowing natural flow through long rivers or channels, percolating through soil to groundwater aquifers or treatment methods like RO or ultra-filtration (or a combination of some of these methods) provide this additional level of treatment. The resulting water is ready to be blended with freshwater and used for drinking purposes. This way, recycled water need not be assigned only for secondary uses but can also become a part of source of water. Awareness campaigns may need to be conducted by city authorities to help remove psychological barriers related to the use of recycled water for drinking.

VII. Urban River Rejuvenation

The water quality of most urban rivers is in deplorable condition, primarily due to indiscriminate dumping of untreated wastes, both solid and liquid especially industrial wastes. Rejuvenation of such rivers not only improves local environment and ecology, but also provides favourable locations for recreational activities. To prevent further contamination of urban rivers, drainage systems should be revamped and thorough sewage treatment should be ensured. Solid waste collection mechanisms should also be improved to reduce indiscriminate dumping into rivers. In addition to centralized Used Water Treatment Plants (UWTPs), in situ treatment technologies can be employed if found feasible and cost-effective. Discharge of treated used water into urban rivers can assist in replenishment of the flows, while boosting the environment and ecology.

Some of the important considerations of an urban water supply system (typical components illustrated in Figure 4.20) are described below:

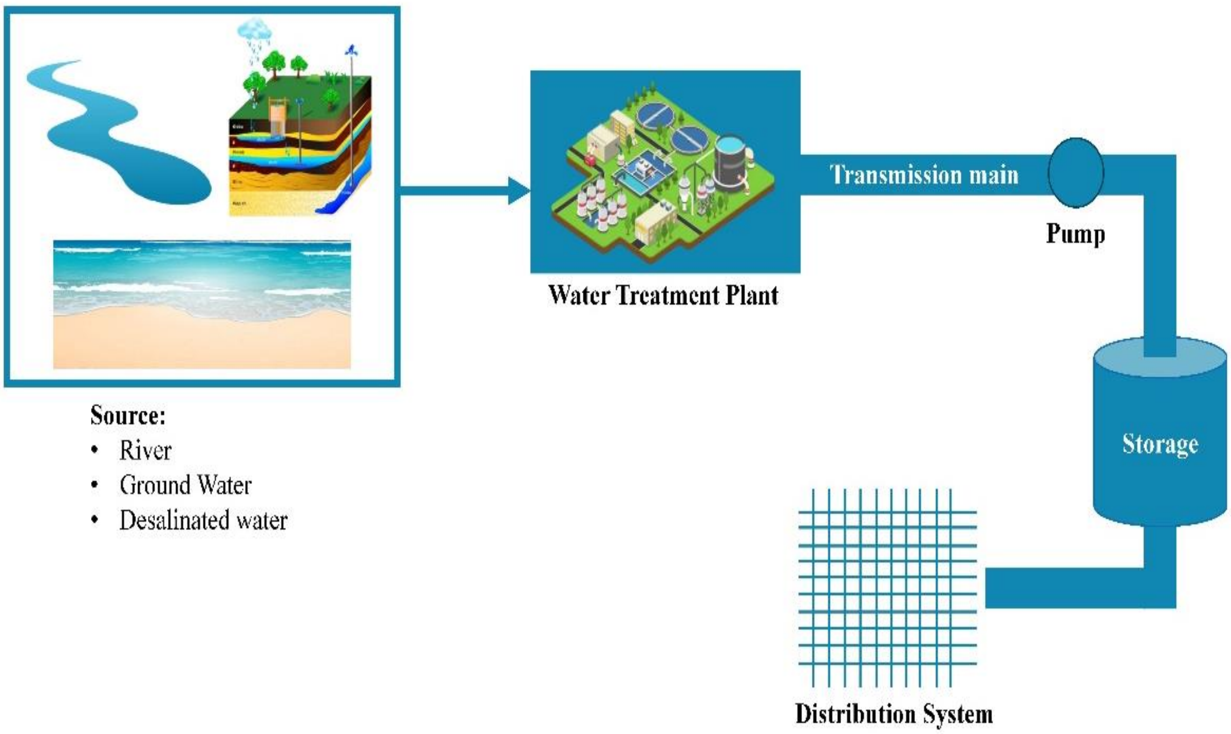

Figure 4.20: Various components of an urban water supply system (Pump if required)

4.12.6.3 Associated Infrastructure

I. Transmission and Storage

The transmission mains are the lifeline between the source, the water treatment plants and the city distribution. Thus, transmission mains should be designed to be able to reliably transfer water long-term, with fail-safe features. Regular maintenance and monitoring of the transmission mains can ensure that the primary water supply source is always available. Storage tanks are an equally important part of the water supply system. Water storage provides a flexibility in intermittent system performance and adds a cushion to water availability in case of sudden shortages. The integrity of storage structures has a direct effect on the quantity, as well as quality of the water present. The elevation of the storage tanks also has an impact on pumping costs, so decisions on tank placement should be made on techno-economic principles.

II. Water Distribution System

WDS operation is inherently uncertain due to random change in demand, flow pattern, pressure head, and ageing. Hence, knowledge of reliability, resilience and vulnerability is important in understanding the system behaviour for different scenarios in a better way. These three aspects can be defined as the probability that the system can provide the required flow rate at the required pressure (or how likely a system will fail), how quickly it can recover from failure, and the severity of failure respectively. For any WDS, reliability, resilience, and vulnerability calculations by developing/using a proper method are of utmost importance to operate the system in an efficient manner in any situation. Random analyses, employing ample historic data, should be used to predict the probable real time performance, as well as future trends under various scenarios of population growth, urban expansion, climate, and lifestyle changes etc.

Reduction of Non-Revenue Water (NRW) should be concerted and continuous effort. District metering Areas based approaches, utilisation of network-based sensors for flow and pressure management and implementing cluster or cohort analyses (utilising network leak data) are now established measures to identify priority areas network improvement. for as the to determine the priority region for network rehabilitation. Such an analyses will help in utilising the funds for the priority network and to gain maximum return in terms of NRW.

4.12.6.4 Efficiency in water use at every stage

In addition to the above-mentioned practice, effective water distribution and use can be achieved by ensuring water efficiency at every stage. This includes the various transmission mains and water supply pipes. Additionally, the use of water saving fixtures at points of use can also significantly reduce per-capita water use.

Canal and Agriculture may be removed as beyond the scope; Leakage/UFW to be mentioned among the demands

4.12.6.5 Data Requirements

A. Physiography

Physiography is the study of physical features of earth's surface. It includes information related to region's elevation details, soil type, and vegetation details. Following aspects are to be studied

- Natural Features
- Elevation Profile
- Land Use and Land Cover

It is to be understood that most of our Indian Cities and surrounding areas are undergoing rapid urbanisation and hence considerable land use changes, resulting in drastic changes in surface runoff as well as recharge characteristics can take place. These physiographical changes expected to occur in the near and remote future should also be accounted for while developing IWRM plans.

B. Hydro–Meteorological Details

Prior to preparation of IWRM, it is important that the hydrometeorological details are collected and analysed. The hydro-meteorological details are combination of hydrological details such as details of precipitation in storm events, land and atmospheric water interaction and meteorological parameters such as rainfall, temperature, and relative humidity. Across the cities, there are very wide variation in rainfall patterns. These variability patterns can be effectively captured by increasing the spatial density of monitoring stations. In other words, higher the number of monitoring stations with higher frequency of data gathering, better is the analysis, especially for storm runoff calculation.

C. Geology and Soil Information

It is recommended to study the geological details of study area in conjunction with groundwater assessment. At the minimum, following aspects should be assessed:

- Geology of Area
    - Geological Age
    - Stratigraphic Units
    - Lithological Characters
    - Water Bearing Characteristics
- Soil types

4.12.7 Stage II – Developing Dynamic Operating Model

4.12.7.1 Dynamic Operating Model (DOM) System, Instrumentation Plan and Telemetry

The Dynamic Operating Model (DOM) will analyse different types of data streams, to understand and optimise the water system. The raw data comes in many forms, including that from deployed remote sensors (flow, water quality, etc.), external organizations (meteorological data, etc.), and existing databases created internally or by other organizations (agricultural data, historic flow data, etc.).

Focus of the DOM system will be on optimisation of system for quantity, quality and cost, and although aspirational in nature, it is recommended to include DOM along with Instrumentation Plan and Telemetry in the IWRM Plan.

The DOM system monitoring framework will drive the identification of data required, and the consequent selection of sensor types and locations. Once the sensor types and locations are identified, the next phase will be the development of an instrumentation plan and a telemetry plan.

Development of an Integrated DOM Dashboard

It is important to establish the baseline for current water availability, prior to implementation of any water supply scheme. Flow and level monitoring are critical, as this information will provide data on additional water that has been made available through these schemes.

The primary goal of the integrated DOM dashboard is to collect data from the different source data streams and convert it, using the decision support system, into actionable information. The conversion of data streams to actionable information involves algorithms to process the data, and presentation of the information in a manner that is intuitive to an operator. The information is therefore presented on an interactive dashboard that provides clear visualization of the information with drill down access to the underlying detailed data.

Development of the visualization dashboard will involve discussion with stakeholders, as the different components of the system are designed and constructed. The information that is developed and incorporated into the DOM dashboard must help the decision makers to understand the critical information for the system, and the best mechanisms for presentation of the information in an intuitive manner. The dashboard will include GIS based, graphical, and numeric presentation methods as appropriate.

The data streams will be collected in different databases for analysis as needed, either historical analysis, or as part of the dashboard presentation (i.e., graphical analysis of data points over time). Each of the data streams will have their own database management tools. The data sources will go through a multi-tiered data management architecture which will validate and provide QA/QC for the data.

Data will be sent via open standards such as web services or leveraging direct database connections as appropriate to support expansion of the system into the future.

Communication and visualization of information to staff at all levels is very important to ensure that all staff have the most up-to-date information available to them. Secure Internet communication methods can be used to rapidly push information to all partners.

Once the data has been processed into information, the information will be converted into a number of Key Performance Indicators (KPIs) that the management staff can use to evaluate the overall performance of the system against set goals and objectives.

The three areas of actionable information that will be derived from the dashboard for the operational optimization tool are water quantity, water quality, and operational efficiency. This has to be done at necessary space / time intervals to understand the system dynamics better. The DOM will become increasingly more valuable as the system starts to develop and real-time data becomes available to allow system optimization to occur.

Bangalore Water Supply and Sewerage Board (BWSSB) has a functional and fully updated GIS portal for water supply, asset management, real-time monitoring of used water treatment plant operations. This portal serves as a remote tool for understanding the ground reality and making informed decisions. In association with the Indian Institute of Science Bangalore's researchers, this portal is being rebuilt to enable real-time acquisition of big data, cleaning, analytics and archiving. This portal will eventually serve as a one-point interface for complicated decision-making through improved assessment and visualization of the ground truth of water systems. The improved portal will be opened for public viewing in the near future. Similar platforms have to be designed for used water treatment & reuse, stormwater etc. and integrated with drinking water portals to get a holistic picture of water resources management for cities or towns.

4.12.8 Stage III – Development of IWRM Plan

The final stage, Preparation of an IWRM Plan, is driven by preparation of a detailed water balance. Preparing a detailed water balance is imperative for any city. Water balance calculations refer to a detailed break-up of the various sources of available water (from surface water or groundwater sources, rainwater harvesting, recycled water etc.), as well as the various demands (residential, institutional, industrial, horticulture, firefighting, ecology/ environment etc., and the water supply that remains unaccounted for). Under changing climate, growing populations and rapid urbanization, the changes in each component of the water balance analysis should be updated for more realistic decision-making. This will aid in the development of various scenarios a city's water system may face and increase preparedness towards unforeseen situations. Figure 4.21 shows the various components to be accounted for in a city's water balance, namely, water resources, water storage units, water treatment units, water demand, used water generation and treatment capacities. Details of a city water balance plan can be found in the subsequent chapter.

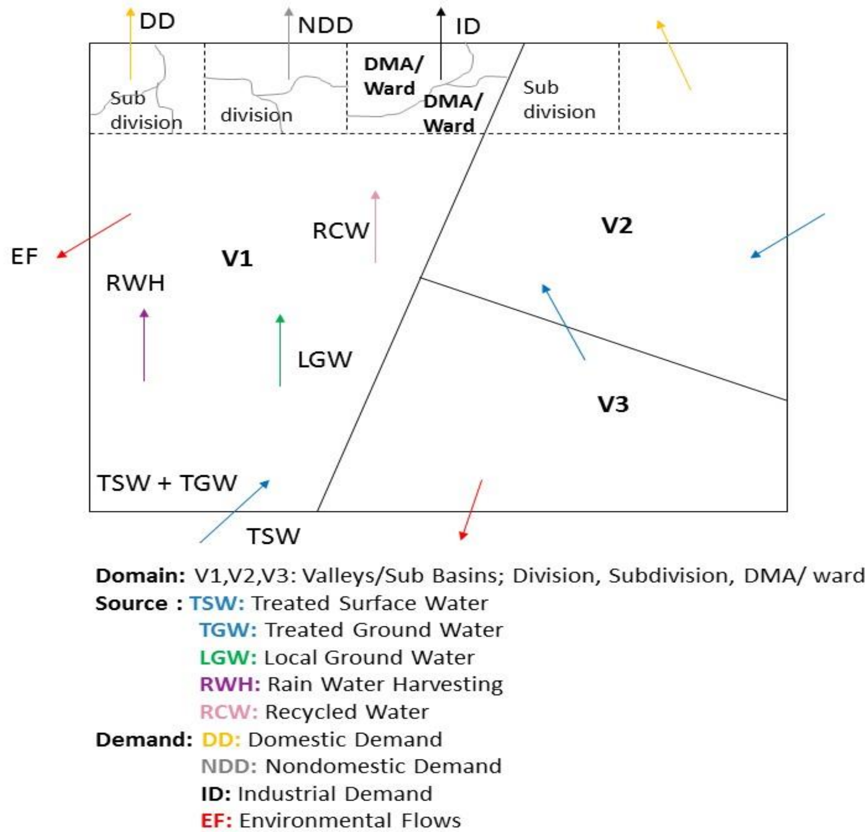

Figure 4.21: Movement of different components of water within a city

4.12.9 Water Resources Assessment- Availability and Demand

The water demand estimate and planning for efficient use of water is important when there is a limit to its availability. A good understanding of future water use will help to optimize plan for future water supply, infrastructure construction and system operations. The following are the types of water demands that needs to be estimated while preparing an IWRM Plan.

- Domestic,
- Non-domestic,
- Commercial,
- Recreational,
- Industrial Water Demand,
- Institutional Water Demand,
- Horticulture Water Demand,
- Firefighting Water Demand,
- Urban Irrigation Water Demand,

It is important to note that there are guidance provided by CPHEEO Water Supply Manual (Central Public Health and Environmental Engineering Organization (CPHEEO), 1999), however, these values should be taken as guidelines, and the project specific water demands must be developed after judicious assessment of water requirements based on water availability, opportunity to utilise the recycled water, and applicable water demand management measures. City Development Plan (CDP) need to be kept in focus while developing water demand plan, to avoid potential conflicts.

The typical planning horizon for water demand projection should comprise of short term (up to 5 years), midterm (up to 15 years) and long term (up to 30 years). It is important to note that this planning horizon is for guidance purpose, as different cities have different population dynamics that are dependent upon economic, environmental and societal factors, however the planning horizon should be such that it provides direction for the city to plan ahead and identify a diverse and resilient water portfolio, with enough leeway to make course correction as city continues to develop.

4.12.10 Potential for Demand Management

Demand management is a critical part of any IWRM Plan. As opposed to the supply side solutions, the cost for implementing demand management measures is modest to relatively low. In the long term, effective demand management would enable best practice management of overall water supply and infrastructure. There is sufficient scope to suggest ways to reduce the actual water consumption rates by using world's best management water practices such as:

- Water-saving fixtures/devices
- Behaviour changes and social awareness/education programmes
- Leakage detection and repair
- Minimisation of non-revenue water losses
- Increasing the reliability of supply / reducing local storage
- Economic pricing with escalating blocks water tariff

The 150 lpcd is a guideline or aspirational design figure. In actual practice water usage should be significantly less and therefore reduce the capacity of water resources to find, minimize the size of water infrastructure and reduce the capital cost and operating costs. It needs to be kept in mind that total of 150 lpcd can be met partly through local supply such as harvested rainwater, use of recycled water etc. Water tariff is a sound tool to reduce water consumption.

4.12.11 Measures to Minimize Water Consumption

Any city could realistically achieve a domestic water demand of about 135 lpcd across whole city, but only after implementing the following measures:

- Higher plumbing and piping standards to prevent leaks
- Strict construction standards, contract supervision and leak testing
- Leakage and non-revenue water monitoring and correction
- Water pricing to deter the waste of water and leakages, with incentives for lower consumption
- Implementation of control devices at critical points to bring in equity
- Strict controls and enforcement of water use rules
- High levels of public awareness campaigns and education

Given the low level of effort desired to achieve good results and cost savings with water demand management it is essential that a city adopts such best management practices.

4.12.11.1 Estimate of Potential Water Savings

Residential demand management is achieved by reducing the per capita water consumption. As the city plans for its future water supply, it is prudent to use a guidance value of 135 litres per day, which is sourced by different water sources in a portfolio (such as surface water, harnessed rainwater on catchment scale, recycled water). As the city approaches towards 24/7 water supply, the city can then implement strong water demand measure to promote lower per capita consumption. For instance, limiting the water to 120 litres per day has the potential to about 11% residential water over the Indian design standard. If provision for non-potable water supply is made say through recycled water, the drinking water supply should necessarily be brought down to 100 lpcd.

4.12.12 Infrastructure Requirements

Water demand management can be enabled through installation of water saving fixtures at points of use. No additional storage, conveyance, pumping and treatment are required since the water saving fixtures control demand simply by limiting the flow of water from the tap or fixture without compromising on user satisfaction/efficiency.

There is no water infrastructure requirement for the implementation of water demand management as the water savings are made at the customer or user side. Nevertheless, the development and implementation of the following measures are needed as a minimum:

- Sound plumbing regulations
- Monitoring and enforcement of plumbing regulations
- Educational programs and public awareness building
- Monitoring and management of non-revenue water and leakages
- Reduction in storage volume at consumer end to reduce unnecessary storage

4.12.12.1 Operation and Maintenance Requirements

Operational and maintenance issues are mainly confined to the monitoring and enforcement of plumbing regulations and effective management & control of Non-Revenue Water (NRW) and leakages both supply side as well as demand side. Information Education and Communication (IEC) activities are continuously required to reinforce the importance of water savings, good plumbing and water use habits.

4.12.13 Institutional and Legal Considerations

Clear governance of the management of water infrastructure and services is required to realise the full potential and benefits of water demand management. As such, the responsibilities for plumbing regulation and enforcement needs to be clear and well designed and implemented from the onset. Responsibility of ongoing and effective public awareness building, and education is also an important aspect for successful water demand management.

The development of sound and best practice plumbing regulations and enforcement of such regulations is the key challenge with water demand management. Good governance is needed in order to realize the full benefits and potential of water demand management. For the public water infrastructure, community-based monitoring against leakages and pilferage can be introduced as governance model. The community should have large representation of women as well as girl students.

4.12.14 Urban Flood Management

Urban catchments are hydrologically quite complex due to the close interaction between natural and anthropogenic processes. It has been observed that the causes of urban floods are quite different, namely it is a consequence of insufficient drainage in response to a sudden high magnitude rainfall event, coupled with imperviousness and lack of flow space. According to the National Disaster Management Guidelines (National Disaster Management Authority, 2010), urban flooding is significantly different from rural flooding as urbanization leads to developed catchments, which increases the flood peaks from 1.8 to 8 times and flood volumes by up to 6 times, when compared with undeveloped land space of same area. Consequently, due to faster flow saturation times (just a few minutes) flooding occurs very quickly (National Disaster Management Authority, 2010). Urban flood water, though conventionally let off into water bodies, can serve as a resource when harvested properly. With requisite quality control, urban flood water can be used for recharge of ponds and tanks, as well as for replenishment of groundwater aquifers. The first step towards flood water harvesting is to improve the general understanding of the urban catchment i.e., exploring the natural and anthropogenic features that may contribute/ alter the hydrology of the region. Extensive catchment analysis and mapping must be done using a variety of techniques, with the end goal of improving familiarity with the catchment features (Sahoo and Sreeja, 2017; Zope et al., 2015). This will also help generate a suite of catchment responses under various different precipitation events, and also for projected climate change scenarios.

In a similar study done for studying and developing urban flood management measures for the entire Bengaluru City, **Error! Reference source not found.** presents Bengaluru’s drainage map.

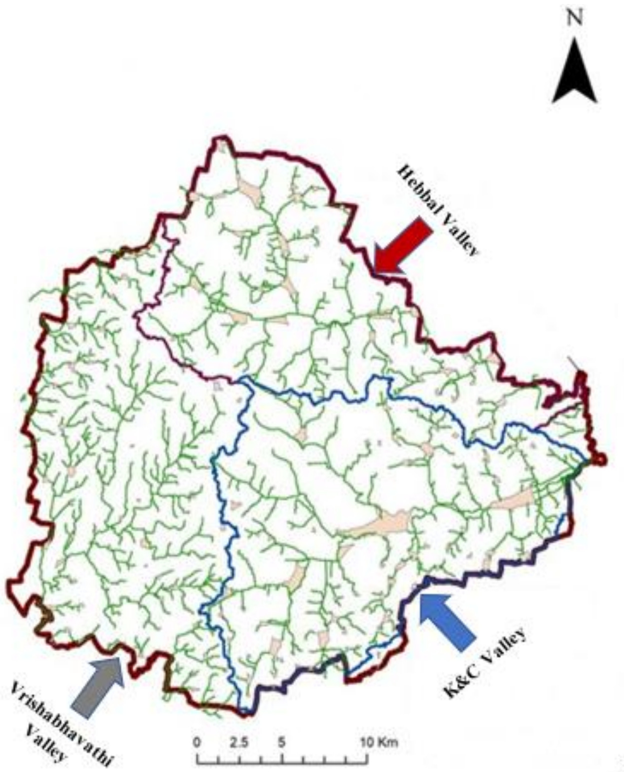

Figure 4.22: Bengaluru's drainage map

4.12.15 Guiding principles for developing IWRM plan

All water infrastructure projects are prepared based on specified goals, desired levels of services, and long-term aspirations. Establishing a set of guiding principles to represent these goals, level of service and aspirations help to describe the fundamental requirements that a project must overcome before it is considered worthwhile implementing or evaluating further. Guiding principles also help in framing the decisions to be made by defining the scope of the issue, the limiting conditions, and desired outcomes.

The Guiding Principles proposed for this project are summarized in Table 4.16**Error! Reference source not found.**. Each includes a description of the corresponding Planning Goal(s) as well as a note on whether it is a basic need or Aspirational goal.

- Planning Goals – This can be qualitative or quantitative. Measurements/Indicators will be used to evaluate if the principles are met. Solutions that meet this criterion will be considered for the project.
- Basic need or Aspirational – This helps to define the planning goals further. Basic goals are the key priorities to meet in order to successfully achieve the outcome of a

sustainable IWRM plan. Aspirational goals are good to have in order to outperform the original goals of the project.

Table 4.16: Proposed Guiding Principles for the IWRM Plan

Guiding Principle	Planning Goals	Basic or Aspirational
Ensure social equity in terms of access to good water quality and quantity to sustain human activities	All solutions must meet current regulatory requirements (for used water discharges, stormwater management, potable water treatment, and fire demand)	Basic
Provide water infrastructure and services that are cost effective over a 30-year life cycle	Long term financial cost (based on life cycle cost) for the integrated system is minimized.	Basic
Ensure maximum efficiency in using scarce water supply and financial resources	Electrical power requirements for system components are minimized.	Basic
Develop in a sustainable manner and without compromising ecosystem	Ecosystem (habitat and biodiversity) are protected or enhanced.	Aspirational
Balance capacity of potable and non-potable systems for steady and secure water supply	demand for both potable and non-potable water is met.	Basic
Minimize potable water use for non-potable purposes	Non-potable water (captured rainwater, reclaimed water, or grey water) provides at least 50% of the traditional potable water demand.	Aspirational
Maximize IWRM Plan flexibility to adapt to changing conditions over time	Recommendations include options that are less susceptible to risks from changing conditions, and capable of retrofitting or upgrading to meet new conditions.	Basic
Facilitate public acceptance	System components/strategies do not cause any public concerns about	Basic

Guiding Principle	Planning Goals	Basic or Aspirational
	safety or reliability, Use of treated recycled water for blending.	
Utilize state of the art principles and solutions, Transparency at every level and involvement of stake holders	Strategies and recommendations are comparable to best practices in other places.	Aspirational

4.12.16 Financial sustainability and stakeholder engagement

To ensure financial sustainability for an IWRM Plan, following 3 key measures should be considered:

- Ensuring that revenues cover all operating expenditure,
- Delivering capital programmes without incurring an unsustainable debt burden, and
- Reducing the existing financial deficit.

To achieve these measures, a three-pronged approach will focus on optimising expenditure, boosting revenue and smart financing (**Error! Reference source not found.**). Effective governance is the necessary foundation that enables all these outcomes.

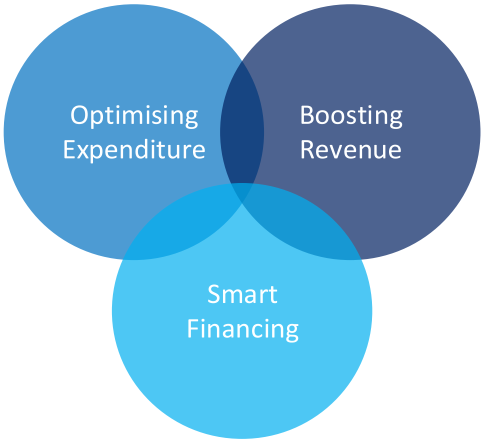

Figure 4.23: Strategy to achieve Financial Sustainability

4.12.17 Challenges in financing the water and used water sector

Water supply and sanitation services provide both social and economic benefits. Water is essential for basic health and sanitation but is also an important enabler for many sectors of the economy, agriculture and manufacturing for example. Because of this dual benefit, stakeholders have varying opinions as to whether water is a basic right to be provided based on social grounds, or whether it should be supplied and charged for based on commercial criteria. Often, an ineffective compromise results, with sources of funding, and expenditure and revenue plans unclear and inconsistent.

Also, in comparison to water, it is arguably harder to recover costs for used water services from consumers. While there is a strong incentive to connect and pay for a clean and adequate water supply to fulfil basic needs, the incentive to pay for proper collection and treatment of the resulting used water is less obvious to the individuals.

With the paradigm shift in viewing used water as a resource than as a waste however, there are stronger arguments and incentives for paying for used water services as a raw material for recycled water production. Financing for water supply and used water management services in general comes from two sources: tariffs, taxes and transfers (the 3Ts), and market-based finance. **Error! Reference source not found.**4.24 explains these f orms of finance.

- The 3Ts are the revenue sources, needed to cover day-to-day O&M, periodic repairs, and full-scale upgrades.
- Tariffs are typically the most predictable revenue source and are usually used to support O&M.
- Tax-funded grants are normally only assured over short to medium time frames, sometimes only year to year.
- Transfers, in the form of official development assistance (ODA) is usually available as a multi-year package. It is usually only available for capital projects and depending on the source organisation, may only be available for certain projects.

- Market-based finance includes loans, bonds or equity, and repairs compensation
- Loans carry interest and have to be repaid
- Bonds have to be repaid at maturity and an additional payment made to remunerate the capital borrowed.
- Shareholders expect dividends.
- Utilities may use market-based finance to pay for large upfront investment costs. Debt servicing and repayments are then met by the 3Ts.
- Strong revenue sources are often a pre-requisite to access finance from loans, bonds and equity.

Figure 4.24: Sources of Finance

4.12.18 Creating Financial Sustainability

Considering the aims for financial sustainability, the following principles can be implemented for an organisation when planning future projects:

- In the short term to mid-term, user charges can be used to finance operation and maintenance related expenses (including debt service), routine capital expenses (replacement of existing assets at end of life), and NRW reduction projects.
- The financial planning shall be such that water utility/organisation must be able to recover the capital cost (including depreciation) in the long term, for organisation's financial sustainability.
- Projects that provide social and environmental benefits without tangible financial returns to water utility/organisation shall be funded using non-debt instruments (i.e., grants and contributions) wherever possible.

The following measures can be adopted to create financial sustainability

4.12.18.1 Optimising expenditure

For most of the water utilities, the funding required to deliver existing operations typically exceeds the revenue it generates through its water tariffs. To close this gap, water utility must identify and address the ways it currently delivers its O&M activities. It shall also seek to develop and deliver its capital schemes more efficiently, thereby reducing the amount of funding it must generate through debt.

A water utility's major sources of operating expenditure are listed in Table 4.17**Error! Reference source not found.** and it is recommended that the water planners look critically at these expenditures to identify opportunities for OPEX reduction.

Table 4.17: Major operational expenses in a water utility

Category	Items
Power	• Pumping of water (surface water and/or other water sources). • Power use at WTPs. • Power use at used water pumping stations. • Power use at UWTP.
Administration and management	• Labour costs at headquarters. • Pension commitments.
Repair and maintenance	• Labour costs associated with O&M. • Materials and equipment for O&M activities. • Pollution cess charges. • Royalty charges
Debt service	• Interest payments.

Category	Items
	• Guarantee commission charges (some funding agencies take certain %age as guarantee charges on outstanding loans).
Depreciation	• Depreciation in the value of fixed assets.

4.12.18.2 Maximising revenue

A water utility's revenue from tariffs covers approximately ranges from 40% to 60% of its operating costs. A water utility shall make the case for altering tariffs and increasing the total tariff revenue by:

- Consulting with customers to understand future demands, the outcomes customers expect, and the amount they are willing to pay. This is likely to vary significantly between different customer types (not necessarily aligned to water utility's current customer distinctions).
- Establishing effective accounting systems so that the real costs of services can be accurately established and then tracked.
- Clearly outlining a long-term strategy for improving services, followed by regular updates and opportunities for customers to engage with the water utility.
- Seeking to establish a clearer link between customer costs (i.e. the tariff) and the benefits that customers receive. This could be achieved by, for example, defining outcome measures and service commitments that water utility shall use its revenues to deliver, and then regularly reporting on performance. It is critical that any tariff increase is accompanied by better service.
- Considering promoting a mechanism of indexation which will enable revenues to grow in line with costs.
- Providing a mechanism for customers to hold water utility to account for its service commitments.
- Planning for potential future regulatory landscapes, such as an independent regulator that shall assess water utility's performance and use this to recommend changes to tariffs. This form of regulation exists in the UK.

4.12.18.3 Financing Options

Effective governance is a pre-condition for smart financing. In particular, governance structures must create clear core functions for policy formulation, regulation, asset holding and service provision. Capital projects in water and used water require large investments over short periods of time, creating assets with long lives which in turn require regular investment in operations and maintenance. A variety of alternative finance options for capital projects exist, each of which has specific advantages and disadvantages. In practice, capital investment and recurrent costs tend to be financed in different ways. Investment is typically funded by grants, loans and bonds whereas recurrent spending is often reimbursed from tariff revenues and subsidies. Ultimately, all expenditure has to come from the 3Ts – tariffs and other user contributions, tax-base subsidies or transfers.

Many global cities have accumulated substantial debts through loans and bonds and in some extreme cases, Detroit for example, these cities have filed for bankruptcy. Debt financing shall only be considered as one part of a sound financial strategy.

In order to finance its projects in a manner that supports its aims for financial sustainability, the water utility must:

- Clearly identify the projects it needs to deliver to achieve its target service levels. Setting the levels of service is therefore also a key task,
- Accurately estimate capital and operating cost requirements. This must consider the full life cycle of asset costs, including operation and maintenance, decommissioning and disposal,
- Evaluate alternative capital funding mechanisms, and
- Assess impact of covering additional operating costs through tariffs.

Figure 4.25**Error! Reference source not found.** presents this methodology.

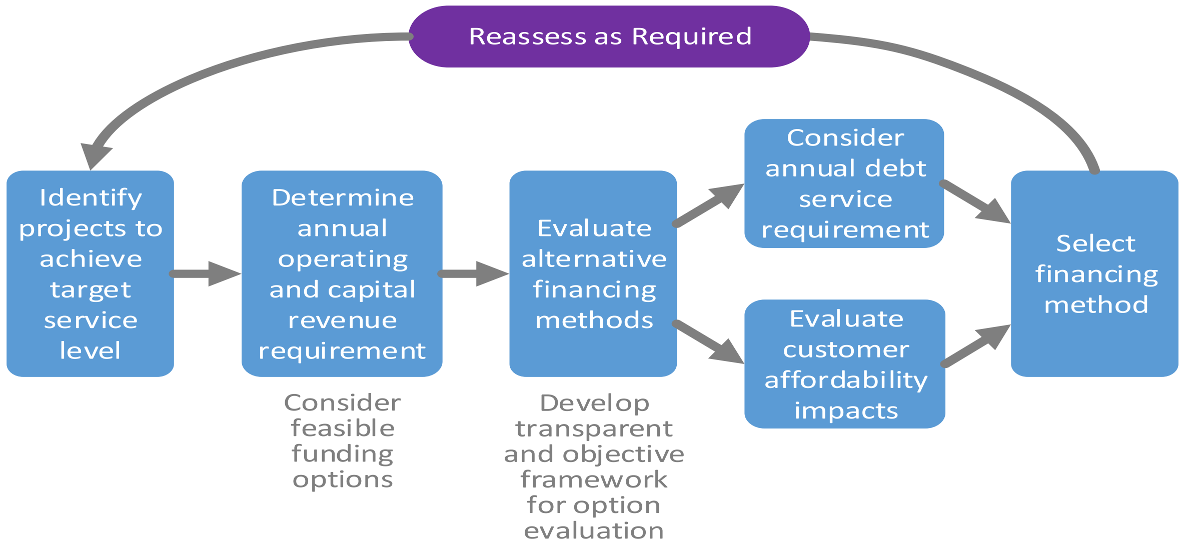

Figure 4.25: Methodology for planning project financing

4.12.19 Stakeholder Identification

Stakeholder identification is a critical component of an IWRM Plan. The stakeholders can be distributed in to two categories:

- Primary Stakeholders – who have a direct interest or influence on the IWRM Plan; it includes:

  - Water Board/Utility, General Public, Municipal Organisations, Land/Building Development Authorities, Regional Development Authorities, Water Resources Conservation/Management Authorities, Pollution Control Boards, State Government, Government of India

- Secondary Stakeholders – who are not responsible for specific activities that relate to water management, but they do have an indirect interest in IWRM Plan; it includes:
  - State Water Supply and Drainage Board, State Urban Infrastructure Development and Finance Corporation, State Industrial and Infrastructure Development Corporation, State Agriculture / Horticulture / Aquaculture/ Energy Depts, Finance Bodies, Research Institutes, Non-Governmental Organisations, Suppliers and contractors, Other utilities

4.12.19.1 Strategy for Stakeholder Engagement

Effective stakeholder engagement requires a comprehensive and inclusive strategy that seeks out engagement and input from a broad range of stakeholders (government bodies, industries and businesses, funding organisations, regulators, community groups and the public). The strategy must also adapt and evolve at different stages in the lifecycle of the IWRM Plan, and a given project, from planning, through design and funding to implementation. At each of these stages, the extent to which a specific stakeholder should be engaged may change, as may their specific interests.

If a comprehensive strategy is not followed, stakeholder engagement becomes a risk leading to a largely reactive process implemented in an authoritarian manner, often in response to crises. In contrast, forward-thinking organisations now consider stakeholder engagement as an early, interactive, and inclusive approach which allows them to identify common ground, optimise options, and deliver mutually beneficial outcomes.

Organisation's stakeholder engagement strategy for a given initiative should comprise a series of stages, as presented in Figure 4.26**Error! Reference source not found..**

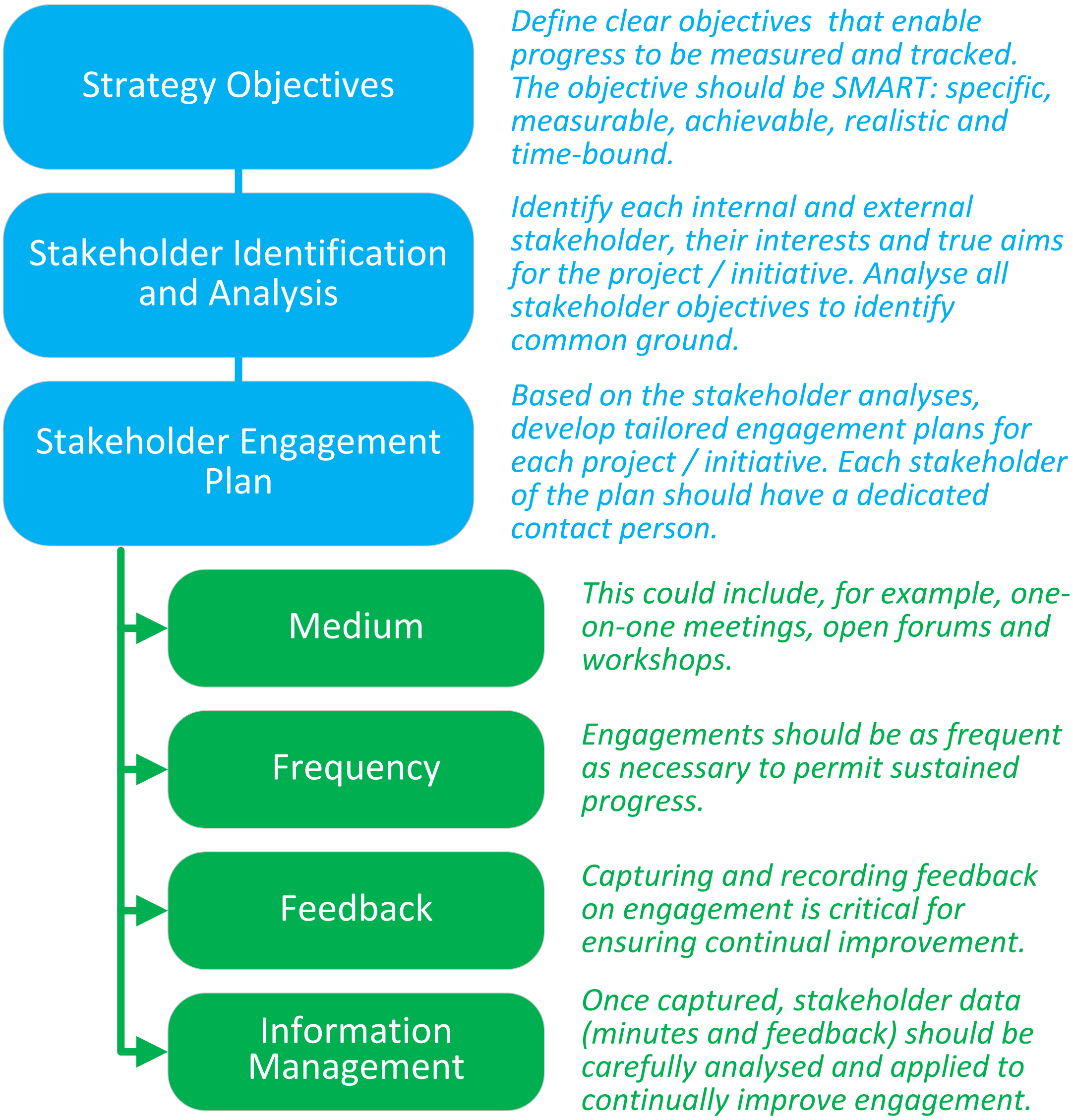

Figure 4.26: Stakeholder Engagement Approach

4.12.19.2 Approach and Format for Stakeholder Engagement

Successful and efficient stakeholder engagement requires a comprehensive and inclusive approach that involves institutional stakeholders as well as local communities.

For each project or initiative, there may be a slight variation in terms of targeted stakeholders; i.e., among the targeted audience for recycled water utilisation, more emphasis will be given to supply of recycled water for non-drinking purposes, industries and commercial establishments and they will be the targeted section, who can afford to pay for the recycled water services.

However, in most of the cases, the broader group of stakeholders will stay similar although the types of engagement, their locations times and frequency, and mechanisms for capturing feedback might change.

Some of the key items constituting the approach towards engaging the stakeholders are as below:

- It is important that each key stakeholder type should be assigned a specific contact person.
- To maximise beneficial outcomes, effective planning of engagement guidelines, as well as early stakeholder contact are key requirements.
- Guidelines for engagement should promote principles of honesty, trust and integrity and include transparency, respect and partnership, ensuring that stakeholders are not judged for their values and that common ground is established.
- In doing so, organisation should be transparent about its own values, interests and expectations at all times.
- It should be acknowledged from the outset of an engagement programme that there will often be disagreements between stakeholders. These disagreements are healthy debates, and their resolution helps to balance and optimise project outcomes.
- Disagreements should not be allowed to negatively affect stakeholder relationships and efforts should be made to ensure that all stakeholders remain receptive to each other's ideas.

Table 4.18: Means of Institutional Stakeholder Engagement

Format	**Details**
One-on-one meetings	Regular one-on-one meetings can be highly effective for bilateral discussions but are less suited to projects or initiatives that involve multiple stakeholders (such an approach does not foster transparency or collective progress). For regular one-on-one meetings, stakeholders should be assigned dedicated contact persons within Water boards in order to foster an effective working relationship.
Forums	Forums for selected attendees or open membership (public meetings) are effective for communicating information or educating about new concepts. The unstructured format may however be less suited to collective planning of projects. Forums could be held virtually to boost attendance however such events require careful management to ensure attendees remain engaged throughout.

Format	Details
Focus groups	Focus groups require a clear agenda, attendance list and expected outcomes. With this planning in place, they can be effective at collectively developing ideas and reaching consensus about important issues.
Working groups	Working groups are ongoing collaborative initiatives between multiple stakeholders that provide a platform for sharing information and coordinating research. Singapore's WaterHub is an excellent example of this concept. The facility provides a venue for collaborative working and an avenue for networking within the broader water industry, locally and internationally.
Questionnaires	Questionnaires can be a useful means of gaining an early understanding or appreciation of stakeholder interest and / or concerns. They should be followed by direct engagement to collectively develop ideas and solutions.

4.13 City Water Balance Plan (CWBPs)

Typical water scenario planning in urban areas emphasises water treatment, supply and subsequent collection and treatment of used water. This kind of an approach fails to account for the revenue potential of treated used water reuse, or even NRW. Clearly, a comprehensive accounting of all possible pathways for generation, use and reuse of water is required, which will enable simultaneous reduction in water wastage, as well as maximum revenue recovery. Additionally, such water balance calculations aid in the development of robust water policy, water management approaches and prudent investment decisions (Bahri, 2012). As cities grow in size and complexity, water balance modelling promotes maximised water reuse and minimises dependence on imported water (Barton et al., 2009).

City water balance Plans (CWBPs) are generally prepared for a base year (e.g., 2020), with relevant projections for an intermediate year (usually 15 years subsequent to base year, i.e., 2035) and a design year (30 years subsequent to base year, i.e., 2050). The CWBPs may have various formats which are enumerated and described below:

i. City Profile and Demographic Data: This consists of a self-explanatory CWBP format, which also contains GIS city map showing city boundaries, zones, wards etc.
ii. Water Sources: As outlined earlier, redundancies in a city's water sources are crucial for ensuring reliable and uninterrupted water supply to its residents. Data from each of these sources has to be carefully collected. If a source is located outside city limits,

the water taken should be considered as borrowed water and should be accounted as such in the water balance.

iii. Urban Water Bodies: All existing urban water bodies (including surface and groundwater sources) should be mapped and their corresponding contribution to the city's water consumption should be ascertained.
iv. Water Supply: The present demand, and gaps in future demand at the intermediate and design year should be assessed. These gaps should be mapped in city maps, and accounted for in future planning or expansion projects.
v. Used water: Used water generation, collection, treatment and any gaps herein should be well reflected in the information collected. Thereafter, the availability of the treated used water for non-potable use in industries, institutions, commercial and domestic settings should be accounted for. The adequacy of used water infrastructure or any gaps therein should be reflected.
vi. City Water Balance Abstract: A city water balance abstract can be prepared by generating data from all of the formats mentioned above. Losses, wastage and other components can be estimated separately and entered.

It is of utmost importance that a baseline calculation for the supply and demand in a city / town etc. is established. Though such baselines are established based on a thumb-rule approach, both static and dynamic approach can be considered for developing a water balance plan. Static approach is better suited for a broader level water resources planning wherein the water balance plan is to be demonstrated at an administrative level to plan for mid to long term water and allied infrastructure needs. Reference to this approach is presented earlier section. Dynamic water balance is suited from operational perspective when the data is available at DMA (or smaller geographical level) and needs to be integrated for managing water resources in real time. This approach can be utilised for developing spatial, temporal, and source wise water equity among different users.

If a city is seen as one of the demand points in a sub-basin, a sub-basin approach of hydrological calculations of source generation and various demands such as irrigation, drinking water, industrial water etc. is the natural approach. However, these types of calculations could be only at a very large scale and could miss out on many aspects like rainwater harvesting, regeneration of used water etc. Even if one were to do the calculations at sub-basin scale, care should be taken to downscale the same to the city scale and understand the interactions between, surface, ground water, rainwater harvesting and recycled water along with demand nodes such as service stations, command areas etc.

To perform such calculations, very definitive water assets including storages, pipelines, pumps etc. need to be mapped and made available in a GIS format. Along with this, the seasonal groundwater table data available need to be mapped as well. The volume of much fresh water that is supplied, recycled water that is generated and how much of it is used in the city, the volume of rainwater harvesting that is being carried out at local scale, indicate direct / indirect availability of water for both potable and non-potable purposes. This, along with the demands at various points in the city, indicates a balance of the water movement. It is also important to be aware of volume of water stored in the city, division / subdivision level and at ward level indicating the security in terms of storage. To show the movement of the above different components of water in a city, Figure 4.27 may be referred. This figure shows the supply in terms of Treated Water, extraction of local ground water, rainwater harvested locally, and recycled water used locally. This has to be balanced with the demand from both domestic as well as nondomestic sectors. The details provided in the earlier sections about demand management can be referred, as necessary. Needless to say, such balance calculations need to be done at city / part of the city like division / subdivision/ DMA / ward scale to get at the water balance scenario. These types of calculations have to be carried out periodically especially for monsoon, non-monsoon season. In all these calculations, environment / ecology needs to be kept in mind. Any city which imports less water from outside will ultimately be moving towards sustainable water resource management. Water balance calculations can be performed from the demand or supply side. Conventionally, a water supply board (supplier) is interested in knowing the various demand factions for each of its sources of water supply. This approach helps in better water apportionment for the supplier and detecting huge losses or unprecedented demands. Conversely, growing cities and towns may need to use values/projections of demands to predict required increase in source supply. This kind of calculations can be performed using demand-side water balance calculations. Due to the ever-increasing water demands and increasing complexity in apportionment problems of towns and cities, up-to-date and accurate water balance calculations are a necessity.

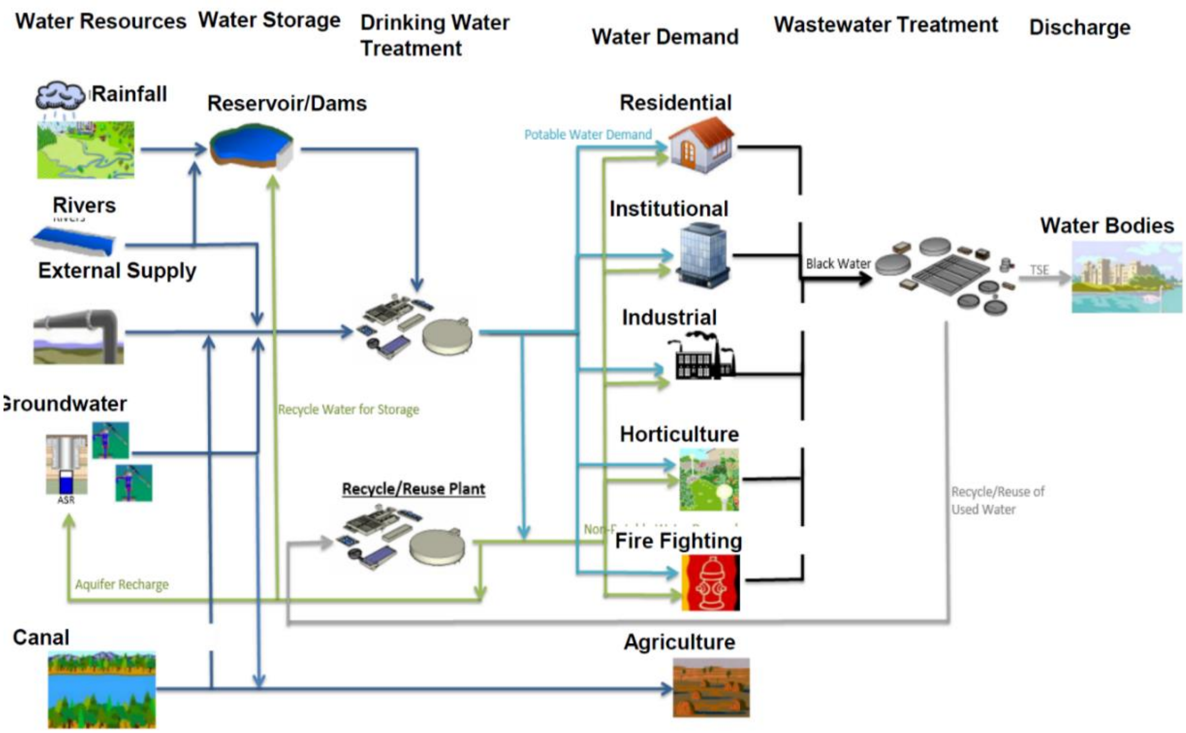

Figure 4.27: Various components to be accounted for in a city water balance (adapted from Jacobs, 2020)

Annexure 4.1: State-wise Depth to water Level and Distribution of Percentage of Wells for the Period of November-2021 in Unconfined Aquifer

S. No.	Name of State/UT	No. of wells Analysed	Depth to Water Level (mbgl)		Number & Percentage of Wells Showing Depth to Water Level in meters below ground level (mbgl) in the Range of											
					0-2		2-5		5-10		10-20		20-40		> 40	
			Min	Max	No	%	No	%	No	%	No	%	No	%	No	%
1	Andaman & Nicobar	94	0.07	7.04	82	87.2	10	10.6	2	2.1	0	0.0	0	0.0	0	0.0
2	Andhra Pradesh	724	0.00	49.99	367	50.7	225	31.1	98	13.5	27	3.7	6	0.8	1	0.1
3	Arunachal Pradesh	10	1.25	6.80	1	10.0	8	80.0	1	10.0	0	0.0	0	0.0	0	0.0
4	Assam	169	0.02	16.67	65	38.5	84	49.7	17	10.1	3	1.8	0	0.0	0	0.0
5	Bihar	593	0.00	10.69	232	39.1	326	55.0	33	5.6	2	0.3	0	0.0	0	0.0
6	Chandigarh	12	2.80	51.31	0	0.0	3	25.0	1	8.3	4	33.3	3	25.0	1	8.3
7	Chhattisgarh	694	0.31	22.00	110	15.9	390	56.2	162	23.3	29	4.2	3	0.4	0	0.0
8	Dadra & Nagar Haveli	17	1.17	7.05	4	23.5	11	64.7	2	11.8	0	0.0	0	0.0	0	0.0
9	Daman & Diu	5	0.14	6.35	1	20.0	2	40.0	2	40.0	0	0.0	0	0.0	0	0.0
10	Delhi	87	0.14	65.67	15	17.2	18	20.7	23	26.4	15	17.2	8	9.2	8	9.2
11	Goa	68	1.10	15.70	6	8.8	32	47.1	24	35.3	6	8.8	0	0.0	0	0.0
12	Gujarat	747	0.00	52.33	170	22.8	276	36.9	177	23.7	88	11.8	33	4.4	3	0.4
13	Haryana	183	0.63	76.50	14	7.7	40	21.9	34	18.6	50	27.3	35	19.1	10	5.5
14	Himachal Pradesh	86	0.24	32.85	23	26.7	29	33.7	18	20.9	14	16.3	2	2.3	0	0.0

S. No.	Name of State/UT	No. of wells Analysed	Depth to Water Level (mbgl)		Number & Percentage of Wells Showing Depth to Water Level in meters below ground level (mbgl) in the Range of											
					0-2		2-5		5-10		10-20		20-40		> 40	
			Min	Max	No	%	No	%	No	%	No	%	No	%	No	%
15	Jammu & Kashmir	213	0.32	31.80	79	37.1	80	37.6	39	18.3	9	4.2	6	2.8	0	0.0
16	Jharkhand	205	0.35	10.09	26	12.7	145	70.7	33	16.1	1	0.5	0	0.0	0	0.0
17	Karnataka	1290	0.01	26.58	502	38.9	454	35.2	287	22.2	46	3.6	1	0.1	0	0.0
18	Kerala	1304	0.01	53.60	330	25.3	459	35.2	425	32.6	83	6.4	6	0.5	1	0.1
19	Madhya Pradesh	1296	0.08	37.76	168	13.0	588	45.4	422	32.6	105	8.1	13	1.0	0	0.0
20	Maharashtra	1757	0.01	54.70	512	29.1	839	47.8	315	17.9	71	4.0	18	1.0	2	0.1
21	Meghalaya	24	0.20	4.80	10	41.7	14	58.3	0	0.0	0	0.0	0	0.0	0	0.0
22	Nagaland	2	3.58	6.05	0	0.0	1	50.0	1	50.0	0	0.0	0	0.0	0	0.0
23	Odisha	1253	0.06	13.60	503	40.1	602	48.0	139	11.1	9	0.7	0	0.0	0	0.0
24	Puducherry	6	0.83	2.50	4	66.7	2	33.3	0	0.0	0	0.0	0	0.0	0	0.0
25	Punjab	176	0.02	42.00	13	7.4	43	24.4	34	19.3	48	27.3	36	20.5	2	1.1
26	Rajasthan	919	0.25	116.98	59	6.4	171	18.6	185	20.1	177	19.3	162	17.6	165	18.0
27	Tamil Nadu	541	0.05	62.50	230	42.5	142	26.2	113	20.9	42	7.8	7	1.3	7	1.3
28	Telangana	545	0.00	50.14	154	28.3	252	46.2	100	18.3	29	5.3	9	1.7	1	0.2
29	Tripura	22	0.31	6.58	6	27.3	13	59.1	3	13.6	0	0.0	0	0.0	0	0.0
30	Uttar Pradesh	650	0.00	43.95	233	35.8	202	31.1	115	17.7	81	12.5	16	2.5	3	0.5
31	Uttarakhand	45	0.04	55.16	7	15.6	11	24.4	15	33.3	6	13.3	4	8.9	2	4.4
	Total	**14470**	**0.00**	**116.98**	**4191**	**29.0**	**5755**	**39.8**	**2923**	**20.2**	**1011**	**7.0**	**384**	**2.7**	**206**	**1.4**

Source: Groundwater Yearbook (CGWB), India 2021-22

Annexure 4.2: Application for issue of NOC to Abstract Groundwater

Annexure 4.3: Yield Test for Wells

General

Pumping tests are made on wells to determine their capacity and other hydraulic characteristics and to obtain information so that permanent pumping equipment can be intelligently selected. Preliminary tests of well drilled as test holes are sometimes made to compare yielding ability of different water bearing formation or different locations in same formation. This information is then used as a basis for selecting the best site for a supply well and the aquifer in which it should be completed.

Measurements

The measurement that should be made in testing wells include the volume of water pumped per minute or per hour, the depth to the static water level before pumping is started, the depth to the pumping level at one or more constant rates of pumpage, the recovery of water level after pumping is stopped and the length of time the well is pumped at each rate during test procedure.

Pumping Procedure

The pump and power unit used for testing a well should be capable of continuous operation at a constant rate of pumpage for several hours. It is important that the equipment be in good condition for an accurate test, since it is not desirable to have a shut down during the test. If possible, the test pump should be large enough to test the well beyond the capacity at which it will eventually be pumped, but this may not be always practicable under field operations.

In the pumping test, the pump is fixed close to the well and water is pumped out. The quantity of water pumped is measured using a circular orifice meter or a V notch. The water discharging from the V notch chamber should be let away in a channel, so that water pumped out does not find its way back into the well through the soil. As water from the well is pumped out, there will be stage where water level remains fairly constant, without any further increase in drawdown. The pumping rate in this position is the yield from the well for that head of depression or drawdown.

Aquifer Pumping Test of Wells

The pumping tests of wells enable determination of Transmissivity (T) and Storability (S) of aquifers which further help calculate decline in groundwater levels associated with pumpage data.

Methods of Solution:

Three methods viz (i) Theis (ii) Copper and Jacob and (iii) Chow are in use world-wide to obtaining average values of T and S in the vicinity of a pumped well measuring effect of well pumpage (i.e., change in drawdown with time) in one or more observation wells under the influence of constant pumping rate.

Annexure 4.4: Disinfection of New or Renovated Wells, Tube wells and Pipelines

Dug Wells

1. After the casing or lining is completed, the procedure outlined below may be carried out before the cover platform is placed over the well:
   (i) Remove all equipments and materials including tools, platforms etc., which do not form a permanent part of the completed structure.
   (ii) Wash the interior walls of the casing or lining with a strong solution of the bleaching powder (50 mg/L chlorine) using a steel broom or brush to ensure thorough cleaning.
   (iii) Pump the water from the well until it is perfectly clear and remove the pumping equipment that was temporarily set up for this purpose.
2. Place the cover over the well and pour the required amount of bleaching powder solution in to the well through the manhole or pipe opening just prior to inserting the pump cylinder and drop pipe assembly. The bleaching powder added should give a dose of 50 mg/L of chlorine in the volume of water in the well. Care should be taken to distribute the chlorine solution over as much of the surface of the water as possible to obtain proper mixing of the chemical with well water, which may be facilitated by running the solution into the well through a hose or pipeline as the line is being alternatively lowered and raised.
3. Wash the exterior surface of the pump cylinder and drop pipe with bleaching powder solution giving 50 mg/L of chlorine when the assembly is being lowered into the well.
4. Allow the chlorine solution to remain in the well for not less than 24 hours.
5. After 24 hours or more have elapsed, the well should be flushed by pumping the water to waste, till the residual chlorine is brought to 1 mg/L.

Tubewells

1. When the well is tested for yield, the test pump should be operated until the well water is as clean and free from turbidity as possible.
2. After the testing equipment has been removed, pour the required amount of bleaching solution into the well slowly just prior to installing the permanent pumping equipment. The dose of chlorine should be maintained at 50 mg/L. Mixing of the chemical with well water may be facilitated by running the solution into the well through a hose or pipeline as the line is being alternatively raised and lowered.
3. Wash the exterior surface of the pump cylinder and drop pipe with bleaching powder solution before positioning.
4. Allow the chlorine solution to remain in the well for not less than 24 hours.
5. After 24 hours or more have elapsed, the well should be flushed by pumping the water to waste till a residual of 1 mg/L of chlorine is obtained. In the case of deep

wells having a high-water level, it may be necessary to resort to special methods of introducing the disinfecting agent in to the well so as to ensure proper mixing of chlorine throughout the well.

Similar procedure is adopted when troubles due to iron bacteria are noticed in the tube wells particularly when they come out as stringy masses along with the water.

Disinfection of Pipelines

When a section of water main is laid or repaired it is impossible to avoid contaminating the inner surface with dirt, mud or water in the trench while the pipes are being fixed into place. Contamination may also occur by accident, negligence or malice, adequate surveillance during working hours and the plugging of open ends after the day's work will reduce these risks. It should be assumed however that the pipe is contaminated despite all the precautions taken to prevent the entry of foreign matter. Secondly the main must be disinfected before it is put into service.

To obtain good results from disinfection and to avoid the hazards of subsequent obstructions and damage to valves, all foreign objects and material should be removed before hand by swabbing and flushing to clean the pipeline. Packing and jointing material should be cleaned and disinfected immediately before use by immersion in a 50 mg/L of chlorine solution for at least 30 minutes.

The presence of hydrants, air vales, gate valves and other openings in and around the section to be disinfected facilitate the injection and extraction of water for flushing and disinfection. Recently developed plastic foam swabs are also useful in disinfection of mains. As they are displaced by water pressure, these swabs wipe clean the inner surface of the pipe. They can isolate the section to be disinfected from the rest of the main and prevent the loss of disinfected solution.

Chlorine compounds are the most commonly used disinfectants for water mains. Strength of the disinfecting solution should be much higher than that normally used for water chlorination. Under normal conditions a strength of 10 mg/L is recommended for a contact period of 12-24 hours. Application for 24 hours is necessary when the chlorine has to penetrate through organic matter coating the inner surface. In emergencies, when it is not possible to leave the section of the main out of service for a long time, the period of contact can be shortened by proportionately increasing the strength of the solution. Thus, for a contact period of 1 hour the strength of solution varies between 120 mg/L and 240 mg/L. When strong solutions are used particular attention should be paid to thorough removal from the main after completion of disinfection as illness and discomfort may result from using highly chlorinated water and the corrosive action of the chlorine may damage pipes, valves, hydrants and house hold plumbing and fixtures.

Procedure for Application

Chlorine gas may be injected directly under the section of the main by a dry feed chlorine or supplied with a special gas diffuser or silver tube and attached to a hydrant or other opening by means of specially plugged valve. After the section has been thoroughly flushed, the entire valve is partly shut to bring water pressure below 1.70 Kg/cm^2.

At the hydrant or opening where the water is discharged, the flow rate is measured to determine the rate at which chlorine gas needs to be delivered. To obtain a concentration of 10 mg/L in the section to be disinfected, the chlorine gas input rate should be 0.9 Kg per 24 hours for every litres per second of flow. The valve of the chlorine is opened and adjusted so that the dial shows the required rate of chlorine flow.

To ensure that the chlorine concentration remains at 10 mg/L throughout the period of contact, the strength of the injected solution should be at least twice as high. A table below shows the amount of disinfectants required for pipes of various diameters in order to provide a chlorine concentration of about 20 mg/L.

Quantity of disinfectants required to provide concentration of 20 mg/L in a 100 m pipe length

Diameter of pipe mm	Quantity in litres in which disinfectant has to be dissolved 10 X Litre	Bleaching Powder (25% available chlorine) gm	Calcium Hypochlorite (70% available chlorine) gm	Sodium Hypochlorite (5% available chlorine) Litre
75	46	37	13	0.16
100	81	65	21	0.33
150	183	146	53	0.73
200	325	260	92	1.30
250	507	405	145	2.03
300	730	584	210	2.92
400	1298	1040	368	5.20

The volume in litres of the disinfecting solution required for 100 m of pipe can be expressed by $V = 0.08\ d^2$ where d is the diameter of the pie in mm.

As soon as the odour of chlorine is detected in water discharged from the main, water samples are taken to determine the chlorine content. When chlorine content reaches a value of 20 mg/L at the other end of the section being disinfected, the discharge hydrant is closed and the flow of the water and chlorine gas are stopped. The water is allowed to stand in the main for 12-24 hours and the chlorine content should be ensured to be not less than 10 mg/L at the end of the period. The mains should be thoroughly flushed with treated water until the water is cleared. Samples for bacteriological tests should be taken every day during the 3 days following disinfection to ascertain that the water is satisfactory in quality.

A similar procedure is used for feeding a mixture of chlorine gas and water by means of a solution feed chlorinator, special rubber hose should be fitted to the plug valve and the silver tube diffuser. A booster pump may be required to provide pressure at least 3 times higher than that in the main, in order to ensure satisfactory injection of the solution.

When calcium hypo-chlorite or chlorinated lime is used for disinfection of a section of a main, the easiest method of application is to inject a strong chlorine solution by means of portable chlorinator. If the intake valve is kept partly open, a small flow of water can enter the pipe to assist in the dispersion of the chemical. The discharge hydrant or valve is shut off when the odour of chlorine is detected in the water flowing out and the section of the main is allowed to fill. The intake valve is regulated so that the required amount of disinfecting solution is injected before the pipe is completely full.

When there is no chlorinator or pump to inject the disinfection solution, the intake valve is shut off after the flushing operation and the section is allowed to drain dry. Then the discharge hydrant or valve is shut off thus leaving the section to be disinfected, isolated from the rest of the main. The disinfecting solution is slowly poured through a funnel or a hose into an intermediate hydrant, valve or opening made for this purpose until the section is completely filled. Precaution should be taken to allow air trapped in the pie to escape; where there is no air valve or other orifice by which the air can be released, one or more service connections could be detached or a hole could be drilled in the top of the pipe.

If the section to be disinfected is short, weighed quantities of calcium hypochlorite or chlorinated lime in powder form may be placed at regular intervals inside the pipes while they are fixed into place. When water is introduced later, the powder will mix with it and produce strong solution of chlorine. The disadvantage is that the powder will be flushed to the far end of the section even the water is admitted slowly and no uniform distribution of disinfectant is possible.

While disinfecting solution remains in two pipes, the valves and hydrants in the section of the main should be operated to ensure that all surfaces come into contact with disinfectant. The valves at either end of the treated section should remain shut during the whole period of contact to prevent the loss of disinfecting solution.