Government of India
Ministry of Housing and Urban Affairs

Atal Mission for Rejuvenation and Urban Transformation 2.0

AIWASI
Australia India Water Security Initiative

Advisory on Urban Waterbody Rejuvenation

ARUP

Atal Mission for Rejuvenation and Urban Transformation 2.0

Australia India Water Security Initiative (AIWASI)

Waterbody Rejuvenation Advisory

Issued | 15 Nov 2023

Disclaimer: this document has been produced for the sole purpose of supporting MoHUA in the AMRUT 2.0 Mission by Arup Pty Ltd. This document is not intended to be used for any other purposes.

Job number 283059-00
Arup Australia Pty Ltd ABN 76 625 912 665

Arup Australia Pty Ltd
108 Wickham Street
Fortitude Valley
Brisbane
QLD 4006
Australia
arup.com

THIS PAGE IS INTENTIONALLY BLANK

Government of India
Ministry of Housing and Urban Affairs

अमृत 2.0
Atal Mission for Rejuvenation and Urban Transformation

Document Verification

Project title	Atal Mission for Rejuvenation and Urban Transformation 2.0 Australia India Water Security Initiative (AIWASI)
Document title	Waterbody Rejuvenation Advisory
Job number	283059-53
Document ref	DOCUMENT REF
File reference	FILE REF

Revision	**Date**	**Filename**			
Issued	15 November 2023	**Description**	Table of Content for the Waterbody Rejuvenation Advisory		
			Prepared by	**Checked by**	**Approved by**
		Name	Gaurav Bhatt	Sian Harrick	Barry Chisholm
		Signature			

Issue Document Verification with Document ☑

THIS PAGE IS INTENTIONALLY BLANK

Executive Summary

As one of the fastest growing economies of the world, India will continue to witness sprawling urban centres as well as rapid urbanisation, leading to changes in land use and potential increase in the hard cover. Coupled with the changing climate, wherein occurrences of high intensity rainfall events are projected to become increasingly common, many urban centres will face the challenges emanating from frequent instances of urban flooding leading to economic and social losses.

Waterbodies have been an integral part of rural and urban India. They provide water for domestic use, irrigation, and livestock while serving as an important source of food. They offer social, environmental, and ecological value through supporting local flora and fauna while providing sustenance and aesthetic value to the local communities.

From flood management perspective, the waterbody play an important role in peak flow attenuation and thereby reducing flood risk and moderating the downstream stormwater flow. In urban settings, healthy urban waterbodies have the potential to provide a broad range of socio-economic benefits such as water supply, flood protection, recreation and amenity, as well as supporting cultural and religious values, and ecological values.

The role of waterbodies in Urban Water Cycle is acknowledged under AMRUT 2.0 Mission. The Mission's guidelines underscores the importance of a waterbody wherein they provide unique advantage in terms of urban environmental and social sustainability while fostering a resilient and thriving urban ecosystems.

The Mission prioritises waterbody management through development of comprehensive Waterbody Rejuvenation and Management Plan to accomplish a transformative, resilient, and sustainable water reform, while enhancing the amenity value of waterbodies

The Objective of this advisory is to help the practitioners in development of a holistic, robust, and implementable Waterbody Rejuvenation Plan and provides a framework for preparation of a Waterbody Rejuvenation Detailed Project Report (DPR).

This advisory acknowledges that while each waterbody is unique in terms of its geographical location, characteristics of its contributing catchment, meteorological features, flora, fauna, existing users and uses, it's purpose is to provide key steps for a comprehensive assessment of the waterbody's condition and developing a corresponding rejuvenation plan that is suitable for the local context.

THIS PAGE IS INTENTIONALLY BLANK

Report Content

Tables

Figures

THIS PAGE IS INTENTIONALLY BLANK

Part A – Background to Waterbody Rejuvenation

1. Introduction

As India continues to be one of the fastest growing economies of the world, we are witnessing sprawling urban centres as well as expansion of our cities going through rapid urbanisation, creating more hard cover through changes in the land use and land cover. Coupled with the changing climate, wherein occurrences of high intensity rainfall events are becoming increasingly common, many urban centres are now grappling with the frequent instances of urban flooding leading to high economic and social losses.

Waterbodies play an important role in supporting and sustaining the local water cycle. They provide societal and environmental sustenance to unique flora and fauna as well as livelihood and aesthetic value to the local communities. One of their critical functions is to provide attenuation within the catchment, allowing for a reduction in flood risk and improving flood response, by storing the runoff, and moderating the downstream stormwater flow.

The AMRUT 2.0 operational guidelines acknowledge the importance of functioning waterbodies and their contribution towards urban water cycle management. As cities strive to balance their developmental needs with environmental and social sustainability, waterbody management emerges as a key component of AMRUT 2.0's endeavour to foster resilient and thriving urban ecosystems and creating Water Sensitive Cities. Hence the mission prioritises waterbody management through development of comprehensive waterbody rejuvenation and management plan to accomplish a transformative, resilient, and sustainable water reform.

1.1 Importance and role of healthy waterbodies

Waterbodies are an integral part of the urban landscape and provide important environmental, economic, and social benefits that are valued and used by the communities surrounding them. Some example waterbodies are shown in **Figure 1**.

Figure 1: Example waterbodies: Amenity at Man Sagar Lake (top figure, Source: https://siliconeer.com), waterbody for religious rituals (bottom left figure, Source: Hindustan Times), and provision of aquatic food (bottom right figure):

Waterbodies have always held important environmental, social, livelihood, economic and cultural significance in India. They provide a source of water for domestic use, irrigation, and livestock as well as important sources of food. In the urban context, healthy urban waterbodies have the potential to provide a broad range of socio-economic benefits such as water supply, flood protection, recreation and amenity, as well as supporting cultural and religious values, and ecological values.

Healthy urban waterbodies have the potential to provide a range of "values and uses" including:

- Water supply
- Groundwater recharge
- Recreation and amenity
- Culture

- Flood protection
- Aquatic food
- Livelihood
- Tourism
- Ecological values (birds, fish, vegetation)
- Religious values

1.2 Need for waterbody rejuvenation

However, this potential is severely compromised when the health of waterbodies is poor, some examples are shown in **Figure 2**.

Dry Sowl kere during the Summer, Bengaluru (Source: www.bengaluru.citizenmatters.in)

Landfill site at Deepor Beel, Assam, Guwahati (Source: www.lakesofindia.com/author/lucygibson98/)

Fire due to illegal dumping of waste mixed with untreated sewage at Bellandur lake, Bengaluru (Source: www.thelogicalindian.com/)

Houses encroaching the dried up Mudichur lake, Chennai (Source: The Indian Express, 2017)

Nagapattinam lake filled with silt, Tamil Nadu (Source: www.thelogicalindian.com)

Hussainsagar lake with poor water quality, Hyderabad (Source: IANS)

Figure 2: Decline in health of waterbodies

External pressures, such as those from land uses in the catchment of waterbodies, and direct pressures, such as encroachment and development within the waterbodies, have impacted the health of waterbodies and their values and uses that the community have come to rely on. Waterbody rejuvenation seeks not only to reduce negative impacts on waterbodies, but to protect and nurture them so that their social, environmental and amenity value enhances into the future.

1.3 Objective and purpose of advisory

The objective of this advisory is to provide users with guidance for developing a holistic, robust, and implementable Waterbody Rejuvenation Plan. While each waterbody is unique in terms of its geographical location, characteristics of its contributing catchment, meteorological features, flora, fauna, existing users and uses, the purpose of this advisory is to provide key steps for a comprehensive assessment of the waterbody's condition and developing a corresponding rejuvenation plan that is suitable for the local context.

This advisory focuses on inland surface standing water systems (i.e., low flow or no flow) that are either ephemeral or permanent in nature, including lakes, ponds, cut-off meanders, wetlands, waterlogged areas, reservoirs or barrages, and ponded sections of rivers or channels.

The advisory covers the key elements for development of a waterbody rejuvenation plan, as shown in **Figure 3**.

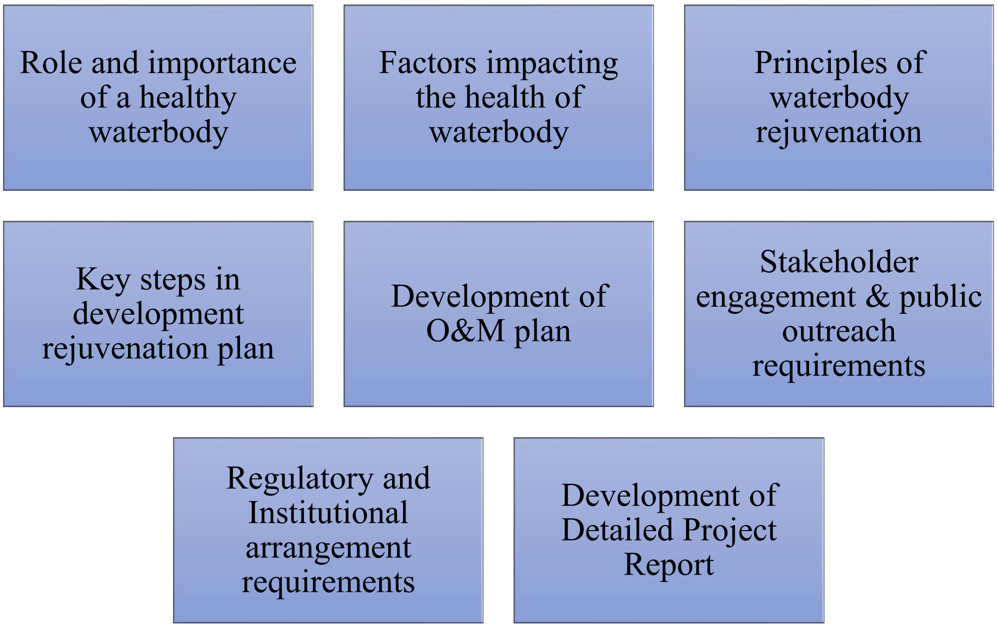

Figure 3: Key elements for development of a waterbody rejuvenation plan

2. Understanding waterbody rejuvenation

Waterbody rejuvenation is a set of actions to improve the health of a waterbody by managing pressures on the waterbody and improving its damaged or compromised elements so that it can better support its values and uses.

The following section presents key processes and factors that impact the health of waterbodies and understanding their interaction in developing a waterbody rejuvenation plan.

2.1 Pressures on waterbodies

Pressures on the waterbodies can include natural factors as well as human activities occurring within the waterbody or its catchment, impacting the waterbody’s health. As such, a waterbody ecosystem extends beyond the waterbody’s footprint into its catchment, which is the land contributing runoff to the waterbody (**Figure 4**).

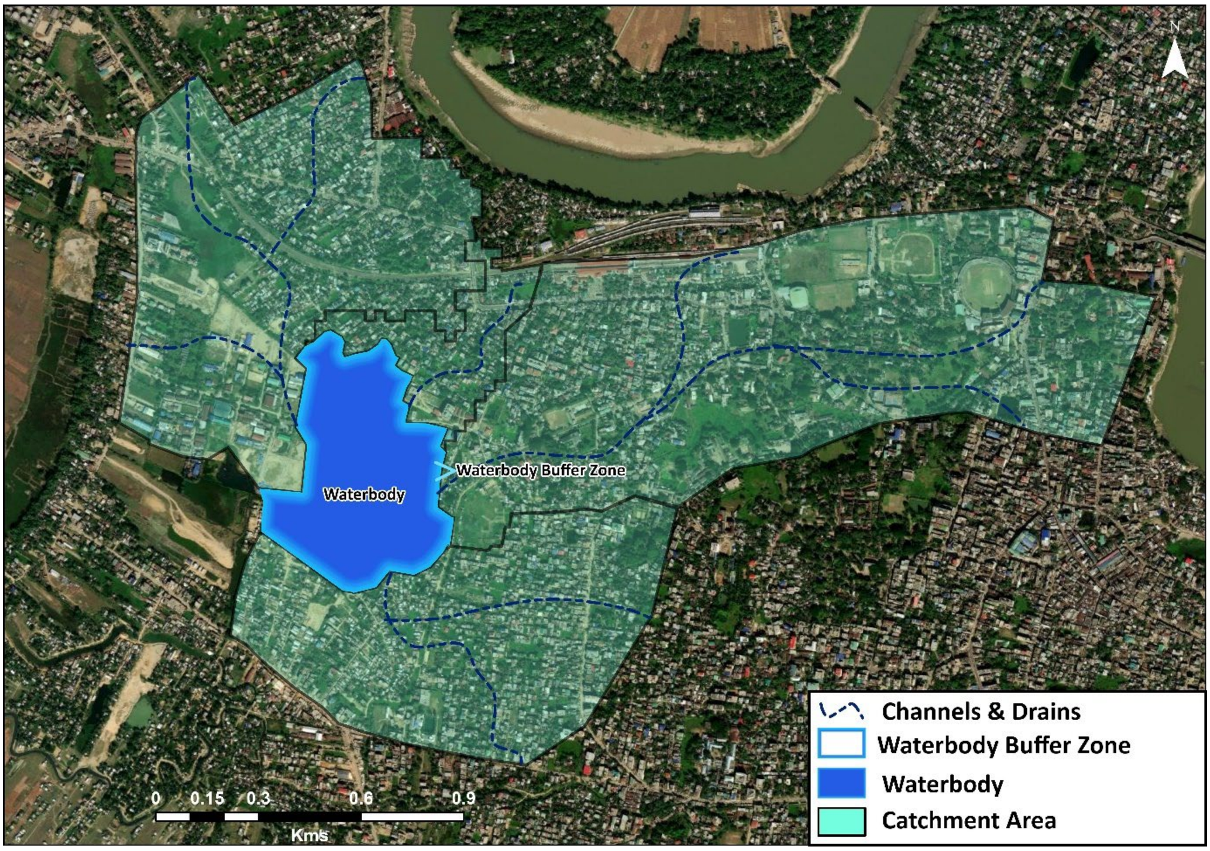

Figure 4: Example of an urban waterbody and its catchment

Pressures affecting waterbodies may be located a long way from the waterbody itself (e.g., polluting activities occurring upstream of the waterbody in its catchment), and therefore it is critical to adopt a whole-of-catchment perspective when rejuvenating waterbodies to ensure pressures are appropriately managed. **Figure 5** shows illustratively some of the pressures that may existing within the waterbody catchment that could impact waterbodies.

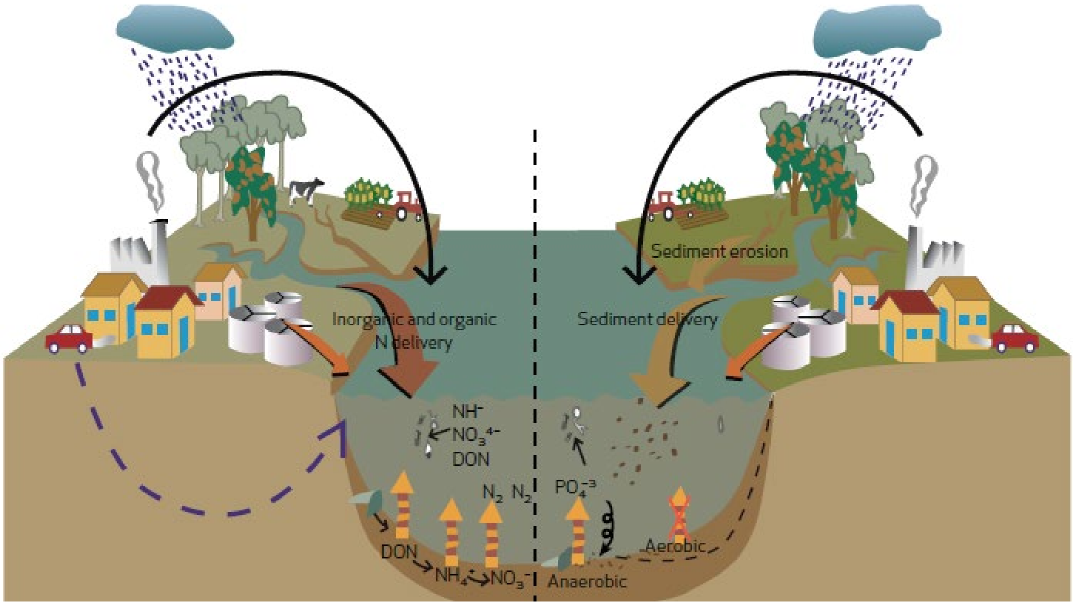

Figure 5: Example of processes in the catchment and within the waterbody (Source: Waterbody Management Guideline (2013), Water by Design

It is necessary to understand the full range of pressures impacting the waterbody and how they should be managed. Key phenomena contributing to the pressure on waterbody, are described in the following subsections.

2.1.1 Urbanisation

Urbanisation is one of the critical growth engines for the economy. Offering ample job opportunities, education, and medical facilities, urban centres and cities continue to act as a magnet to which people migrate from different parts of the country and the world.

However, with increased demand for land to accommodate additional businesses and population, often urbanisation entails modification of land use and land cover to create new infrastructure, thereby altering the physical and hydrological characteristics of catchment of urban waterbodies. Often, the growth of the urban population exceeds the pace of water utilities and drainage infrastructure development in the region. Waterbodies and their contributing drainage network often bear the brunt of such development.

Catchment flooding, inadvertent discharges of untreated used water from areas that are not connected to sewerage, illegal dumping of waste in or around the waterbodies and drains, and change in quantity and quality of diffuse stormwater runoff generated in the waterbody catchment causes severe deterioration of the health of the waterbody. In many cities, the used water treatment plants are located in the vicinity of a waterbody, discharging treated water into them. If such treatment plants are not performing well or are under maintenance, untreated or undertreated water may be discharged into the downstream waterbodies, further deteriorating the water quality.

In some cities, there have been instances of laying used water pipelines within stormwater drains to take advantage of the drain's gradient, increasing the risk of leakage of sewage into waterbody catchments. Often, the stormwater drains in cities are exploited as an illegal site for dumping garbage and solid waste. Some examples are shown below in **Figure 6**.

Figure 6: Used water pipelines laid within the stormwater drain and prevalent solid waste dumping in drains

Figure 7 below, shows the contrast between a forested and an urbanised catchment, and the impacts on water hydrology and runoff.

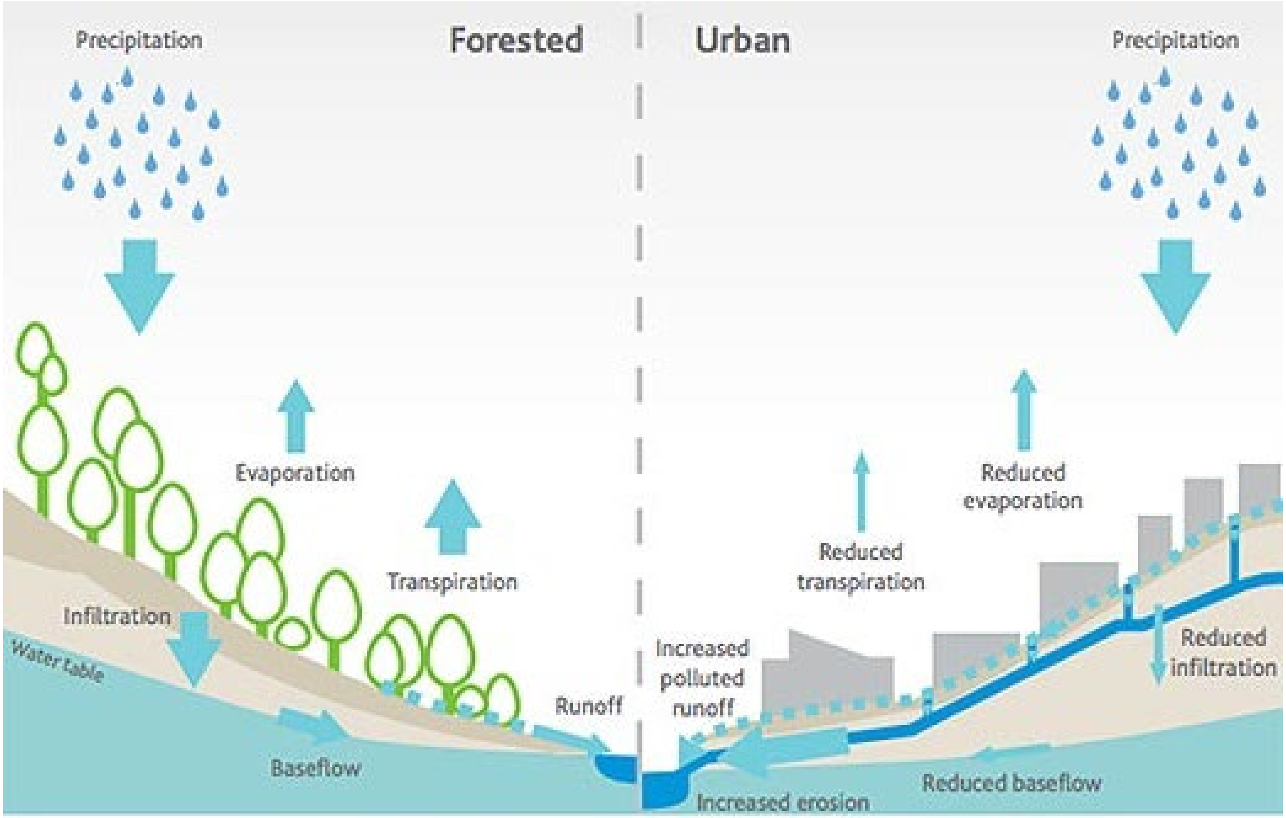

Figure 7: Impact of change in land cover on urban hydrology

When the degree of disturbance becomes significant within a waterbody's catchment, this can impact on the health of the waterbody through:

- higher pollutant load into the waterbody (litter, sediment, nutrients, heavy metals, oils, etc)
- higher frequency and larger flows into the waterbody, leading to erosion and scouring of banks and bed and changes in the hydrologic regime of the waterbody
- reduced baseflow into the waterbody.

Therefore, while conventional approaches to stormwater management may focus primarily on drainage and flood protection, to achieve waterbody rejuvenation, diffuse pollution and hydrologic disturbances in waterbodies must also be considered.

2.1.2 Groundwater use

Urbanisation and the associated increase in impervious surfaces also impact local groundwater recharge. The interaction between waterbodies and groundwater plays an important part in lake sustainability and waterbody rejuvenation, both from the perspective of water quality and quantity. The three main modes of interaction between waterbodies and groundwater are shown below in **Figure 8**

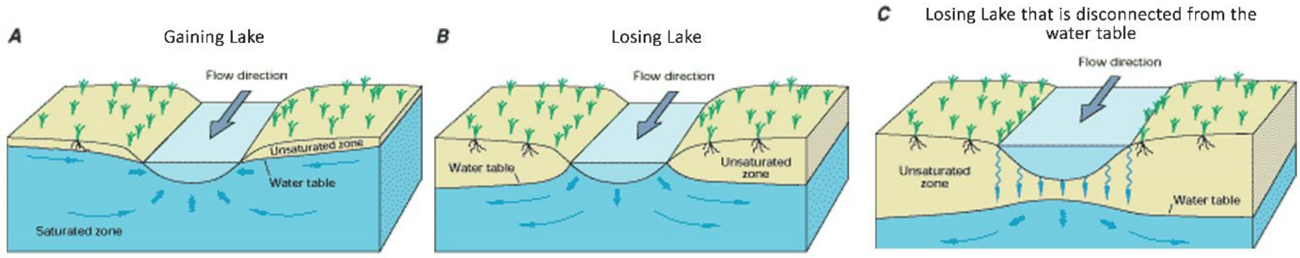

Figure 8: Modes of interaction between waterbodies and groundwater

With an increase in contaminants entering the waterbody, shallower water tables are typically more susceptible to pollution, due to the reduced time and capacity for attenuation of contaminants between the surface and the groundwater table.

Therefore, when formulating a waterbody rejuvenation strategy, it is important to understand the status of groundwater and its extraction as well as the hydrogeology in the catchment area, as these can have a large influence on the hydrologic regime and water quality in the waterbody.

2.1.3 Climate change

The changing climate is having an impact on the intensity, location, duration and frequency of extreme rainfall events and drought. In an urbanised system, the impacts of these hydrological extremes are evident, with flooding having severe repercussions for urban infrastructure (stormwater drains, used water systems), life and properties (particularly buildings in low lying areas, basements, and urban slum settlements).

For waterbody rejuvenation, it is important that the long-term historic variation in meteorological characteristics, particularly rainfall and evaporation, are well understood. This data can be used to determine the seasonal trends of rainfall and evaporation, especially during monsoon and summertime, including recorded extreme rainfall events, and recorded flood extent impacting the waterbody/catchment area. Online resources are available for download to support assessments of projected rainfall data in the face of climate change, including gridded data from https://climateknowledgeportal.worldbank.org/download-data.

Based on comprehensive analyses of long-term meteorological data along with the catchment physical characteristics such as land use and land cover, hydrology, contributing drainage infrastructure to the waterbody, variation of groundwater in the catchment area, an informed waterbody rejuvenation plan should be developed.

2.2 Features and processes influencing a waterbody

The health of a waterbody is based on the condition of the following factors.

- **Catchment and waterbody processes** which explain the major inputs into the waterbody (in terms of water, nutrients, sediments, carbon, and other chemicals as a result of interaction between the hydrological cycle, geology, vegetation, and land use practices in the catchment) and key processes within the waterbody itself.

- **Hydrologic regime and hydraulics.** The hydrologic regime refers to the magnitude, timing, frequency and duration of inundation in the waterbody. It is the product of catchment runoff, groundwater connection and other water sources. Hydraulics refers to water movement into, within, and out of the waterbody.
- **Water quality** which is primarily determined by inputs from the catchment (natural factors and human activities), as well as processes within the waterbody, such as mixing, circulation, and interaction with sediments.
- **Physical form** which refers to the shape of the waterbody, profile of its banks and profile of its base (bathymetry). Physical form is influenced by natural factors (e.g., geology and topography) and human activities within the waterbody and its catchment.
- **Aquatic and riparian ecosystems** which refers to the flora and fauna conditions within the waterbody and its buffer zone (plants, animals and microbial life), and usually depend on and develop in response to the hydrologic regime, water quality and physical form of the waterbody.
- **Stakeholder and community engagement**. Communities are often the guardians of waterbodies. An educated, aware and active community can positively impact the health of a waterbody through care, advocacy and monitoring.

Waterbody health responds to pressures that act on the waterbody either directly or within the catchment of the waterbody. Therefore, it is important to have a thorough understanding of these features and processes and their interaction.

The following section **Part B – Plan to Practise** presents the key tasks and activities to be undertaken as part of developing Waterbody Rejuvenation Plan.

THIS PAGE IS INTENTIONALLY BLANK

Part B – Plan to Practice

3. Development of a waterbody rejuvenation plan

The following section presents key steps involved in the development of a waterbody rejuvenation plan. While the below general principles apply, it is important to note that waterbody characterisation and rejuvenation requirements are dependent upon various region-specific features such as climatic zone, meteorology, land use and land cover, hydrology, hydrogeology, etc., and would require contextualisation of approach based on the local conditions.

3.1 Understanding waterbody rejuvenation framework

There are two fundamental steps involved in formulating a waterbody rejuvenation project: a situation assessment of the waterbody (Stage 1); followed by development of a waterbody rejuvenation plan (Stage 2) as shown in **Figure 9**. A Detailed Project Report (DPR) for waterbody rejuvenation should cover these two stages.

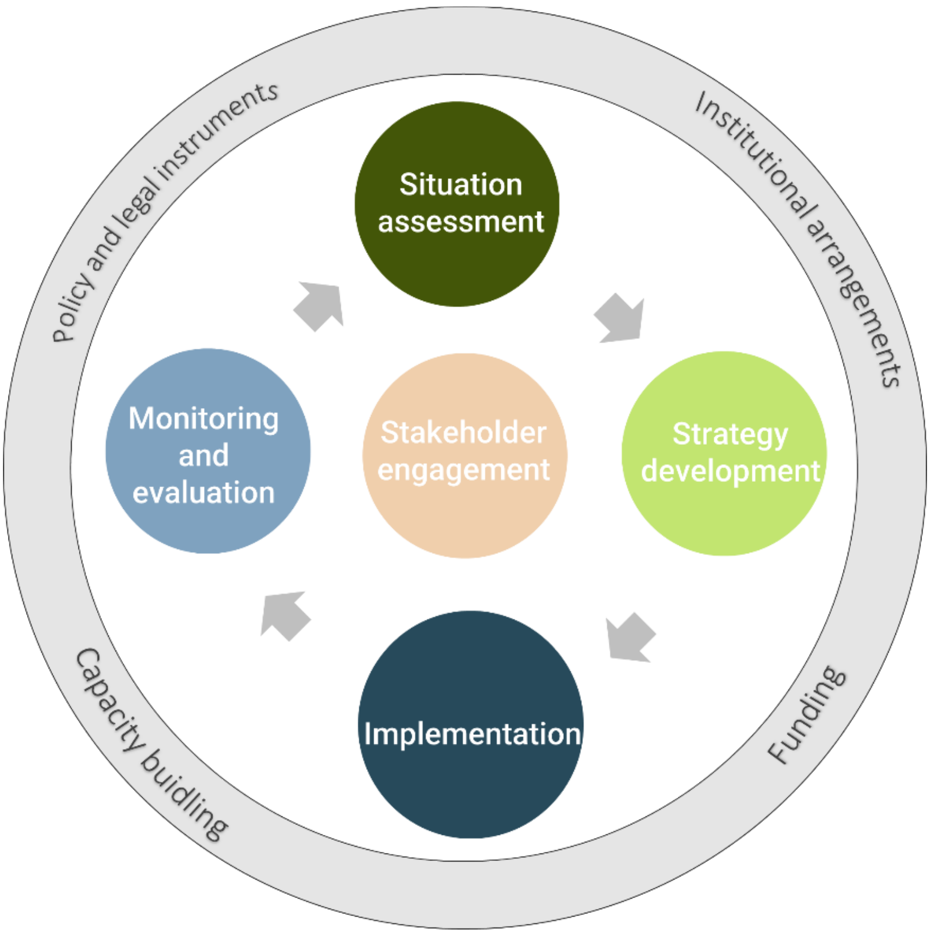

Figure 9: Waterbody Rejuvenation Framework cycle.

Situation assessment and Strategy development are the two fundamental steps for formulating a waterbody rejuvenation project. This section of the advisory outlines what needs to be considered in both Stage I and 2 including a list of fundamental aspects to consider. An indicative framework is also provided to ensure critical elements in Stage 1 and 2 are considered by proponents who are developing a waterbody rejuvenation DPR.

Implementation refers to the execution of the proposed actions, while monitoring & evaluation is about determining the extent to which the waterbody rejuvenation goals and objectives have been met over time. These two aspects are not covered in this advisory.

3.2 Situation assessment

One of the critical requirements in developing a Waterbody Rejuvenation Plan is to undertake a comprehensive situation assessment of the waterbody and its contributing catchment.

This includes undertaking the following key activities:

- Identification of the key drivers and objectives for the Waterbody Rejuvenation Plan based on the values and uses in Section **1.2** of this document.
- Collecting the waterbody and catchment's physical feature information through reconnaissance survey and available secondary data to identify any major technical, social, and environmental issues related to the waterbody's current condition.
- Identification of any ongoing waterbody restoration works, and infrastructure works (e.g., for water, used water or drainage) that have a bearing on the waterbody.
- Identification of data gaps and developing strategy for primary data collection required (explained in subsequent section) for a holistic analysis.
- Identification of key stakeholders including residents and collecting their inputs regarding waterbody restoration.

3.2.1 Establishing watershed characteristics

To establish the waterbody's contributing watershed characteristics, the following data should be collected for analysis.

Land use and land cover (LU & LC): LU and LC have a significant bearing on the quality and quantity of runoff generated within the catchment. Increase in imperviousness leads to reduced time of concentration[1], quantity of flow as well as the quality of runoff. Typical urban land uses comprise commercial, industrial, residential (high, medium low density), institutional, agricultural, forest, open urban land etc. The land use will also provide guidance on the kind of point and non-point pollution sources that are likely to be present in the runoff. Based on LU

[1] Time of concentration (Tc) is the time required for runoff to travel from the hydraulically most distant point in the watershed to the outlet.

LC Maps, the % imperviousness can be calculated to determine the quantity of runoff that will be generated in the catchment. Online resources available for assessment of Land Use and Land Cover are provided in **Appendix C C1 – Establishing** watershed characteristics.

Hydrogeology: The interaction between waterbody and groundwater is controlled by soil type, degree of rock weathering and fracture pattern, and rainfall. Soil type in the catchment area of the waterbody determines the opportunity for infiltration to the groundwater as well as interconnection between the waterbody and shallow groundwater. Based on hydrogeology of waterbody's catchment, opportunities for artificial recharge can be developed. In an urban catchment, available open land such as parks, open fields, etc., provide an opportunity for groundwater recharge. and should therefore be designed with appropriate levels and edge treatments to allow for surface runoff from the surrounding areas to reach and be collected.

While developing the opportunities for artificial recharge at the catchment level, the most favourable formation for artificial recharge would be terrace gravels or sandy alluvium associated with river valleys and/or palaeo-channels. Based on existing soil characteristics and its infiltration potential, strategic interventions such as infiltration basins and galleries, bio swales, infiltration trenches, porous pavements, etc., can be placed to enhance groundwater recharge within the waterbody's catchment. Online resources available for assessment of soil type, land use and land cover are provided in **Appendix C C1 – Establishing** watershed characteristics.

Catchment topography and drainage information: Information on the catchment topography provides forms and features of a waterbody's catchment area. This can be used to develop a bare earth surface model, indicating relevant features such as general land elevation and catchment slope, as well as hydrological characteristics, such as sub-catchment features and connectivity among waterbodies within the catchment, identification of flood prone areas, and pattern of surface runoff.

Topographical data should be supplemented by drainage information: this can be obtained through a stormwater drainage survey providing cross-sectional and longitudinal section, as well as water control structures, particularly for any primary stormwater drains that lead directly to the waterbody, and any that connect different waterbodies within the catchment. These data are critical for developing the waterbody rejuvenation plan as they will influence the conveyance of flow, point source pollution, possible flood risk and development of remedial measures. Sources of topographical and drainage information are provided in **Appendix C C1 – Establishing** watershed characteristics.

3.2.2 Establishing waterbody characteristics

For developing the Waterbody Rejuvenation Plan, it is important to understand its physical features as well as its physico-chemical characteristics of the waterbody, and the following data are recommended for collection and analysis.

Waterbody bathymetry: Bathymetric survey is used to assess the current water carrying capacity of the waterbody, and assessment of the volume for desilting required to bring waterbody to its natural condition, including need for further deepening to augment storage.

Bathymetry data is critical for developing the Waterbody Rejuvenation Plan, and the grid size for survey points can be selected based on the size of waterbody. the grid size for survey points can be selected based on the size of waterbody. A minimum grid size of 10 m × 10 m is recommended for waterbody bathymetry surveys. Sources of topographical and drainage information are provided in **Appendix C C2 – Establishing** waterbody and meteorological characteristics.

Waterbody inlet, outlet, and bypass structure: The total volume of water that can be held in each waterbody is a function of its storage curve (water stored versus waterbody depth), its inlet and outlet structure elevation, and the capacity of the downstream drainage system's conveyance capacity. Therefore, while developing the waterbody rejuvenation plan, waterbody inlet and outlet surveys should be done to capture the type of structures, their invert elevation, existing flow control measures, and the waterbody boundary survey to ascertain the High Flood Level.

The bypass structures ensure that, where the waterbody receives any dry weather flow in the form of untreated used water discharges or excess flow during high rainfall events, the waterbody can be safely bypassed such that these flows do not enter it. If the waterbody receives treated used water discharges as dry weather flow, it is critical that the long-term quality of such water is determined, and in the event of any maintenance work in the treatment plant, there are arrangements to ensure that any untreated water does not enter the waterbody.

Water and sediment quality of waterbody: The water quality data, i.e., physico-chemical and biological parameters, are indicative of natural or anthropogenic activities in the waterbody's catchment area. Any long-term pollution adversely impacts sediment quality, aquatic flora, and fauna along with associated food webs. Sediment is an integral and inseparable component of aquatic environment and plays an key role in the dynamics and balance of ecosystems. Therefore, collection of water and sediment quality data is critical for developing a Waterbody Rejuvenation Plan. The recommended parameters for water and sediment quality are provided in **Appendix A – Recommended quality parameters.**

Current users/uses and existing Operations & Maintenance (O&M) practices: As part of any rejuvenation plan, it is important to identify the current and post-restoration users and uses of the waterbody, existing operation and maintenance practice for waterbody management. Following any waterbody rejuvenation project, it is recommended that the following be developed and implemented:

- Stakeholder and public outreach program
- O&M plan
- waterbody monitoring plan (presented in the subsequent section)

3.2.3 Meteorological characteristics

Meteorological characteristics assessment and analysis, including consideration of climatic conditions, rainfall, and evaporation data, are critical for developing the waterbody rejuvenation plan. Assessment of these parameters will provide the temporal and spatial trend of rainfall and evaporation patterns over the long term. Identification of occurrences of extreme climatic events, such as high-intensity rainfall or drought events, as well as potential future impacts of climate change on these, will also help inform the remedial measures necessary to sustainably maintain the health of the waterbody and the ecosystem that is dependent on it. Moreover, these parameters to develop waterbody's water balance. To account for spatial variability, it is recommended that rainfall data be collected from multiple rain gauges. The meteorological data time frame should ideally be collected for longest available time to account for variability trend analyses as well as calculation of potential runoff generation. Recommended time interval resolutions for rainfall and evaporation data are, respectively, hourly, and daily.

3.3 Waterbody rejuvenation plan interventions

This section presents the key interventions that can be used in developing a Waterbody Rejuvenation Plan. Sections A-D below provide details of each intervention in terms of its application (purpose and functionality), design and planning considerations, and operations and maintenance considerations. The interventions have been grouped into these four sections based on their main function:

- **Section A** – Flow management measures which are measures that influence the volume and frequency of water moving into and out of a waterbody, including how long water resides in the waterbody (duration), and how water moves within the waterbody (hydraulics)
- **Section B** – Physical form measures which refer to measures to restore or modify the profile of the waterbody's base and banks to improve flow movement in the waterbody (hydraulics) and to achieve the desired water depths to support aquatic and riparian vegetation and other "values and uses" (such as water storage to meet water supply requirements).
- **Section C** – Aquatic and riparian vegetation management which includes measures to improve coverage and diversity of desirable aquatic and riparian vegetation within and around the waterbody, to ensure healthy flora and fauna (an essential element of a healthy waterbody).
- **Section D** – Treatment measures which refer to measures that manage inputs (pollutants) generated in the catchment to improve water quality entering the waterbody. Water quality in a waterbody is influenced both by processes within the waterbody and inputs from the catchment. Hence, in addition to treatment measures, actions that address issues with water regime, hydraulics, aquatic and riparian vegetation, and physical form of the waterbody should also be considered to improve water quality in the waterbody.

The following presents the classification of identified measures within each of the above four types of intervention that may be used as part of a waterbody rejuvenation plan.

Table 1: Classification of identified measures for waterbody rejuvenation

Flow management measures	Physical form measures	Aquatic and riparian vegetation management	Treatment measures
A1 – Flow intersection and diversion around waterbody A2 – Flow diversion into waterbody A3 – Flow mixing and aeration A4 – Flow redirection A5 – Flow recirculation A6 – Flow (stormwater) retention in the catchment	B1 – Bathymetry and bank reshaping B2 – Desilting	C1 – Aquatic planting C2 – Riparian planting C3 – Aquatic weed removal and management	D1 – Primary Treatment D1.1 – Settling tank D1.2 – Sedimentation pond D1.3 – Anaerobic baffled reactor D2.1 – Constructed wetland D2.2 – Floating wetlands D2.3 – In-situ drain treatment D2.4 – Biofiltration system

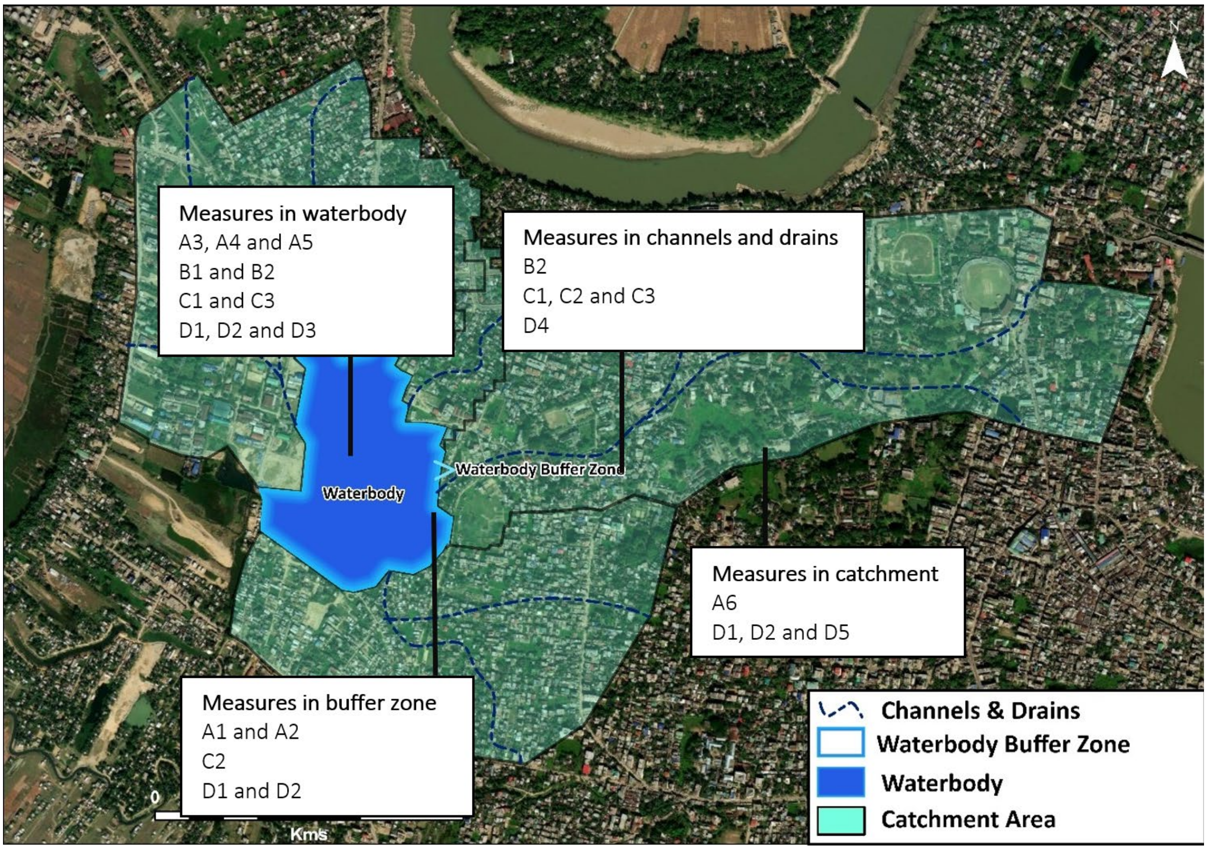

Figure 10: Common measures used to improve health of a waterbody and their locations of application

The below presents the measures that may be implemented to address typical problems in waterbodies (Refer to sections A-D below for details on each measure).

Table 2: List of measures that may be implemented to address common problems in waterbodies

Typical problems in waterbodies	Potential measures
Poor water regime and hydraulics	
Uncontrolled inflow; Frequent flooding	• A1 – Flow interception and diversion • A6 – Flow (stormwater) retention in catchment
Reduction in stored volume; Reduced inflow to waterbody	• A2 – Flow diversion into waterbody and outlet management
Poor flushing of waterbody and formation of eutrophic zones	• A2 – Flow diversion into waterbody and outlet management • A4 – Flow redirection • A5 – Flow recirculation

Typical problems in waterbodies	**Potential measures**
	• B1 – Bathymetry and bank reshaping Other potential measures: • Redesign stagnant zones as wetlands • Retrofit inlet and outlets to maximise flushing
Low dispersion of incoming flow in the waterbody (Short-circuiting)	• A4 – Flow redirection • B1 – Bathymetry and bank reshaping Other potential measures: • Move inlets/outlets or remove clump vegetation to promote longer flow paths
Physical alteration	
Accumulation of coarse sediments, organic matter and litter in waterbody bed	• B2 – Desilting • D1 – Primary treatment
Erosion of banks	• B1 – Bathymetry and bank reshaping • C1 – Aquatic planting • C2 – Riparian planting Other potential measures: • Reinforce areas prone to erosion with rock protection • Rock lining channels that direct high uncontrolled flows down the banks of the waterbody
Growth of invasive flora and fauna/loss of ecological values	
Loss of desired aquatic and riparian vegetation	• C1 – Aquatic planting • C2 – Riparian planting
Aquatic weed/flora infestation	• C3 – Aquatic weed removal
Invasive fauna	• Trapping and removal of pest species • Regular dewatering of waterbodies to manage exotic fish

Typical problems in waterbodies	Potential measures
	• Improve habitat and water quality for native species • Implement a native fish stocking program • Improving fish passage among waterbodies
Loss of water quality	
High concentration of nutrients (nitrogen and phosphorus)	• A3 – Mixing and aeration (particularly if phosphorus is released from bed sediments due to low dissolved oxygen) • A5 – Flow recirculation (through wetlands) • B2 – Desilting • C1 – Aquatic planting • C2 – Riparian planting • D1 – Primary treatment • D2.1 – Constructed wetland • D2.2 – Floating wetland • D2.3 – In-situ drain treatment • D2.4 – Biofiltration system Other potential measures: • Diversion of dry weather flow, particularly untreated used water
High turbidity levels	• B2 – Sediment removal • C1 – Aquatic planting • C2 – Riparian planting • D1 – Primary treatment Depending on levels of suspended solids and dissolved solids in incoming flows, other potential measures: • D1-D2 • Repair bank erosion

Typical problems in waterbodies	Potential measures
	• Remove exotic fish that promote sediment resuspension
Pathogens	Measures that can reduce pathogens to some extent: • D2.1 – Constructed wetland • D2.3 – Floating wetland • D2.3 – In-situ drain treatment • D2.4 – Biofiltration system Other potential measures: • Diversion of dry weather flow, particularly untreated used water • Remove or cull waterfowl
Algal bloom	• Refer to actions for addressing high nutrients and high turbidity. • A2 – Flow diversion into waterbody (to flush algae) and outlet management
Stratification and low dissolved oxygen	• A3 – Flow mixing and aeration • A4 – Flow redirection • A5 – Flow recirculation • B1 – Bathymetry and bank reshaping (fill zones with poor water movement) • C1 – Aquatic planting • C2 – Riparian planting (provision of shade to reduce surface water temperature and risk of stratification) • D2.2 – Floating wetlands (reduce surface water temperature and risk of stratification)
Contamination by toxic chemicals	• Monitoring of water quality in the drains contributing to waterbody to thwart illegal dumping • Bypass arrangements

Typical problems in waterbodies	Potential measures
	• Clean-up activities from spills

The details of measures identified in the **Table 2** above are provide under **Appendix B. Potential measures for waterbody rejuvenation.**

For easy referencing and understanding of the reader, the **Rejuvenation opportunities and choices** are presented in **Figure 11**.

THIS PAGE IS INTENTIONALLY BLANK

Common problems in waterbodies and catchment → | Location

Interventions ↓		Excessive flows; Dry weather flow (used water)	Insufficient flows; Pollutant dilution; Water turnover/recirculation	Poor flushing; Lack of mixing; Dense stratification	Short-circuits	Accumulation of coarse sediments, organic matter and litter	Erosion of banks	Loss of desired aquatic and riparian vegetation	Aquatic weed infestation	Nuisance fauna	Eutrophication	High turbidity levels	Pathogens (marginal reduction only)	Algal bloom	Stratification and low dissolved oxygen	Contamination by toxic chemicals	*In Waterbody*	*In Buffer Zone of Waterbody*	*In Channels and Drains*	*In Catchment*
A Flow management measures	A1 – Flow interception and diversion around waterbody	•				•	*		•	•	•	•	•	•	*	•		A1		
	A2 – Flow diversion into waterbody		•	•	•			*							*					
	A3 – Flow mixing and aeration		•			•					•		•	*	•					
	A4 – Flow redirection			•	•	*			*	*	*		•	*		*				
	A5 – Flow recirculation		•	•	•				*	*	•			*						
	A6 – Flow (stormwater) retention in the catchment	•					•	•						*		*				
B Physical form measures	B1 – Bathymetry and bank reshaping			•	•		•							*						
	B2 – Desilting			•	•	•		•	•		•	*		*	*					
C Aquatic and riparian vegetation management	C1 – Aquatic planting				•	•		•	*	*	•			*	*					
	C2 – Riparian planting					•	•	*	*	*										
	C3 – Aquatic weed removal and management				•			•	•	•	•	*		•						
D Treatment measures	D1 – Primary Treatment																			
	D1.1 – Settling tank					•		*	*	*	*	*	*	*		*				
	D1.2 – Sedimentation pond					•		*	*	*	*	*	*	*		*				
	D1.3 – Anaerobic baffled reactor					•		*	*	*	*	*	*	*		*				
	D2 – Secondary Treatment																			
	D2.1 – Constructed wetland					•		•	•	*	•	•	*	*	*	*				
	D2.2 – Floating wetlands					•			*	•	*	*		*	*					
	D2.3 – In-situ drain treatment					•			*	*	*	*		*		*				
	D2.4 – Biofiltration system					•			*	*	*	*		*		*				
E Other Measures	Reduce size of the waterbody		•																	
	Drain and seal the base of the waterbody if there is excessive infiltration		•																	
	Fix any leaks in the outlet structures			•	•															
	Redesign stagnant zones as wetlands					•			•	•			*	*	*	*				
	Retrofit inlet and outlets to maximise flushing			•							*			*						
	Move inlets/outlets or remove clump vegetation to promote longer flow paths				•															
	Reinforce lake bank and peripheral areas prone to erosion erosion control measures					•	•				*	•		*						
	Rock lining channels that carry high uncontrolled flows to the waterbody					•					*	•								
	Trapping and removal of pest species								•	•		*		•	*					
	Regular dewatering of waterbodies to manage exotic fish			•	•	•			*	*	*				*					
	Improve habitat and water quality for native species			*		•			•		•			•	*					
	Improving fish passage between rivers and waterbodies					•			*	*	*	*		*						
	Remove exotic fish which promote sediment resuspension								*	*	*	•		*						
	Treat runoff from intensive agricultural zones																			
	Limit waterfowl					•		*	*	*	*			*						
	Clean-up activities from spills					•		•			•	•			•	*				

P	**Primary measure**
S	**Secondary measure**

Jurisdiction/Applicability of Measures

- In Waterbody
- In Buffer Zone of Waterbody
- In Channels and Drains
- In Catchment

Figure 11: Rejuvenation opportunities and choices

THIS PAGE IS INTENTIONALLY BLANK

3.4 Waterbody monitoring requirements

The effectiveness of waterbody rejuvenation interventions is predicated on the improvement in the availability of hydrometric and water quality data.

Waterbody monitoring is important as it underpins efficient O&M and long-term sustainability. Some of the key advantages of waterbody monitoring plan are:

- Better quantification of the relationship between rainfall and runoff, which will help to minimise the risk of damage and disruption due to issues pertaining to flooding
- Effective real time operation of treatment and storage elements by allowing gates to be opened and closed according to prevailing levels and flow conditions
- Effective and reliable determination of quality of influent to better manage loadings and treatment to avoid significant contamination.

Flow monitoring: Flow meters installed within stormwater drains help to estimate the amount of runoff generated in the catchment. This is used to design the drain capacity. Data collected from flow monitors installed at the entrance or exit of the waterbody can be used to predict trends in the amount of runoff reaching and exiting the waterbody.

Flow monitoring methods available are:

- Control structure
- Acoustic Doppler measurement (side-looking or vertical)
- Time of travel ultrasonics
- Spot flow measurement using channel survey and handheld velocity measurements with a velocimeter
- The preferred and recommended location of monitoring stations could be:

Flow monitoring sites of individual waterbody: These would help to determine the flow rates into the waterbody. As such, the location of these sites would be best near to (but not next to, so as not to be influenced hydraulically) the inlet.

Flow monitoring sites on drains: These would ideally be located in a free flowing stretch of a drain that is clean, straight, with no bends, blockages, constrictions or changes in shape within 100m.. This would determine the true rainfall-runoff relationship for similar catchments.

Flow monitoring sites at Used Water Treatment Plant (UWTP): This approach is used if the waterbody is downstream of UWTP and receives treated effluent from the plant. This would help to warn site operators of potential floods and mitigate flood risk through bypassing the waterbody.

Flow measurement and corresponding frequency as presented in **Table 3** below, is recommended to be included as part of waterbody monitoring plan:

Table 3: Flow monitoring sampling

Data	Frequency	Methods of communication
Flow	• High data resolution: hourly • Moderate data resolution: twice daily. Facility should be available to measure hourly flow in case of rainfall event.	• Automatic-digital, data stored on site for manual collection; and • Automatic digital, data transmitted by phone network to offsite database. • Manual reading

Water quality: Water quality monitoring is critical to assess the efficacy and proper functioning of any waterbody rejuvenation plan. Apart from understanding the pollution from the watershed, water quality monitoring helps determine the level of treatment achieved at each level of depth of the waterbody (in cases where natural treatment systems, such as floating wetland, are installed in the waterbody). The below **Table 4** presents sample type and sampling locations for assessment of water quality in the waterbody.

Table 4: Sample type and sampling locations for water quality assessment in a waterbody

Sample type	Sampling point	Relevance
Lake water	Shallow zone	Representative of quality of water in the waterbody
	Deeper zone	
Lake sediment	Sediment surface	Representative of state of eutrophication of the waterbody and its overall health.
Inlet water	At inlet	Representative of quality of water entering the waterbody.
Outlet water	Outlet	Representative of quality of water, particularly demonstrating the efficacy of any deployed natural treatment system.

The recommended frequency of sampling for all sample types is at the minimum bi-monthly. The quality parameters recommended for water and sediment quality assessment are provided in **Appendix A – recommended quality parameters.**

3.5 Stakeholder engagement

The success of any waterbody rejuvenation intervention is dependent on cooperation among all stakeholders, many of whom are likely to have different objectives for management of the waterbody. It is therefore imperative that key stakeholders are engaged early to identify their respective drivers. To determine appropriate engagement strategies, it is critical that all stakeholders are classified. Classification can be undertaken using several characteristics, including ownership, geographical proximity, influence, and the potential to contribute financially to the project. Moreover, waterbody rejuvenation interventions should be considered through a gender equality, disability, and social inclusion (GEDSI) lens. This is particularly key during stakeholder engagement. As noted in the AMRUT 2.0 operational guidelines, while formulating all projects, it "should be ensured that households of informal settlements and low-income groups are duly considered".

The stakeholders can be grouped into two categories:

- Primary Stakeholders – who have a direct interest or influence on the waterbody management; these include:
  - municipal organisations, land/building development authorities, regional development authorities, water board/utility, water resources conservation/management authorities, pollution control boards, central and state governments, general public and communities including women or women's groups dependent on the waterbody for their water needs or those living in close proximity
- Secondary Stakeholders – who are not responsible for specific activities that relate to waterbody management, but they do have an indirect interest in waterbody; these include:
  - state agriculture/horticulture/aquaculture/energy departments, research institutes, non-governmental organisations, suppliers and contractors,

3.5.1 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 waterbody rejuvenation plan, and of a given project, from planning, through design and implementation. At each of these stages, the extent to which a specific stakeholder should be engaged may change, as may their specific interests. All stakeholder 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.

Healthy debates and disagreements are essential to the working of a stakeholder group and should be viewed positively. The focus of a stakeholder engagement should be on finding solutions and that all stakeholders remain receptive to each other.

Potential formats for stakeholder engagement are provided below.

3.5.1.1 Water forums

Forums for selected attendees or open membership (public meetings) are effective for communicating information or educating about new concepts. The less structured format may however be less suited to collective planning of projects.

A diverse mix of forum attendees should be sought. Representatives across the Gender, Equality and Social Inclusion spectrum, such as local women groups or non-profit groups working with urban poor communities should be sought. Specific identification of how vulnerable groups can be engaged may be initiated in these forums and later carried through into focus groups.

Existing local research institutions and academia working in waterbody rejuvenation should be part of these forums.

Forums can be organised as physical meetings or virtual platforms to increase outreach, however, such events require careful management to ensure attendees remain engaged throughout.

The Delhi Water Forum was launched in January 2023 under the AIWASI Community Demonstration Project, and this can be leveraged further for waterbody rejuvenation in the National Capital Territory of Delhi. Similarly, existing forums on water can be used to open discussion on waterbody rejuvenation in other states.

3.5.1.2 Waterbody focus groups

The forums organised at a city level can help set up focus groups on waterbodies. Focus groups require a clear agenda, attendance list and expected outcomes. They can be very effective in brainstorming ideas for specific groups and needs.

Focus groups can focus on different geographies within a state/city and different social groups especially women and children. For example, seeking engagement of specific groups such as the federation of self-help groups to understand the needs of women, especially those dependent on waterbodies for their water needs, can help design and manage waterbodies and their rejuvenation more effectively.

These groups can also become neighbourhood watch groups that can help build awareness on sustenance and maintenance of waterbodies. In addition, they can also be involved in water testing.

These opportunities have also been clearly stated in the AMRUT 2.0 guidelines and the GESI (Gender Equality and Social Inclusion) guidelines for AMRUT 2.0. Focus groups can help explore possible collaborations with citizens' groups and build awareness on the issue.

3.5.1.3 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.

3.5.1.4 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. Other qualitative methods using both online and offline methods of engagement for greater outreach can help strengthen the data base especially regarding vulnerable and underserved areas of the city/state.

These groups should be anchored by the municipal authorities in the city as they are able to bring together multiple stakeholders including community/political and women representatives. Based on the above format, a city-level stakeholder engagement of waterbody rejuvenation strategy may include:

Water forums	
City- and state-level forums using online and offline platforms to initiate discussion on waterbody rejuvenation involving individuals and organisations, industries working in the water sector and active in the state/city, and the public sector. Examples may include municipal and development authorities, mayors/councillors, water departments, district/zonal offices, premier engineering colleges with research on water, water research organisations, water companies, nonprofits, community-based organisations and federations.	
Focus groups on water body rejuvenation covering different geographies and social groups	
Resident welfare associations of planned areas with waterbodies that are mostly used for recreational purposes.	Federations and nonprofits working with communities living in vulnerable parts, disaster prone areas and communities using waterbodies for water needs
Water departments and state and city authorities managing waterbodies, flood control and irrigation departments, municipal authorities responsible for operation and maintenance of waterbodies	Academia, technology leaders and industrial partners, contractors working on nature-based as well as mechanised solutions for waterbody rejuvenation and management.
Waterbody working groups	
Area-based working groups on geographical and topographical challenges. Social groups and vulnerable groups based working groups based on challenges of population densities, vulnerable communities, uses of waterbodies, etc.	

3.6 Development of institutional framework

The objective of institutional frameworks is to create an effective ecosystem that supports sustainable management of waterbodies. The National Plan for Conservation of Aquatic System[2] (MoEF CC, April 2019) underscores the importance of institutional frameworks by stating that "effective institutional structures need to be created within the States and UTs to ensure cross sectoral decision making for wetlands". Therefore, there is a requirement to establish effective institutional arrangements for implementation of sustainable waterbody rejuvenation programs.Such a framework is required to ensure smooth implementation of the project, and O&M of assets that will be created under the project.

The institutional framework may include setting out the formation of a committee, which would be responsible for project monitoring, review of progress and monitoring the quality of work and schedule of project implementation, and subsequently management of waterbody post-execution of the rejuvenation plan. Guidance and suggestions of the committee on technical and management related issues of the project shall be helpful in resolving the intra- and inter-departmental issues and challenges. Resolution of any public grievances and hindrances may also be facilitated with the help of the committee.

In some instances, a government organisation may be responsible for managing multiple services, however, the below list provides departments that may typically be considered for selection of members of the committee, depending upon the services these departments provide within the relevant local context. The structure of the committee can be decided based on the key stakeholder departments that have a bearing on the functioning and management of the waterbody. These departments may include:

- Municipal corporation/irrigation and flood control department/public works department – drainage infrastructure
- Lake development authority (where these exist) – lake management
- Regional development authority/city planning authority – land use, land cover
- Water board/utility – water and used water services
- Forest department – plantation of flora species
- Fisheries department – management of fishes in the waterbody
- Department of industries – Industrial effluent management
- Public representation – Lake focus groups, non-government organisations, public representative, research institutions

As noted in the previous section, it is critical to use a GEDSI lens in waterbody rejuvenation interventions. In this regard, existing government outreach programs in health and education can be leveraged for GEDSI-specific inputs. For example, in every city most of the slums/urban villages or unplanned areas has a network of ANMs (Auxiliary nurses and midwives) now

[2] http://moef.gov.in/wp-content/uploads/2019/09/NPCA-MOEFCC-guidelines-April-2019-Low-resolution.pdf

known as ASHA workers who can provide key insights on challenges faced by women in vulnerable areas. Similarly, schoolteachers and principals of government schools can help highlight issues of underserved areas. Federated self-help groups or representatives under NULM can also be part of a formal mechanism of seeking GEDSI inputs.

3.7 Framework for preparation of Waterbody Rejuvenation Detailed Project Report (DPR)

The aim of the framework presented below is to identify and present important tasks and activities that should be considered while developing a comprehensive waterbody rejuvenation DPR. This framework may be adapted to cover a cluster of waterbodies that fall within the same catchment, have similar characteristics, and have similar pressures and problems.

3.7.1 Stage 1 –Situation Assessment

Situation Assessment is the key step towards developing a comprehensive Waterbody Rejuvenation DPR. It includes:

- Assessment of key features of the waterbody that influences its physical form, such as location, water spread area, water carrying capacity, flow control infrastructure, etc.
- Physicochemical analyses of stored water and sediment within the waterbody to assess the degree of eutrophication,
- Meteorological assessment for understanding the variation in rainfall patterns, and occurrence of extreme flood or drought events,
- Assessment of peripheral and catchment level features such as stormwater drainage infrastructure, expanse of water and used water infrastructure, land use and land cover, etc., that have a bearing on the quality and quantity of runoff generated,
- Understanding waterbody's social, environmental, and economic impact on the community it serves, as well as the key stakeholders who influence waterbody management.

Waterbodies serves multiple purposes, and therefore while developing the Waterbody Rejuvenation Detailed Project Report (DPR), it is critical that a comprehensive waterbody situation assessment is undertaken. It will help the planning/implementing agency to develop a contextual and implementable plan which aligns with the rejuvenation needs of waterbody, as well as the needs of the community that the waterbody serves.

The following section presents step wise description of tasks to be undertaken as part of Situation Assessment

3.7.1.1 Compilation of key waterbody details

Objective of this task is to collect key details pertaining to distinctive physical, environmental, and operational features of the waterbody. Some of the major activities undertaken in this task includes assessment of:

- Physical characteristics such as water spread area, recorded water storage volume,
- Flow control measures,
- Distinctive environmental features
- Ownership and jurisdiction details, including major stakeholders who have a bearing on the waterbody

The following **Table 5** presents the description, objective, and source of data required for compiling comprehensive details of the waterbody.

Table 5: Compilation of key waterbody details

Description	**Objective**	**Source**
Key waterbody details		
Location	• Waterbody's physical features • Relative location and connectivity in catchment	• Municipal corporation, lake development authority • Secondary reports • Primary survey – drainage, waterbody bathymetry
Area (ha)		
Average depth (m)		
Volume (m^3)		
Number of inlets and outlets		
Environmental features	Visible features indicating the current environmental condition of waterbody, such as presence of algal blooms, any overgrowth of aquatic and terrestrial plants, local avifauna, any evidence of used water inputs	• Secondary reports • Reconnaissance survey
Jurisdiction	Towards development of waterbody rejuvenation implementation, O&M Plan	• Municipal corporation, lake development authority, revenue department
Ownership		
Stakeholders	Major stakeholders, including public representative groups, NGOs, that have a direct or indirect bearing on the waterbody management	Non-government organisations, research institute, community groups engaged in management of the waterbody

This information feeds into subsequent task, collation of meteorology and watershed features that is required to undertake qualitative and quantitative analyses of runoff entering the waterbody.

3.7.1.2 Collation of meteorology and watershed features

A waterbody can typically receive water from multiple water sources including dry weather flow, wet weather flow, groundwater infiltration, direct rainfall, overflows from the upstream etc. The outflows from the waterbody can be in the form of extraction for different uses, seepage, downstream discharges, and evaporation. The wet weather flow contributed through surface runoff during a rainfall event, and water loss due to evaporation, are primarily driven by the meteorology.

The objective of this task is to undertake a comprehensive collection of meteorological data, as well as watershed features that have an impact on overall water balance of the waterbody. This task entails following key activities:

- Marking the primary catchment area contributing surface flow to the waterbody,
- Understanding the stormwater drainage infrastructure that carries the surface runoff to the waterbody,
- Land use and land cover within the catchment area of waterbody; the land use type and the land cover will have an impact on the quality and quantity of generated runoff,
- Hydrogeology around the waterbody to establish the waterbody and groundwater interaction,

The following **Table 9** presents the description, objective, and source of data required for collating the meteorological and watershed features.

Table 6: Collation of meteorology and watershed features

Description	**Objective**	**Source**
Meteorology and watershed features		
Catchment area (sq.km)	• Flow contributing area	• Municipal corporation, lake development authority • Soil & Land Use Survey of India • DEM analysis (refer to **Appendix C Data sources**)
Drainage information	• Contributing drainage infrastructure (incoming, outgoing, peripheral, diversion)	• Municipal corporation, lake development authority • Secondary reports • Primary survey – drainage

Description	Objective	Source
Land uses and cover	• Runoff generation	Refer to **Appendix C Data sources**
Hydrogeology	• Waterbody and groundwater interaction, infiltration • Development of catchment scale measures to enhance absorption of runoff in groundwater (such as bio swales, infiltration basin)	
Other sources contributing to the waterbody	• Flow from upstream used water treatment plants, untreated used water discharged in the drains leading to the waterbody • Development of waterbody's water balance	Refer to data availability listed in **Appendix C Data sources**
Meteorology – rainfall and evaporation	• Rainfall in the catchment area to calculate runoff • Establish rainfall trend over years, extreme flood and drought events • Evaporation data to assess the evaporation losses	

The outputs from this task will feed in to subsequent task, establishing waterbody characteristics to understand the health of waterbody.

3.7.1.3 Establishing waterbody characteristics

Establishing waterbody characteristics entail understanding the features and processes that have an impact on quality, as well as quantity of water stored within a waterbody. It includes assessment of

- Quality of water and sediment in the waterbody,
- Flora and fauna in the vicinity of waterbody,
- Current users and uses of that are directly or indirectly dependent on the waterbody,

- The kind of external pressures, emanating from changes in the land use and land cover, change in hydrologic characteristic in the catchment impacting the surface runoff, pollution due to point and nonpoint sources,
- Waterbody's water balance to capture the inflows (from the catchment, infiltration), outflows (downstream discharges, groundwater losses, any other consumptive uses), and the minimum environmental volume requirement for the water body,
- Physical form of waterbody that includes lakebed profile, water carrying capacity, lake boundary, etc.,

The following **Table 7** presents the description, objective, and source of data required for establishing the waterbody characteristics.

Table 7: Establishing waterbody characteristics

Description	Objective	Source
Waterbody characteristics		
Water and sediment quality Flora and fauna	• Assessment of waterbody health • Quality of water entering and exiting the waterbody • Quality of sediment	• Refer to **Appendix A – Recommended quality parameters** • Secondary reports from forest department/environment department/municipal organisation/lake development authority regarding flora and fauna • Primary survey for flora and fauna assessment
Values and uses	To identify the current services that waterbody provides. It may include: • Water supply, groundwater recharge, flood protection, livelihood, recreation, culture, tourism, ecological values (birds, fish, vegetation), religious values.	• Municipal corporation, lake development authority • Reconnaissance survey • Secondary reports and literature • Primary survey – drainage

Description	Objective	Source
Existing pressures on waterbody	To identify natural factors and human activities affecting the health of the waterbody. These include: • Catchment disturbances – changes in land use, land cover impacting quality and/or quality of runoff • Hydrologic disturbances – changes in drainage infrastructure leading to capacity or connectivity constraints • Point or non-point sources of pollution – discharge of treated used water, untreated used water discharges from areas not connected with network, illegal dumping of waste in the waterbody's peripheral areas – leading to eutrophication and reduction in water carrying capacity • Impact of climate change – frequent flooding or drought instances	Refer to the following: For assessment of land use and land cover changes refer to • **Appendix C Data sources** For drainage infrastructure • Municipal corporation, lake development authority • Primary survey for drainage Pollution entering waterbody and groundwater • Lake water and sediment quality (**Appendix A.1 – Water and sediment quality** testing of waterbody) • Groundwater quality (**Appendix – A.2 – Groundwater quality**) Reconnaissance survey, primary survey for drainage Impact of climate change: • Long-term trend analyses of rainfall, flood and drought events
Existing water balance of waterbody.	To assess the waterbody's water balance – the amount of water entering the waterbody and deducting the minimum environmental storage of waterbody (to sustain local flora and fauna) and any downstream discharge. • **Inflow** to the waterbody includes – runoff from the	Refer to data availability listed in **Appendix C – Data sources**

Description	Objective	Source
	catchment, direct rainfall, flow contributed through treated used water from upstream, untreated used water (if any) coming from settlements that are not connected with waterbody and discharging in drains leading to waterbody • **Waterbody's environmental storage and outflows** from the waterbody includes – evaporation loss, minimum environmental waterbody water storage, and any downstream discharge,	
Description of waterbody physical form	To assess the physical form of the waterbody, potential quality of silt deposition, amount of desilting required for storage capacity enhancement. Waterbody physical form representation is done using bathymetry data and plotting it to generate the lake-bed profile, and calculating the waterbody storage capacity at the outlet level.	Bathymetry data – presented in form of X, Y and Z coordinates, where X and Y presents the lateral position of the given point relative to survey start point, and Z represents the sediment depth and water depth at the same point.
Description of waterbody flora and fauna condition (including in buffer zone) based on	To assess the current flora and fauna that the waterbody is supporting. When studied in conjunction with the water and sediment quality outputs, it also informs presence of intrusive	• Secondary reports from forest department/environment department/municipal organisation/lake development authority regarding flora and fauna • Primary survey for flora and fauna assessment

Description	Objective	Source
primary or secondary data	vegetation species that causes infestation of weeds.	

The output from this and earlier tasks forms the basis for development of Stage 2 – Development of Waterbody Rejuvenation Plan.

3.7.2 Stage 2 – Development of Waterbody Rejuvenation Plan

Development of Waterbody Rejuvenation Plan requires a holistic assessment of waterbody as well as the factors that impact its functioning. It is important to note that the output from Stage 1 forms the basis for developing a comprehensive and holistic Waterbody Rejuvenation Plan.

The key tasks to be undertaken as part of Waterbody Rejuvenation Plan includes:

- Creating a vision for the Waterbody Rejuvenation with identification of specific and measurable outcomes to achieve it,
- Development of contextual and waterbody specific measures to manage the pressures on waterbody, while enhancing its social, environmental, and ecological value,
- Development of design for engineering infrastructure along with costs,
- Identification of Operation and Maintenance activities required as part of Waterbody Rejuvenation,
- Development of project implementation plan, and
- Development of stakeholder engagement and public education & outreach plan.

The following **Table 8** presents the description and interventions required as part of development of Waterbody Rejuvenation Plan.

Table 8: Development of waterbody rejuvenation plan

S. No.	Description	Interventions
	Description of vision for the waterbody	The vision for the waterbody rejuvenation, and finalisation of the measurable outcomes that are aligned with the vision, should be developed in consultation with the key stakeholders of the waterbody. The vision should align with identification of key values and uses that waterbody intends to serve. The specific and measurable outcomes may include: • Water quality targets to be maintained at inlet and outlet • Finalising the uses and users that the waterbody will serve
	Identification of specific and measurable outcomes to achieve the vision	

S. No.	Description	Interventions
		• Water carrying capacity of waterbody, and level of flood protection • Revenue targets, if any, through specific activities such as fishing, access to water base activities such as boating, leasing for community functions
	Selected intervention measures to help manage pressures on the waterbody, reduce impacts on the waterbody, and improves its overall health	The interventions identified within waterbody, fringe area, and at the catchment level should improve the overall ecological and environmental health of the waterbody and promote strong social value for the communities dependent on it. • Desilting and de-weeding plan – based on deepening and/or desilting requirement development of waterbody zonation plan, proposed desilting process, de-silting quantity, and disposal plan (refer to **Appendix B1 – Bathymetry and Bank Reshaping** and **Appendix B2 – Desilting, Appendix C3 – Aquatic weed management and removal),** • Constructed wetland, floating wetlands (refer to **Appendix D 2.1 – Constructed wetland** and **D 2.2 – Floating wetland**) • Waterbody inlet, outlet and periphery management – rehabilitation/construction requirement of flow control structures, silt and pollutant traps, dry weather flow diversion drains, incoming and outgoing drain desilting and structural repair requirements, lake bank erosion control measures, security fencing to prevent waste dumping, placement of waste bins along the periphery, security guard room, lighting requirement, community toilets (for flow management in catchment and within waterbody, refer to **Section A of Appendix B – Potential measures for waterbody rejuvenation**) • Aquatic and riparian vegetation management (refer to **Appendix C1 – Establishing watershed characteristics** and **C2 – Establishing waterbody and meteorological characteristics**) • Fish population – introduction of locally suitable fish species for the waterbody based on experimental phase plan (for one year) and stocking plan (for three years)

S. No.	Description	Interventions
	Design of engineering infrastructure interventions required as part of waterbody rejuvenation **Development of Bill of Quantities for capital works and O&M activities** **Preparation of project implementation plan, waterbody monitoring plan, and stakeholder engagement plan**	The design of engineering infrastructure should be done in conformance with applicable local codes, guidelines, and water quality standards, supported by necessary drawings, calculations, maps, hydrologic and hydraulic modelling outputs (if any), etc. All engineering drawings should be prepared in CAD format. Spatial analyses should be done preferentially in ArcGIS format. The implementation plan should identify the key activities along with their implementation timelines with necessary float as required. The design, calculation, spatial distribution maps, O&M regime etc., should include the following: • Calculation of runoff volume • Design of drainage improvement works, catchment improvement works • Design of waterbody inlet and outlet • Wetland design • Any primary and secondary treatment system design • Lake-bed profile, and desilting & de-weeding quantities along with disposal plan • Capital cost of identified interventions • Operation and maintenance regime and associated cost • Flow and water quality monitoring plan • Project implementation plan • Stakeholder engagement plan to facilitate implementation, monitoring and evaluation

3.7.3 Description of interventions

As described under Interventions in **Table 8**, the waterbody rejuvenation include development of

- **Flow management measures** which include interception and diversion of dry weather flow, flow redirection, redistribution, diversion in to the waterbody,
- **Physical form measures** which include bank reshaping and desilting,

- **Aquatic & riparian vegetation management** which include identification of plant species suitable for aquatic and riparian planting, as well as removal of aquatic weed,
- **Water quality management plan** which includes identification of parameters and sample collection frequency to monitor the health of waterbody.

These interventions are presented under **Part C –Interventions for waterbody rejuvenation**, which comprehensively covers and presents the aspects listed above.

THIS PAGE IS INTENTIONALLY BLANK

Part C –Interventions for waterbody rejuvenation

Appendix A – Recommended quality parameters

A.1 – Water and sediment quality testing of waterbody

Table 9: Sampling points for water quality monitoring

Type of sample	Sampling Points	Sample collection zone	Significance
Lake water	Shallow zone	Epilimnion[3]	Water quality at these locations will represent water quality variation between shallow and deeper zones.
	Deeper zone	Hypolimnion[4]	
Lake sediment	Shallow zone	Sediment Surface	Sediment quality at these locations provide indication of health of the waterbody.
	Deeper zone		
Inlet water	Inlet to the lake	Inlet	Water quality at this location will represent quality of water entering the waterbody.
	Inlet to floating wetland (if proposed)		Water quality at this location will represent quality of water entering the floating wetland (if proposed).
	Inlet to marshy wetland (if proposed)		Water quality at this location will represent quality of water after floating wetland. This data will help assess the floating wetland treatment efficiency.
Outlet water	Outlet of the lake.	Outlet	Quality of water exiting the waterbody.
Outlet water	Outlet of marshy wetland (if proposed)	Surface	Water quality at this location will represent quality of water after natural treatment. This data will help assess the treatment efficiency of floating, marsh wetlands and natural treatment as a unit.

[3] The uppermost layer is called the epilimnion and is characterized by relatively warm water where most photosynthesis occurs.

[4] The hypolimnion or under lake is the dense, bottom layer of water in a thermally-stratified lake.

Table 10: Recommended list of parameters and sampling frequency for water quality monitoring

S. No	Parameters	Frequency of sampling		
		Pre-project	**During project implementation**	**Post-project**
A – Physico-chemical parameters				
1	Ambient temperature (ºC)	Once	Bi-Monthly	Quarterly
2	Water temperature (ºC)	Once	Bi-Monthly	Quarterly
3	pH	Once	Bi-Monthly	Quarterly
4	Conductivity, µmho/cm	Once	Bi-Monthly	Quarterly
5	Transparency (m)	Once	Bi-Monthly	Quarterly
6	Total hardness as $CaCO_3$ (mg/l)	Once	Bi-Monthly	Quarterly
7	Total dissolve solids (mg/l)	Once	Bi-Monthly	Quarterly
8	Total suspended solids (mg/l)	Once	Bi-Monthly	Quarterly
9	Total alkalinity as $CaCO_3$ (mg/l)	Once	Bi-Monthly	Quarterly
10	Dissolved oxygen (DO) (mg/l)	Once	Bi-Monthly	Quarterly
11	Total organic carbon (mg/l)	Once	Bi-Monthly	Quarterly
12	Biochemical Oxygen Demand (BOD^5) (mg/l)	Once	Bi-Monthly	Quarterly
13	Chemical oxygen demand (COD) (mg/l)	Once	Bi-Monthly	Quarterly
14	Total Nitrogen (mg/l)	Once	Bi-Monthly	Quarterly
15	Ammonia (mg/l)	Once	Bi-Monthly	Quarterly
16	Total Kjeldahl Nitrogen (mg/l)	Once	Bi-Monthly	Quarterly
17	Nitrate (mg/l)	Once	Bi-Monthly	Quarterly
18	Total Phosphorous as P (mg/l)	Once	Bi-Monthly	Quarterly
B – Biological Parameter				
1	Total coliforms	Once	Bi-Monthly	Quarterly

S. No	Parameters	Frequency of sampling		
		Pre-project	**During project implementation**	**Post-project**
	organism (MPN/100 ml)			
2.	Faecal Coliforms (MPN/100 ml)	Once	Bi-Monthly	Quarterly
C – Heavy Metals				
1	Lead (Pb) (µg/l)	Once	Quarterly	Semi-annually
2	Nickel (Ni) (µg/l)	Once	Quarterly	Semi-annually
3	Cobalt (Co) (µg/l)	Once	Quarterly	Semi-annually
4	Zinc (Zn) (µg/l)	Once	Quarterly	Semi-annually
D – Pesticides				
1	Total BHC, (µg/l)	Once	Quarterly	Semi-annually
2	Total DDT, (µg/l)	Once	Quarterly	Semi-annually
E – Biodiversity Study				
1	Phytoplankton primary productivity (mg $C/m^3/d$) & Chlorophyll-a (µg/l)	Once	Quarterly	Semi-annually
2	Phytoplankton species richness & community abundance	Once	Quarterly	Semi-annually
3	Zooplankton species richness and community abundance	Once	Quarterly	Semi-annually
4	Macrophytes species	Once	Quarterly	Semi-annually
5	Species composition & population dynamics of fish based on survey of catch from fisherman	Once	Quarterly	Semi-annually

Table 11: Recommended list of parameters and sampling frequency for sediment quality monitoring

S. No	**Parameters**	**Frequency of Sampling**		
		Pre-project (once)	**During project implementation**	**Post-project (At least for 2 years)**
A – Physico-chemical parameters				
1	Total Nitrogen (mg/l)	Once	Quarterly	Half-yearly
2	Total Kjeldahl Nitrogen (mg/l)	Once	Quarterly	Half-yearly
3	Total Phosphorous (mg/kg)	Once	Quarterly	Half-yearly
4	Calcium (mg/kg)	Once	Quarterly	Half-yearly
5	Magnesium (mg/kg)	Once	Quarterly	Half-yearly
B – Heavy Metals				
1	Lead (Pb) (µg/kg)	Once	Quarterly	Half-yearly
2	Nickel (Ni) (µg/kg)	Once	Quarterly	Half-yearly
3	Cobalt (Co) (µg/kg)	Once	Quarterly	Half-yearly
4	Zinc (Zn) (µg/kg)	Once	Quarterly	Half-yearly
C –Pesticides				
1	Total BHC (µg/kg)	Once	Quarterly	Half-yearly
2	Total DDT (µg/kg)	Once	Quarterly	Half-yearly

A.2 – Groundwater quality

Typical comprehensive test for groundwater abstraction in an urban environment would comprise of the parameters provided below in the **Table 12** below. However, the number of parameters can be reduced, subject to the specific risks being considered for any given scheme, and the actual species detected in the initial rounds of monitoring:

Establish groundwater chemistry

Method: Samples of borehole water using purpose-built observation wells and at nearby third party abstractions

Frequency: Quarterly during operation.

Table 12: Establishment of groundwater chemistry

Basic parameters	Major ions	Hydrocarbons	Trace metals/metalloids	Microbiology	Pesticides (if potential contaminant sources in catchment)
• pH • Dissolved oxygen • Temperature • Conductivity • Redox potential • Odour/visual appearance • Odour	• Chloride • Fluoride • Iron (total and dissolved) • Manganese • Nitrate • Ammonium • Hardness as CaCO3	• Mineral oils screen • Total phenol • VOCs • SVOCs	• Arsenic • Aluminium (total and dissolved) • Boron • Cadmium • Chromium (total) • Chromium (hexavalent) • Copper (dissolved)	• Total coliforms • E. coli • Cryptosporidium – (filter sampled) • Giardia – (filter sampled)	• Suite as per National drinking water standards https://law.resource.org/pub/in/bis/S06/is.10500.2012.pdf

Basic parameters	Major ions	Hydrocarbons	Trace metals/metalloids	Microbiology	Pesticides (if potential contaminant sources in catchment)
• Colour • Suspended solids	• Alkalinity as HCO3 • pH • Sulphate • TDS		• Cyanide (total and free) • Lead • Manganese (total and dissolved) • Mercury • Molybdenum • Nickel • Selenium • Zinc		

Appendix B – Potential measures for waterbody rejuvenation

The following section of Appendix B presents interventions that are applicable to remediate problems typically identified while implementing a waterbody rejuvenation plan.

Section A. Flow management measures

A1 – Flow interception and diversion around waterbody

Application level		Beneficial effect on waterbody health	
Catchment	✓	Hydrology and hydraulics	✓
Incoming channel		Physical form	
Buffer zone	✓	Water quality	✓
Waterbody		Aquatic and riparian ecosystems	

Application

Interception and diversion of incoming flow is applied to improve the hydrology of a waterbody (e.g., if the waterbody receives excess water) and/or to improve water quality in the waterbody by diverting polluted water to a treatment asset. For instance, where dry weather flows are highly polluted from untreated wastewater, interception and diversion of dry weather flows around the waterbody to a treatment system may be required. This intervention generally requires hydraulic structures (e.g., weirs, gates, pits, pipes, bunds, open channels) to intercept and divert water around the waterbody.

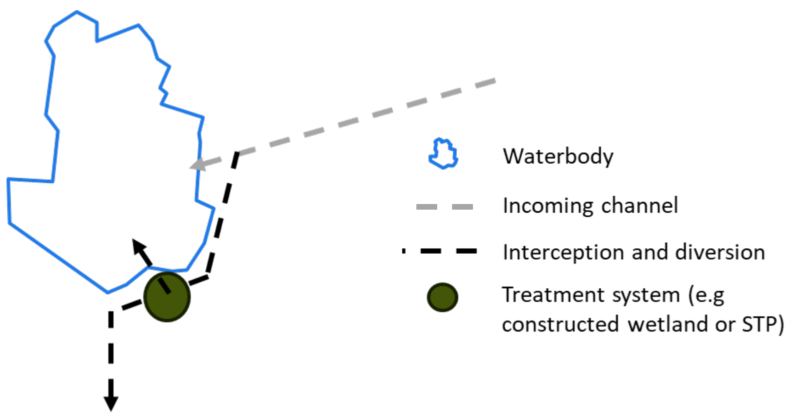

Figure 12. Interception and diversion schematic

Planning and design considerations

This intervention requires an understanding of the hydrologic and water quality problems and requirements of the waterbody. Consideration should be given on the impacts of the interception and diversion intervention on the hydrologic regime of the waterbody and the "values and uses" of the waterbody (for instance interception and diversion may reduce inflow during the dry season and affect amenity value of waterbody). The hydraulic design of the diversion structure must be carefully undertaken to enable diversion of "low flows" (e.g., polluted dry weather flows) but enable higher flows (e.g., stormwater runoff) to enter the waterbody (or another treatment system targeting stormwater pollutants). Furthermore, diversion of polluted water around the waterbody without treatment does not address pollution downstream of the waterbody and may in fact worsen water quality downstream.

Figure 13. Interception & Diversion structure at Mahadevapura Lake, Bangalore (Source: CDD India)

Operations and maintenance considerations

As such interventions are largely hydraulic structures, maintenance activities include clean-out of sediment and litter accumulated within the infrastructure, and to fix erosion issues of earthen bunds when they arise. Additionally, care must be taken to ensure all levers of hydraulic gates are functioning adequately, especially before monsoon, to ensure smooth operation.

A2 – Flow diversion into waterbody

Application level		Beneficial effect on waterbody health	
Catchment	✓	Hydrology and hydraulics	✓
Incoming channel		Physical form	
Buffer zone	✓	Water quality	✓
Waterbody		Aquatic and riparian ecosystems	

Application

Flow diversion into a waterbody may be required for several reasons including to top up the waterbody, or to improve water quality by improving flow circulation, turnover of water in the waterbody, or to lower pollutant concentration (dilution) in the waterbody. This intervention generally requires hydraulic structures (e.g., weirs, gates, pits, pipes, open channels) to divert water to the waterbody.

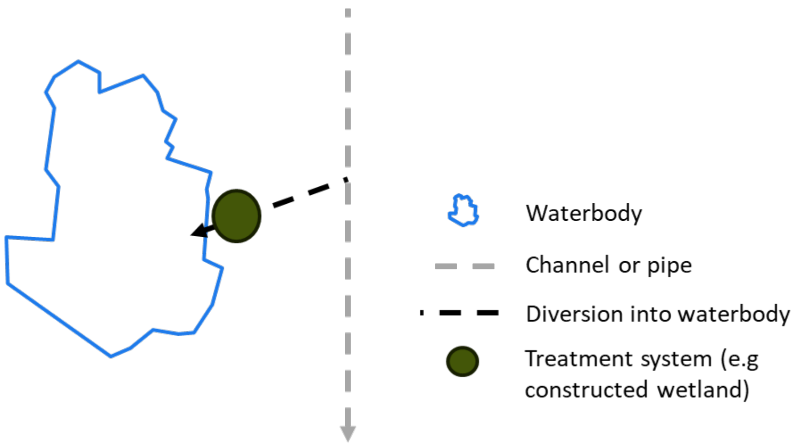

Figure 14. Schematic of flow diversion into waterbody

Planning and design considerations

This intervention requires an understanding of the hydrologic and water quality problems and requirements of the waterbody. A water balance analysis is required to be undertaken to understand the inflows and losses from the waterbody. The amount, quality, flow rate, position of the inlet and direction of the flow in the waterbody are fundamental elements to consider ensuring effectiveness of this technique. It generally requires introduction of large volumes of water into the waterbody. It can also be capital cost intensive because of the water diversion infrastructure. However, it can also be cost effective if there is a supply of good quality water and the costs of facilities and their maintenance for delivering water to waterbody are not high. This technique has been successfully used in small waterbodies.

The hydraulic design of the diversion structure must be carefully undertaken to enable diversion of the required volume and flow rate, and to allow diversion to be stopped if needed (e.g., using gates).

Operations and maintenance considerations

As such interventions are largely hydraulic structures, maintenance activities include clean-out of sediments and litter accumulated in the diversion infrastructure, and fixing erosion issues of earthen bunds when they arise. Additionally, care must be taken to ensure all levers of hydraulic gates are functioning adequately, especially before monsoon, to ensure smooth operation.

Where water is diverted from a nearby treatment plant, water quality monitoring must be undertaken to ensure that the quality of water entering the waterbody adheres to requirements that support its desired values and uses.

A3 – Flow mixing and aeration

Application level		Beneficial effect on waterbody health	
Catchment		Hydrology and hydraulics	✓
Incoming channel		Physical form	
Buffer zone		Water quality	✓
Waterbody	✓	Aquatic and riparian ecosystems	

Application

Mixing and aeration should aim to promote both convection (movement of water within the waterbody) and oxygenation of water. Effective mixing devices are typically one of two types:

- Floating or submersible pump systems which pumps and circulates water from poorly mixed areas (e.g., stagnant areas) to well-mixed areas (including from the base of the waterbody to the surface).
- Aerators – these systems release air bubbles at the base of the waterbody to promote both convection and oxygenation.

Mixing and aeration can also be used to disrupt layers of stratification that often occur in deep and still waterbodies. Stratification occurs when there is a significant difference in density where water layers at the bottom are heavier than the surface water which prevents the different layers from mixing. The lack of mixing between layers means that oxygen does not make it through to the bottom water layers which changes the way nutrients are processed in the waterbody sediments. As a result, nutrients are more readily released into the water column which can lead to algal blooms. By breaking down the stratification layer, oxygen makes it to the bottom layers creating conditions where nutrients can break down more naturally.

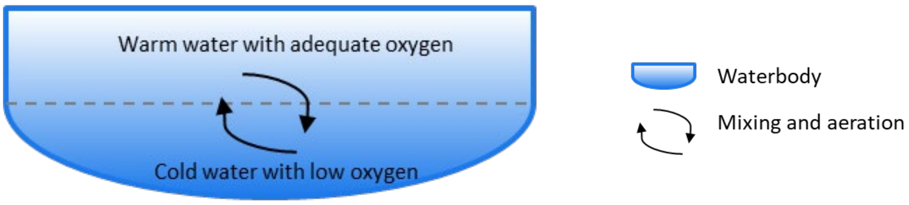

Figure 15. Mixing and aeration

Planning and design considerations

Mixing and aeration is a well-established technique but is generally feasible for application in small waterbodies. Capital and operational costs can become prohibitive when applied over a large waterbody or for waterbodies with extensive deep zones. Where low dissolved oxygen in a waterbody is a problem, this intervention alone may not address the problem –

measures to improve water quality entering the waterbody (see section D) may also be required.

Operations and maintenance considerations

Sub-surface pumps and aerators require maintenance to remove build-up of organic material, algae, sludge, and sediments collected on their motors and other mechanical parts. Without maintenance, the build-up will become thick over time and cause motors to strain, over-heat and perform less effectively.

A4 – Flow redirection

Application level		Beneficial effect on waterbody health	
Catchment		Hydrology and hydraulics	✓
Incoming channel		Physical form	
Buffer zone		Water quality	✓
Waterbody	✓	Aquatic and riparian ecosystems	

Application

This intervention is about improving flow distribution in the waterbody to reduce occurrence of short-circuits and stagnant zones in the waterbody. The shape of a waterbody and the locations of its inlets and outlets influence how water moves in the waterbody. For instance, waterbodies that have a low length to width ratio with a single inlet and outlet point can suffer from poor flow distribution resulting in short-circuits and stagnant zones. Short-circuit flow paths are typically narrower and deeper channels within the waterbody (often not visible) that carry a sizeable proportion of the flow compared to the rest of the waterbody. Short-circuits occur due to channelisation of the flow, which may be promoted by zones of sparse vegetation, erosion, or funnelling of flow between features (e.g., islands, accumulated sediment, and litter, etc).

Construction of flow bunds or baffles within the waterbody is a useful technique to promote flow distribution within the waterbody (and reduce channelisation) by directing water along a longer flow path. The use of flow bunds and baffles can also improve water quality by avoiding stagnant zones. Similarly, a flat bathymetry perpendicular to the flow path can ensure an even flow distribution across the flow width rather than channelisation along a deeper section (see also B1 – Bathymetry and bank reshaping).

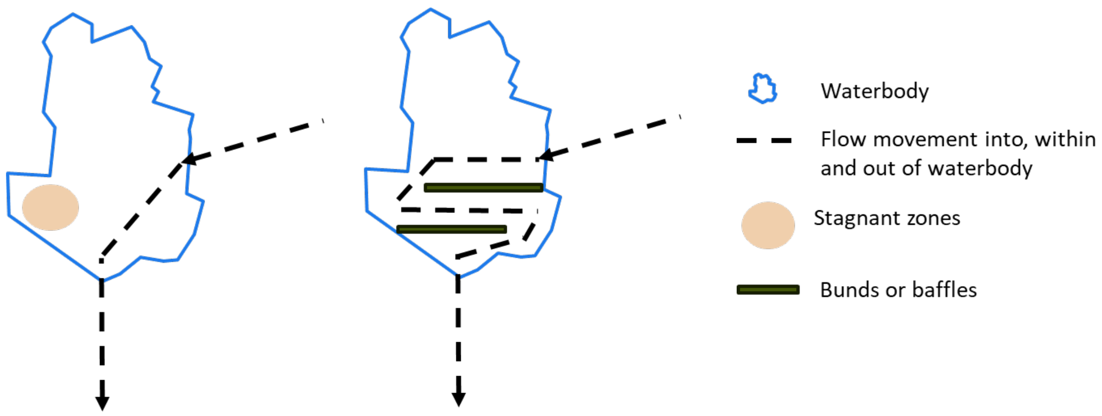

Figure 16. Schematic of flow redirection in a waterbody using flow bunds or bafflers

Planning and design considerations

This technique requires an understanding of hydraulic (water movement) problem within the waterbody. It requires the waterbody (or sections of the waterbody) to be dewatered so that the bunds can be constructed. This technique has been successfully applied in small- to medium-sized waterbodies where it is feasible and acceptable to drain the waterbody to facilitate construction of bunds.

Operations and maintenance considerations

As such interventions are largely earthen bunds, maintenance activities mostly relate to fixing erosion issues that arise with the earthen bunds.

A5 – Flow recirculation

Application level		Beneficial effect on waterbody health	
Catchment		Hydrology and hydraulics	✓
Incoming channel		Physical form	
Buffer zone		Water quality	✓
Waterbody	✓	Aquatic and riparian ecosystems	

Application

Another effective method to promote mixing of water in a waterbody is to install a recirculation system which pumps and circulates water from poorly mixed areas (e.g., stagnant areas) to well-mixed areas. There may be areas of the waterbody that are poorly flushed and do not receive flowing water. These are often isolated and deep areas of open water that become stagnant and are sometimes accompanied by odour or algal growth.

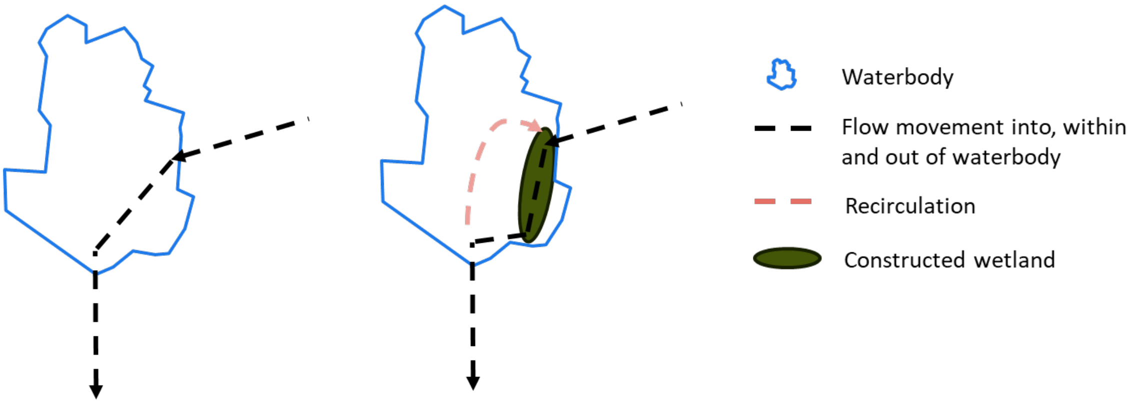

Figure 17. Schematic of flow recirculation in a waterbody

Planning and design considerations

This technique requires an understanding of where poorly flushed zones are in the waterbody and understanding the volume of water in these zones. The aim of recirculation is to move volume of water in the dead zones every 2-3 days. For example, a 2 m deep, 20 m^2 zone equates to a volume of 40,000 litres of water. For this water to be pumped out in 3 days (4320 mins), it would require a pumping rate of 10 L/min. Given the low flow rates, a solar powered recirculation system can often be used.

Recirculating water from the waterbody through a constructed treatment wetland can be used to improve water quality in the waterbody. This method is often used to manage algal bloom in a waterbody. Constant recirculation through the treatment wetland improves water quality in the long term and thereby reducing likelihood of algal bloom in the waterbody. Consideration must be given to the design of constructed treatment wetlands that receive both inflows and recirculated waterbody flows.

Operations and maintenance considerations

Sub-surface pumps require maintenance to remove build-up of organic material, algae, sludge, and sediments collected on their motors and other mechanical parts. Without maintenance, the build-up will become thick over time and cause motors to strain, over-heat and perform less effectively.

Useful resources

Water by Design (2013), Waterbody Management Guideline, Healthy Waterways Ltd, Brisbane, Australia (https://waterbydesign.com.au/)

A6 – Flow (stormwater) retention in the catchment

Application level		Beneficial effect on waterbody health	
Catchment	✓	Hydrology and hydraulics	✓
Incoming channel		Physical form	✓
Buffer zone		Water quality	✓
Waterbody		Aquatic and riparian ecosystems	✓

Application

The creation of impervious surfaces in a waterbody catchment significantly increases the volume and frequency of stormwater runoff entering the waterbody which can lead to erosion and scouring of banks and beds and change the hydrologic regime of the waterbody (and in turn impacting on aquatic ecosystems). Conventional approaches to stormwater management focus on drainage and flood protection and do not address the issue of diffuse pollution and hydrologic disturbances in waterbodies from stormwater runoff. The table below presents structural measures that can be applied to reduce the volume and frequency of stormwater runoff generated in the waterbody catchment. Such measures may be appropriate in urban greenfield or retrofit areas, on public and private lots, and/or within the waterbody buffer zone.

Planning and design considerations

Figure 18: Rainwater and stormwater harvesting

Rainwater and stormwater harvesting capture and store runoff from impervious surfaces for water supply. Additional benefits include regulating stormwater runoff volume and frequency (benefitting waterbodies) and reducing peak flows (for flood protection). As rainwater and stormwater contains pollutants, some of which are harmful to humans including pathogens and micropollutants, rainwater and stormwater harvesting schemes should be designed to safely collect, treat, and store water.

Figure 19: Porous pavement

Porous pavements are permeable surfaces that allow water to seep into the ground. Benefits include regulating stormwater runoff volume and frequency (benefitting waterbodies), reducing peak flows (for flood protection) and groundwater recharge. They often have an underlying storage reservoir filled with aggregate material that provides temporary storage prior to infiltration into the underlying soils. Porous pavements take on many forms – from permeable pavers to pebble material loosely bound together with resins that allow penetration of water. Porous pavements are not recommended in areas with high water table, and for soils that are saline, sodic and have high shrink/swell characteristics.

Figure 20: Infiltration system

An infiltration system (e.g., gravel trenches) collects stormwater runoff and allow it to slowly infiltrate into the surrounding soils. Benefits include regulating stormwater runoff volume and frequency (benefitting waterbodies), reducing peak flows (for flood protection) and groundwater recharge. Infiltration systems can include surface systems such as infiltration ponds and sub-surface systems such as gravel trenches. Minimum buffer distances are required to protect structural integrity of infrastructure such as buildings. Infiltration systems are not recommended on slopes > 5%, for areas with high water table, and for soils that are saline, sodic and have high shrink/swell characteristics.

Operations and maintenance considerations

A key maintenance activity for rainwater and stormwater harvesting systems is to remove accumulated litter, sediment and organic water in the storages, pipes entering and leaving the storages, and in any filter screens installed. Infiltration systems require removal accumulated litter, sediment (coarse and fine) and organic water that accumulate at the inlets or on the surface. Porous pavement may require vacuuming with a commercial cleaning unit (or a combination of low-pressure water and vacuuming) to remove fine sediments which can clog the infiltration layer overlying the storage.

Useful resources

CSIRO (2005), Water Sensitive Urban Design (WSUD) Engineering Procedures – Stormwater, CSIRO Publishing, Australia.

Section B. Physical form measures

B1 – Bathymetry and bank reshaping

Application level		Beneficial effect on waterbody health	
Catchment		Hydrology and hydraulics	✓
Incoming channel		Physical form	✓
Buffer zone		Water quality	✓
Waterbody	✓	Aquatic and riparian ecosystems	✓

Application

The shape of a waterbody including the profile of its base (bathymetry) influences flow movement in the waterbody amongst several other factors. Poor flow distribution and short-circuits can result in areas within the waterbody that are poorly flushed, becoming stagnant and isolated and sometimes accompanied by odour or algal growth.

The base and banks of a waterbody can be reshaped or reprofiled to 1) improve water movement in the waterbody (which in turn can improve water quality in the waterbody), 2) achieve the desired water depths to support aquatic and riparian vegetation and other "values and uses" (such as increased water storage to meet water supply requirements), and 3) improve safety at edges of waterbodies.

Planning and design considerations

The design of the bathymetry should aim to achieve suitable water depths to ensure establishment and long-term viability of emergent aquatic vegetation. The tolerance of aquatic vegetation to inundation depth varies significantly across species, and growth declines as water depths increases. For instance, many emergent species can be sensitive to water depths, with growth difficulties in permanent water depths greater than 0.3 m. The range in water depths and the inundation frequency and duration should be studied to inform suitable plant species in the waterbody (noting species native to the local region are recommended).

Waterbodies with depths > 3 m and steep edges are also vulnerable to stratification and weed infestation. Shallow systems tend to be more resilient and stable compared to deep systems. Shallow waterbodies (< 3 m) with gradually sloping edges provide ideal conditions for aquatic vegetation to grow, and also improve safety at edges of waterbodies.

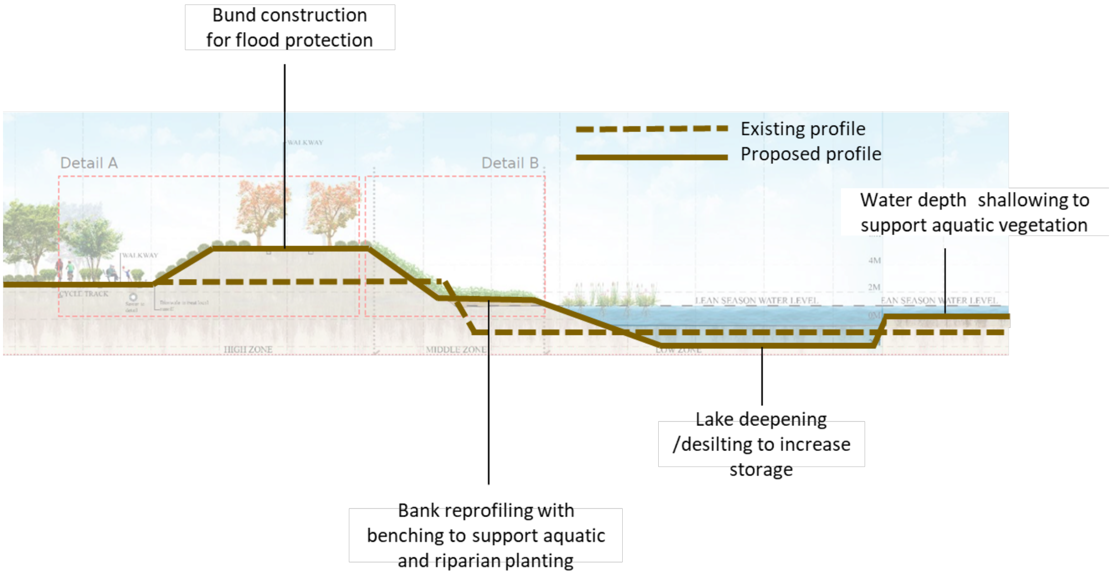

Figure 21. Example of bathymetry and bank reshaping

Compared to shallow zones, deep water provides inferior nutrient removal, with reduced nitrification and oxidation of organic matter by dissipating flow momentum and mixing. However, the low velocity in deep zones does assist with sediment removal and helps to break short circuits. Hence it is important for the bathymetric design to allow water to flow through a mix of shallow zones and deeper zones. As part of bathymetry reshaping, some zones can be "filled" to ensure shallower water depths for establishment of aquatic vegetation (**Figure 20**). Similarly, infilling of stagnant zones which are prone to poor water quality can also be considered. The slope of the waterbody "underwater banks" can also be modified with a gentler profile (instead of a steep profile) to promote establishment of aquatic vegetation on the banks. The banks can also be shaped to create submerged "benches" for aquatic planting.

Operations and maintenance considerations

Maintenance includes clean out of sediments, litter and organic material that accumulates at the base of the waterbody and along the banks. This is to ensure the desired profile of the waterbody base and banks is maintained (see B2 – Desilting).

B2 – Desilting

Application level		Beneficial effect on waterbody health	
Catchment		Hydrology and hydraulics	✓
Incoming channel		Physical form	✓
Buffer zone		Water quality	✓
Waterbody	✓	Aquatic and riparian ecosystems	

Application

Desilting is a maintenance activity to clean out sediments, litter and organic material that accumulates at the base of the waterbody and along the banks. Desilting ensures the desired profile of the waterbody base and banks is maintained, as well as its water holding capacity. Desilting can also play a role in improving water quality of the waterbody by removing material and pollutants that have accumulated at the base of the waterbody over time. Whist regular desilting is an important activity to undertake at the waterbody, measures should also be considered to manage pressures that cause the problem (e.g., unmanaged erosion in the catchment and sediment runoff from construction sites). These measures will reduce the frequency of desilting required in the waterbody.

Figure 22. Desilting of Sembakkam Lake, Chennai (Source: The Nature Conservancy)

Planning and design considerations

Understanding the depth of silt deposition is essential in planning any desilting activity. A bathymetry survey can provide insights on the level of silt accumulation by comparing the historic water depth and the existing water depth of the waterbody. It is often difficult to identify the historic depth of a waterbody but consultation with the local community can provide insights. Sediment samples at varying depths can also be collected and analysed for silt content. Generally, as sample depth increases, silt content in the samples reduces and the soil characteristics would start exhibiting that of the surrounding geology.

To undertake desilting, two broad approaches are followed:

- Wet Dredging: In this approach, the sediments are removed without dewatering the waterbody using dredgers installed over a floating platform/barge. This technique is commonly applied in large waterbodies where either diversion of incoming runoff or dewatering is not possible. One major challenge is the re-suspension sediments into the water column which can affect water quality.
- Dry Dredging: In this approach, the incoming water to the waterbody is diverted and the waterbody is dewatered to facilitate the removal of silt using mechanical excavators. Sometimes, temporary bunds are created within waterbody to allow for smooth desilting activity and movement of heavy machinery. Desilting is widely adopted in arid parts of India where urban and peri-urban waterbodies are usually dry before the monsoon. It is worth noting that use of heavy machinery can compact the bed of the waterbody and reduce infiltration/groundwater recharge.

Spot desilting can also be undertaken in priority areas of the waterbody such as inlet zones where sedimentation is highest, or areas where there is minimal disruption to livelihood activities (fishing/irrigation), or where there is ease of access, or areas where impacts on flora and fauna can be minimised or avoided.

Testing of sediment quality is recommended to inform disposal or reuse of the material. This is because contaminants from urban catchments which can accumulate in the waterbody bed sediments can be harmful to humans and to the environment if disposed or reused inappropriately.

Operations and maintenance considerations

Desilting is not a one-time activity and needs to be undertaken at regular intervals. If desilting has not been undertaken for a long time, desilting can form part of a broader activity to reshape the bathymetry and banks of the waterbody (see B1 - Bathymetry and bank reshaping).

Section C. Aquatic and riparian vegetation management

C1 – Aquatic planting

Application level		Beneficial effect on waterbody health	
Catchment		Hydrology and hydraulics	
Incoming channel	✓	Physical form	
Buffer zone		Water quality	✓
Waterbody	✓	Aquatic and riparian ecosystems	✓

Application

Aquatic planting can be applied within the waterbody or within the incoming channels, rivers or drains. Aquatic planting is applicable for all types and sizes of waterbodies, although wetlands can be expected to have large coverage of aquatic vegetation already. Existing aquatic vegetation of high value should be protected during waterbody rejuvenation works. Additional planting can be undertaken once earthworks are completed such as reprofiling of the waterbody bathymetry and banks.

Aquatic vegetation, especially emergent and submerged plants, within a waterbody plays an significant role in managing water quality in the waterbody (**Figure 22**). Planting permanent emergent vegetation around the perimeter of a waterbody intercepts pollutants in runoff from the land immediately surrounding the waterbody. It also provides several other services including habitat provision, bank stabilisation, and nutrient uptake. Similarly, submerged aquatic vegetation in waterbodies provide multiple services including habitat provision, sediment stabilisation (restraining resuspension of bottom sediments into water column), and nutrient uptake.

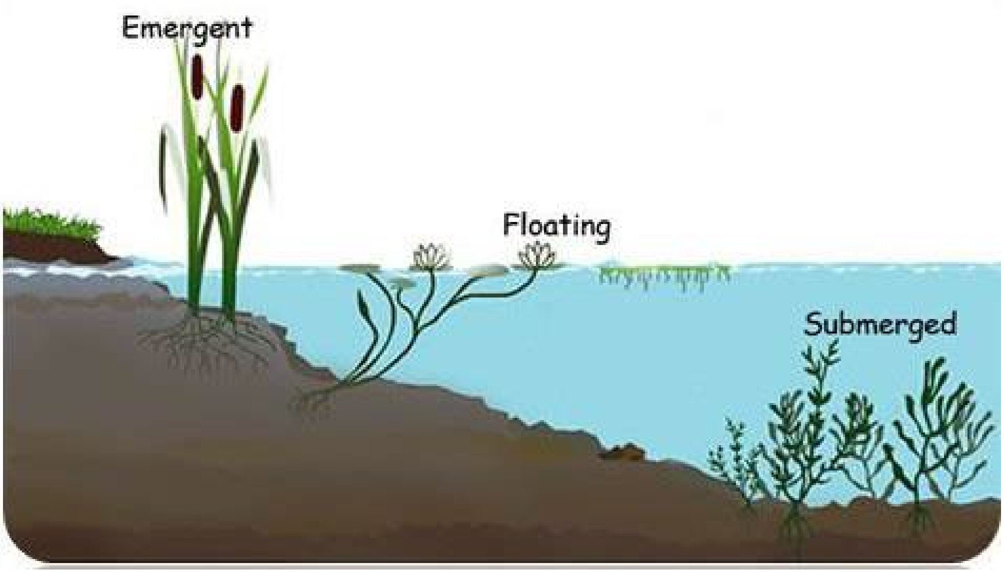

Figure 23. Different categories of aquatic planting (Source: ksuweb.kennesaw.edu/)

Planning and design considerations

Planting permanent emergent vegetation around the perimeter of a waterbody is relatively low cost and easy to implement. Planting of submerged vegetation can also be carried out in the shallow margins of open water zones with relative ease. Planting should take place during the dry season to ensure a high success rate of plant survival and establishment. The waterbody water level can also be lowered temporarily to facilitate planting.

The bathymetry of the waterbody may need to be modified to achieve suitable water depths to ensure establishment and long-term viability of emergent aquatic vegetation (see B1 – Bathymetry and bank reshaping). The tolerance of aquatic vegetation to inundation depth varies significantly across species, and growth declines as water depths increases. For instance, many emergent species can be sensitive to water depths with growth difficulties for permanent water depths greater than 0.3 m.

Aquatic vegetation may require netting during the plant establishment phase to reduce grazing from birds.

Figure 24. Establishment of aquatic emergent vegetation around the perimeter of waterbody (Source: Coimbatore Lake restoration)

Whist aquatic vegetation generally has a beneficial effect on values and uses such as water supply, recreation, amenity, and ecological values, it can also have a negative effect on recreational values by impacting access to the waterbody for instance. This impact can be minimized by managing aquatic vegetation close to the banks where access to water is desired or by avoiding emergent vegetation where water-based recreation is desired. Aquatic vegetation can also worsen flooding by reducing flood storage within the waterbody. This impact can be avoided by offsetting the loss of storage from aquatic planting with additional air space for flood detention within the waterbody (e.g., by raising the flood bunds).

Operation and maintenance considerations

Low-skilled personnel can perform routine maintenance activities such as removal of weeds, clean out sediment and rubbish, and replacement of plants as necessary. Another consideration is to draw down the water level to enable drying out of aquatic vegetation for a short period of time, as this can assist with plant regeneration and growth as well as access to shallow zones for maintenance.

Useful resources

Water by Design (2013), Waterbody Management Guideline, Healthy Waterways Ltd, Brisbane, Australia (https://waterbydesign.com.au/)

C2 – Riparian planting

Application level		Beneficial effect on waterbody health	
Catchment		Hydrology and hydraulics	
Incoming channel	✓	Physical form	
Buffer zone	✓	Water quality	✓
Waterbody		Aquatic and riparian ecosystems	✓

Application

The riparian or buffer zone of the waterbody is the land that adjoins the waterbody and directly influences or is influenced by the body of water. In this document, the riparian zone is defined as the area between the water edge and the surrounding built environment (houses, buildings, roads, etc.).

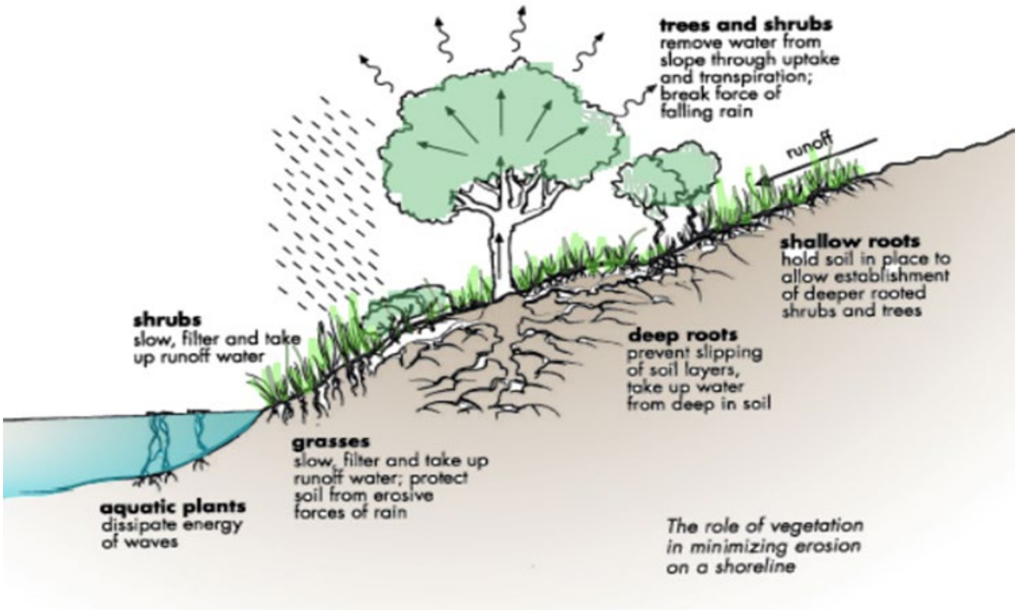

Figure 25: Role of riparian vegetation (Source: Adapted by Jean Miller, DNR)

Riparian planting can be applied within the waterbody buffer zone or along the buffer zones of incoming channels, rivers, or drains. Riparian planting is applicable for all types and sizes of waterbodies. Existing riparian planting should be protected during waterbody rejuvenation earthworks. Additional planting with the buffer zone can be undertaken as soon as earthworks or any planned disturbances within that zone are completed.

Planting a healthy riparian zone benefits the health of a waterbody by protecting its water quality and supporting the aquatic ecosystem. It protects water quality by regulating nutrient and sediment inputs from the adjacent land into the waterbody. It supports the aquatic ecosystem by providing habitat such as overhanging branches, leaves, branches, and logs.

Riparian zones often provide a dense and diverse vegetation community in comparison with other landscapes and support a much higher number and density of terrestrial animals compared to surrounding landscapes. This is largely because the zone provides a water supply in addition to food sources associated with water such as semi-aquatic insects. Riparian zones also provide a corridor that allow animals to move through the landscape to disperse and to access resources. In urban environments, where habitat is fragmented, the role of riparian zones in providing connectivity both along the riparian corridor and to core habitat patches outside the riparian corridor is critical.

Riparian zone also provides a range of other services such as supporting amenity and aesthetics, and stabilising waterbody banks by preventing erosion which can cause sedimentation, reduce habitat availability, impact water quality, and slow the flow of water. Riparian corridors can also improve well-being by providing pathways for active travel, active recreation facilities such as playgrounds, cultural and social facilities, and passive opportunities to recreate and connect with nature.

Planning and design considerations

Planting riparian vegetation is relatively low cost and easy to implement. It is critical that suitable species are planted in correct zones so that the plants are subject to conditions which are suitable to their requirements. Soil moisture availability and inundation pattern (frequency and duration) are particularly important with species selection transitioning from aquatic/semi-aquatic species closer to the water's edge where the soil is moist and inundation is seasonal and can last for a long duration, to dry tolerant species where the soil is well-drained, and inundation is infrequent and last for a short duration (**Figure 25**). The slope of the waterbody banks can be modified where possible with a gentler profile (instead of a steep profile) to promote establishment of riparian vegetation on the banks and improve safety along the water's edges. The creation of "benches" above the water's edge is another technique to facilitate establishment of riparian vegetation (refer to B1 – Bathymetry and bank reshaping).

Hard infrastructure should be restricted in the riparian/buffer zone. Infrastructure such as paths, benches, playgrounds, constructed treatment wetlands may be allowed.

Riparian zones also play an important role in flood conveyance and attenuation by detaining runoff from the catchment and reducing the magnitude of flood pulses downstream. However, in urban areas, increasing riparian vegetation on the floodplain can make flooding worse. This impact can be avoided by offsetting the loss of storage from riparian planting with additional air space for flood detention within the waterbody (e.g., by raising the flood bunds) or by ensuring a healthy riparian vegetation across the catchment so that the magnitude of flood pulses is reduced upstream in the catchment before reaching the waterbody.

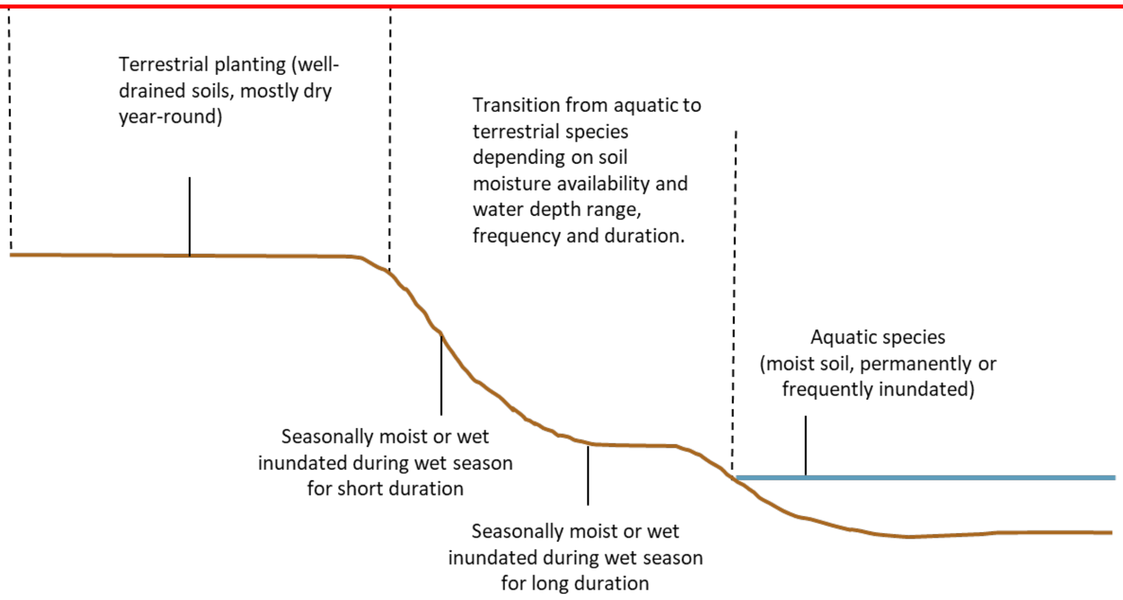

Figure 26. Zoning to guide riparian planting based on soil moisture and inundation pattern.

Operation and maintenance considerations

Low-skilled personnel can perform routine maintenance activities such as removal of weeds, clean-out of sediment and rubbish, and replacement of plants as necessary.

Useful resources

Melbourne Water (2019), Constructed Waterway Design Manual, Australia, (https://www.melbournewater.com.au)

C3 – Aquatic weed removal and management

Application level		Beneficial effect on waterbody health	
Catchment		Hydrology and hydraulics	✓
Incoming channel		Physical form	
Buffer zone		Water quality	
Waterbody	✓	Aquatic and riparian ecosystems	✓

Application

Problematic aquatic weed is an issue in its own right but it is usually symptomatic of broader issues such as poor water quality in the waterbody. The presence of aquatic weeds may be due to several factors including:

- Weed infestation in the upstream catchment
- Excess sediment accumulation in the waterbody
- High nutrient concentrations in the waterbody
- Seed dispersal
- Lack of regular maintenance

Investigation should be undertaken to confirm the proportion and species of weeds present, and the causes of the weed infestation. Understanding a weed's biology or ecology may influence the timing of the control method. For example, it may be beneficial to control a particular weed before it seeds to prevent further spread of the infestation.

There is a range of methods commonly used to control weeds. An integrated approach, where several control methods are used in a co-ordinated manner, is often the most effective long-term strategy. This section discusses mechanical harvesting to remove large infestations of aquatic weeds from waterbodies. Mechanical harvesting is the application of floating harvesters, excavators, or draglines (chains) to remove floating or submerged aquatic weeds. It can be applied to any size or types of waterbodies. Mechanical harvesting is an effective short-term control of aquatic weeds but unlikely to eradicate them. Use of chemicals (herbicides) and biological controls (e.g., insects) to manage aquatic weeds need specialist advice and is not covered in this advisory.

Planning and design considerations

Specialised floating harvesters can remove floating aquatic weeds or cut and remove weed biomass at a fixed depth below the water surface. An excavator can remove floating and submerged aquatic weeds from open water areas. This normally involves scooping plants from the water with a bucket. If using excavators, use floating booms to concentrate floating aquatic weeds. Long-reach draglines, such as chains or nets, can remove floating or submerged aquatic weeds. This involves pulling the chain or net through the water using

a tractor. Only use this method when other methods of weed control are unfeasible as draglines can damage desirable macrophytes.

Figure 27. Mechanical removal of aquatic weeds in Rankala lake (Source: GHONE, A. S., & SINGAL, S. K. Performance Evaluation of Deweeding Operations Implemented for Conservation of Rankala Lake, India.)

Operations and maintenance considerations

As it is a short-term solution, mechanical harvesting needs to be regularly repeated.

Section D. Treatment measures

Treatment measures are generally implemented as part of a treatment train. A treatment train is a meaningful combination and sequencing of treatment assets each targeting specific pollutants in order to achieve the overall treatment objectives. For waterbody rejuvenation, a treatment train usually consists of pre-treatment, primary treatment, and secondary treatment measures. For instance, constructed wetlands are often implemented as part of a treatment train (**Figure 27** and **Figure 28**).

- Pre-treatment – refers to the removal of coarse solids such as sand, plastics, and litter with the aim to protect downstream treatment assets from accumulation of solids. Pre-treatment uses physical removal mechanisms. Measures include screens and floatation systems.
- Primary treatment – refers to the stage of the treatment process that focuses on removal of solids, sediments, and organic matter mostly by the process of sedimentation. Measures include settling tanks, sedimentation ponds, sediment ponds, and Anaerobic Baffled Reactors.
- Secondary treatment – refers to the stage of the treatment process that focuses on removal of biodegradable organic matter, suspended solids, and nutrients (phosphorus and nitrogen).

In urban areas, flows into waterbodies are usually contaminated with untreated wastewater. Where high organic material is present in the incoming flows, the primary treatment measure should be carefully designed to enhance removal and digestion of organic matter.

Figure 28. Constructed wetland installed at Rajokri lake, Delhi (Source: Srivastava and Prathna, 2021)

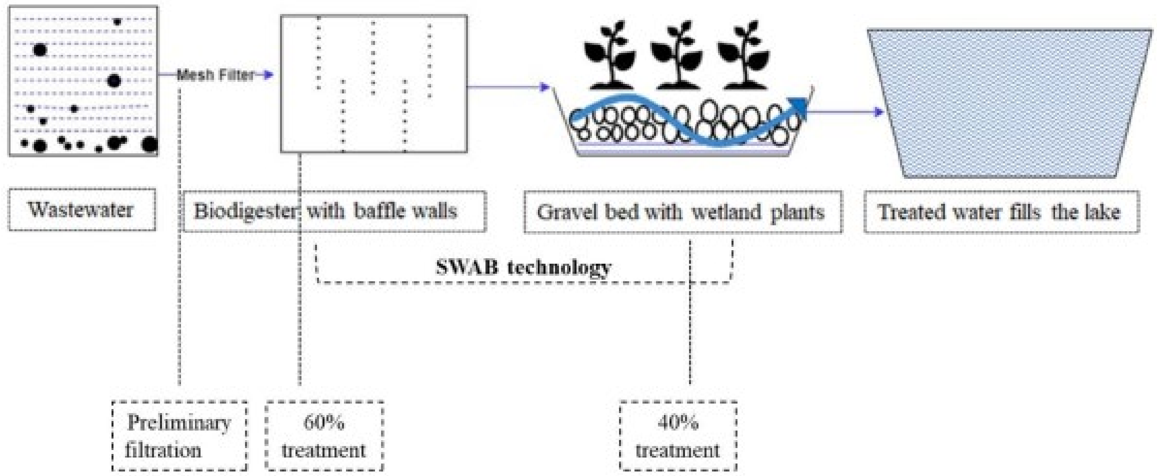

Figure 29. Schematic of a treatment train (Source: Srivastava and Prathna, 2021)

D1 – Primary treatment

D1.1 – Settling tank

Application level		**Beneficial effect on waterbody health**	
Catchment	✓	Hydrology and hydraulics	
Incoming channel		Physical form	
Buffer zone	✓	Water quality	✓
Waterbody		Aquatic and riparian ecosystems	

Application

A settling tank is one of several primary treatment options for wastewater treatment. It targets removal of solids and organic matter by sedimentation process. It can be applied at the inflow points to a waterbody or at any location in the catchment where discharge of wastewater is a problem. The low velocity in a settler allows settleable solids to sink to the bottom and material lighter than water to float to the surface. Settlers can achieve reduction in suspended solids of 50-70% and reduction in Biochemical Oxygen Demand (BOD) of 20-40%.

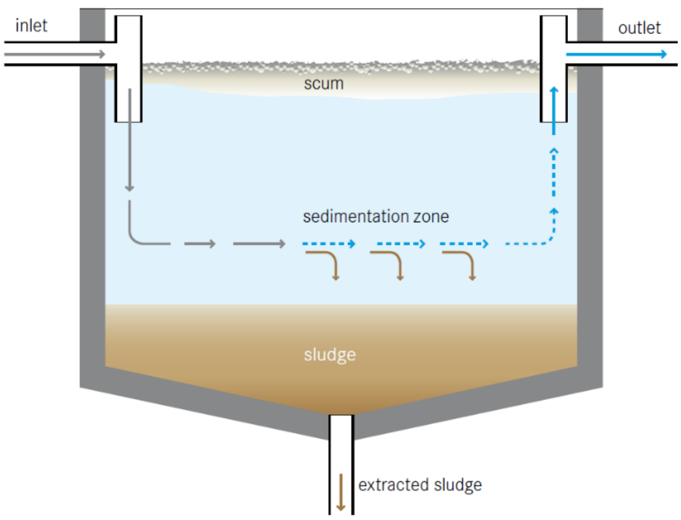

Figure 30. Illustration of a settling tank (Tilley et al., 2014)

Planning and design considerations

Settlers are typically designed with a hydraulic retention time of 1.5-2.5 hours. The tank should be designed to ensure satisfactory treatment performance at peak flow. The sizing of the tank depends on the wastewater characteristics, retention time and sludge removal rate.

Operation and maintenance considerations

Access should be provided for a truck to access the location as the sludge must be regularly removed.

Useful resources

Manual on Constructed Wetland as an Alternative Technology for used water management in India.

D1.2 – Sedimentation pond

Application level		Beneficial effect on waterbody health	
Catchment	✓	Hydrology and hydraulics	
Incoming channel		Physical form	
Buffer zone	✓	Water quality	✓
Waterbody		Aquatic and riparian ecosystems	

Application

A sedimentation pond is one of several primary treatment options for used water treatment. It targets removal of solids and organic matter by sedimentation process. It can be applied at the inflow points to a waterbody or at any location in the catchment where discharge of used water is a problem. It can also be applied as the primary treatment asset for stormwater treatment targeting removal of sediments by sedimentation process (also referred to as "sediment ponds").

Sedimentation pond works by slowing water allowing settleable solids to sink to the bottom and material lighter than water to float to the surface. Settlers can achieve reduction in suspended solids of 50-70% and reduction in BOD of 20-40%.

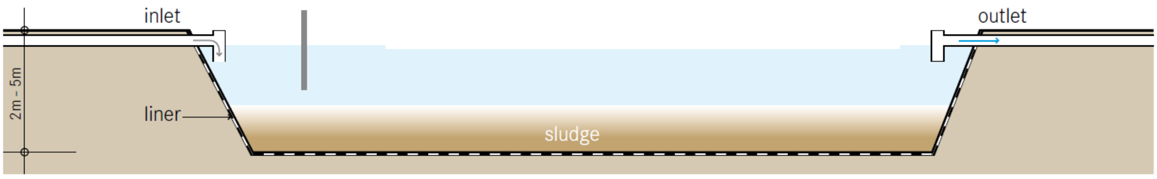

Figure 31. Illustration of a sedimentation pond (Tilley et al., 2014)

Planning and design considerations

Settlers are typically designed with a hydraulic retention time of 1.5-2.5 hours. The tank should be designed to ensure satisfactory treatment performance at peak flow. The sizing of the tank depends on the used water characteristics, retention time and sludge storage volume and removal rate.

For stormwater treatment, the sediment pond should be designed to capture most of the target coarse sediment (typically 125 µm or larger). It should only capture a small number of finer particles and contaminants, which should be removed by secondary treatment assets downstream. Key design consideration includes the design flow rate, volume of storage for sediment capture and frequency of sediment removal.

Operation and maintenance considerations

Access should be provided for a truck to access the location as the sludge or accumulated sediments must be regularly removed. The sedimentation pond can be drained of water to allow access. An excavator can reach from the side or may need to enter the pond.

Useful resources

Manual on Constructed Wetland as an Alternative Technology for used water management in India.

CSIRO (2005), Water Sensitive Urban Design (WSUD) Engineering Procedures – Stormwater, CSIRO Publishing, Australia.

D1.3 – Anaerobic baffled reactor

Application level		Beneficial effect on waterbody health	
Catchment	✓	Hydrology and hydraulics	
Incoming channel		Physical form	
Buffer zone	✓	Water quality	✓
Waterbody		Aquatic and riparian ecosystems	

Application

An anaerobic baffled reactor is one of several primary treatment options for used water treatment. It targets removal and digestion of organic matter in used water. It can be applied at the inflow points to a waterbody or at any location in the catchment where discharge of used water is a problem.

Used water is forced to flow through a series of baffles which increases contact time with active biomass (bacteria in accumulated sludge) and enhances removal and digestion of organic matter. BOD can be reduced by up to 90%.

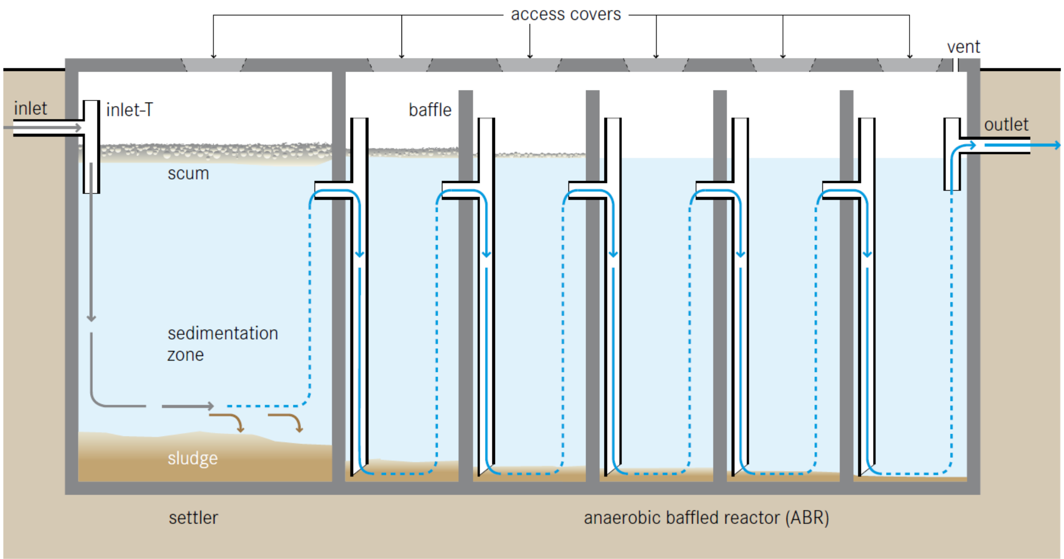

Figure 32. Illustration of an Anaerobic baffled reactor (Tilley et al., 2014)

Planning and design considerations

This technology is most suitable where there is a constant amount of incoming used water. The majority of settleable solids are removed in the sedimentation chamber (settler). A separate pre-treatment settler can also be included in the design. Typical inflows can range from 2 to 200 m^3 per day. The hydraulic retention time can range between 48 to 72 hours.

Operation and maintenance considerations

Access should be provided for a truck to access the location as the sludge must be regularly removed (particularly from the settler). Accessibility to all chambers is required for maintenance, and the tank should be vented for release of odorous and harmful gases.

Useful resources

Manual on Constructed Wetland as an Alternative Technology for used water management in India.

D2 – Secondary treatment

D2.1 – Constructed wetland

Application level		Beneficial effect on waterbody health	
Catchment	✓	Hydrology and hydraulics	
Incoming channel	*	Physical form	
Buffer zone	✓	Water quality	✓
Waterbody	✓	Aquatic and riparian ecosystems	

* See D4 – In-situ drain treatment for horizontal flow filter which operates based on the same processes as in constructed wetlands.

Application

Constructed wetland forms the secondary stage for treatment of used water or stormwater. It targets removal of suspended solids, organic matter, and nutrients (nitrogen and phosphorus) and to some extent pathogens in used water. It can also be applied for treatment of stormwater to target removal of suspended solids, organics, and nutrients and, to some extent, pathogens.

Constructed wetlands are man-made engineered system consisting of macrophytes grown in a natural or imported substrate designed to remove pollutants from incoming flows. Constructed wetlands are a well-established intervention and are applicable for all types and sizes of waterbodies. It can be applied at the inflow points to a waterbody, within a waterbody (attractive when land availability is a constraint), or at any location in the catchment for treatment of used water or stormwater.

Constructed wetlands can be designed and integrated in the landscape, and therefore enhance amenity of the waterbody with minimal impact on the community uses. Constructed wetlands can also enhance the aquatic ecosystem of the waterbody by supporting native vegetation and aquatic organisms.

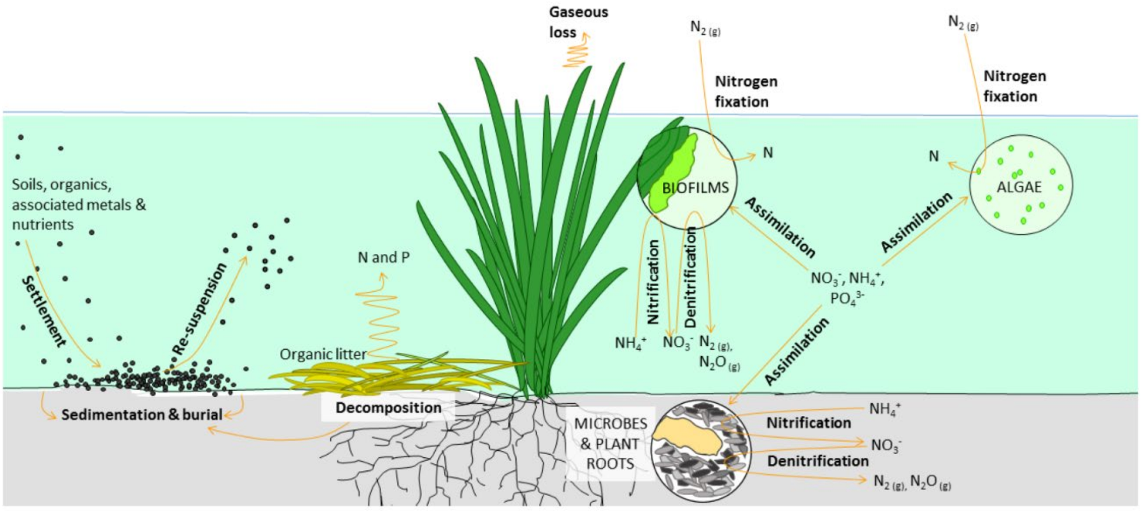

Figure 33. Treatment processes in a constructed wetland (Payne et al, 2015)

Processes

The main pollutant removal processes for sediments, organic matter and nutrients in constructed wetlands including sedimentation, decomposition, filtration, adsorption, plant assimilation, and nitrogen transformation. Apart from denitrification, which is a pathway for permanent removal of nitrogen, all other processes serve to contain pollutants within the wetland substrate and plant tissues. Pollutants that are not contained are eventually exported from the wetland.

Dominant processes include:

- Decomposition of organic compounds to simpler forms consuming oxygen in the process.
- Settlement of suspended solids, and nutrients and organic compounds in particulate forms to the base of the wetland into the substrate.
- Assimilation of inorganic nutrients in plants and algae in their tissues.
- Adsorption of ammonium and phosphorus to soil particles and organic matter
- Transformation of ammonium to nitrates under aerobic conditions (nitrification process) and subsequently from nitrates to nitrogen gas under anaerobic conditions (denitrification process) by bacteria.

Pathogens may also be retained via adsorption, sedimentation of particulates, natural die-off, burial and sunlight exposure.

Planning and design considerations

Constructed wetlands should be constructed once primary treatment measures are in place (See D1 – Primary Treatment) to protect the macrophyte zone from accumulation of solids and ensure effective treatment. The macrophyte zone generally requires 3-5 days contact time of polluted water with the plants, substrate, and associated microbial community. Constructed wetlands have effective pollutant removal performance as long as the system is designed and sized to manage the pollutant loading.

There are various design configurations for constructed wetlands which can broadly be categorised into 1) surface flow and 2) sub-surface flow systems (see **Figure 33** and **Figure 34**).

In surface flow systems, water flows above the substrate. The wetland base is generally lined with clay and covered with a substrate with native vegetation (e.g., cattails, reeds and/or rushes). In sub-surface flow systems, water flows through the substrate (generally gravel or sand) either in a vertical direction (vertical flow) or horizontal direction (horizontal flow). The substrate acts as a filter for removing solids with the microbial community supported by the substrate/plant-root matrix responsible for other pollutant removal processes.

A surface flow constructed wetland is generally simpler to construct (than a sub-surface flow wetlands) using locally available materials and can achieve high removal of suspended solids and moderate removal of pathogens, nutrients, and heavy metals. It is appropriate for used water with low pollutant loading after some type of primary treatment. It can tolerate variable water levels and nutrient loads. It is also appropriate for stormwater treatment. Good design and maintenance can prevent such systems becoming breeding grounds for mosquitoes and can minimise safety risk including contact with polluted water from standing water.

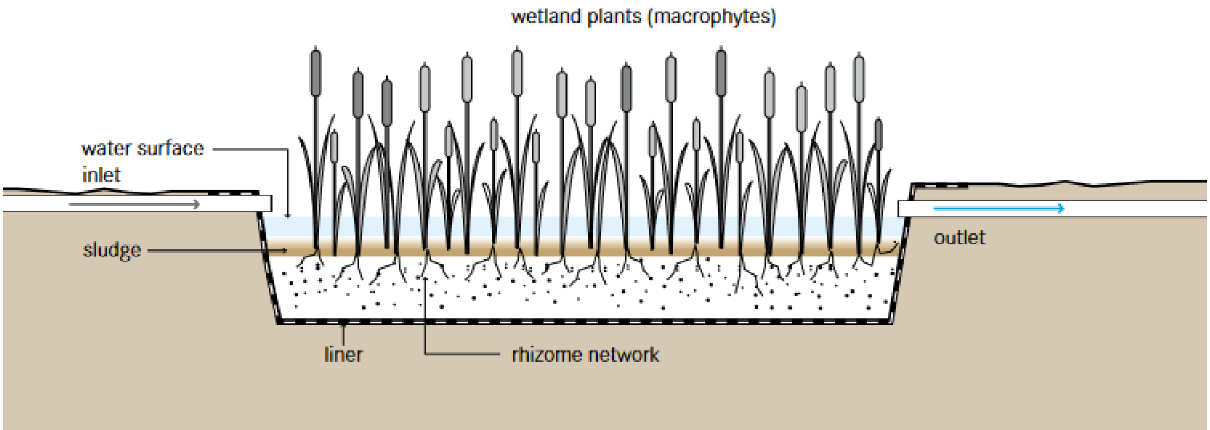

Figure 34. Illustration of a surface flow constructed wetland (Tilley et al., 2014).

A sub-surface horizontal flow constructed wetland is used for secondary treatment of used water after some type of primary treatment. The bed is lined to prevent leaching and the wetland is shallow to maximise water contact with vegetation roots. Clogging is a common problem and hence primary treatment is important as well as selection of substrate (gravel or sand is generally suitable but sand is more prone to clogging). It is not appropriate for blackwater. As water flows below the surface, human and wildlife contact with polluted water is minimised and mosquito breeding is reduced as there is no standing water.

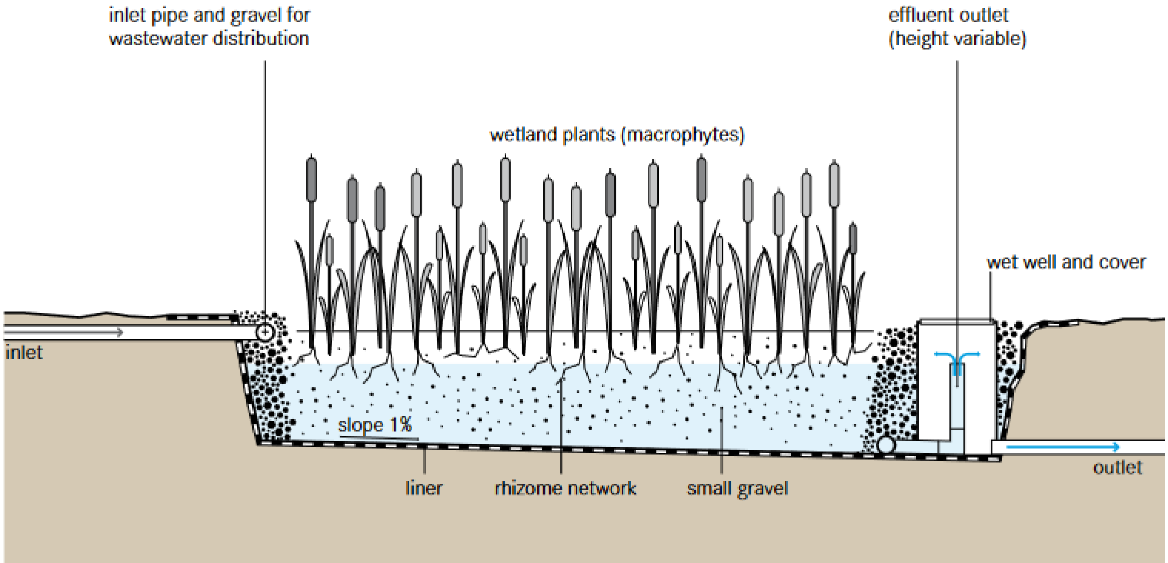

Figure 35. Illustration of a sub-surface horizontal flow constructed wetland (Tilley et al., 2014)

The planning and design of constructed wetlands requires expertise in civil, hydrology and hydraulics, stormwater and used water management, landscape design and plant species selection targeted for pollutant removal with tolerance to polluted water.

Constructed wetland systems can also be installed within the catchment to treat used water at the source (e.g. at the lot or neighbourhood scale such as in **Figure 35**). Components of the treatment train generally include a settler tank and/or an anaerobic baffled reactor, a sub-surface horizontal flow planted gravel filter, and in some instances a polishing pond depending on uses.

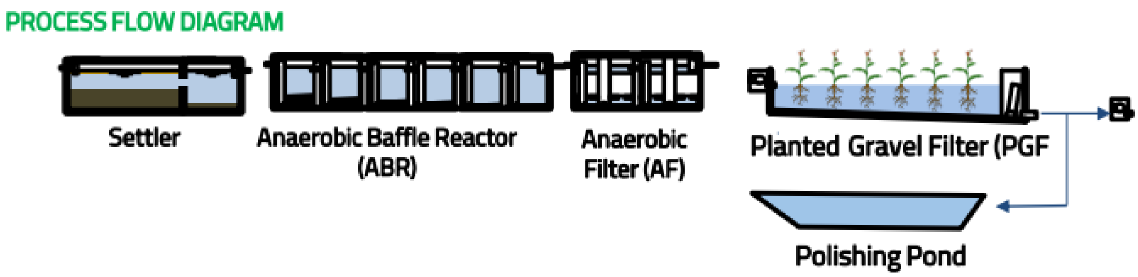

Figure 36. Schematic of a decentralised used water treatment system installed at Arvind Eye Hospital, Pondicherry (Source: CDD Society)

Operation and maintenance considerations

Low-skilled personnel are required for key maintenance activities including removal of accumulated solids and material, removal of solid waste, cut back and thinning of vegetation, harvesting and replacement of plants, and maintaining flow paths through the entire width of the macrophyte zone and ensuring no short-circuits. Replacement of substrate at the inlet zone for sub-surface systems is required generally every 10 or more years.

Useful resources

Manual on Constructed Wetland as an Alternative Technology for used water management in India.

Central Pollution Control Board (CPCB). (2019). Manual on Constructed Wetland as an Alternative Technology for Used water Management in India. *Ministry of Science & Technology, Ministry of Environment, Forest & Climate Change. Government of India.* Retrieved from: https://dbtindia.gov.in/sites/default/files/Print_Version_of_CW_Manual-23_May-2019.pdf

UN-HABITAT, 2008. Constructed Wetlands Manual. UN-HABITAT Water for Asian Cities Programme Nepal, Kathmandu. Retrieved from: https://sswm.info/sites/default/files/reference_attachments/UN%20HABITAT%202008%20Constructed%20Wetlands%20Manual.pdf

CSIRO (2005), Water Sensitive Urban Design (WSUD) Engineering Procedures – Stormwater, CSIRO Publishing, Australia.

Melbourne Water (2020), Wetland Design Manual, Australia, (https://www.melbournewater.com.au)

D2.2 – Floating wetland

Application level		Beneficial effect on waterbody health	
Catchment		Hydrology and hydraulics	
Incoming channel		Physical form	
Buffer zone		Water quality	✓
Waterbody	✓	Aquatic and riparian ecosystems	

Application

Floating wetlands are purpose-built devices consisting of emergent macrophytes growing on a floating platform in a waterbody's open water. The floating platform consists of a buoyant mat and structures (e.g., PVC pipes, fibreglass, bamboo). Plants are established directly into the floating platform with roots growing into the water column.

Application of floating wetlands is usually targeted at polishing water quality or for low to moderately polluted waterbodies. For waterbodies that are highly polluted (e.g., high levels of nutrients and BOD), application of floating wetlands alone will not be sufficient to address the problems, with primary and secondary treatment measures to capture pollutants before it enters the waterbody also required. Floating wetlands can also be applied for algae and mosquito control in a waterbody.

A key advantage is that it can be implemented within the footprint of the waterbody requiring no land take and excavation. Another advantage is that the buoyancy of the structure adjusts with varying water depths in the waterbody – plants are therefore less sensitive to changing water depths. They also enhance the aquatic ecology and aesthetics of a waterbody.

Processes

The main pollutant removal processes occur largely within the submerged plant root mat and its biofilm:

- Decomposition of organic compounds to simpler forms consuming oxygen in the process
- Assimilation of inorganic nutrients in plants and algae in their tissues
- Adsorption of ammonium and phosphorus
- Transformation of ammonium to nitrates under aerobic conditions (nitrification process) and subsequently from nitrates to nitrogen gas under anaerobic conditions (denitrification process) by bacteria

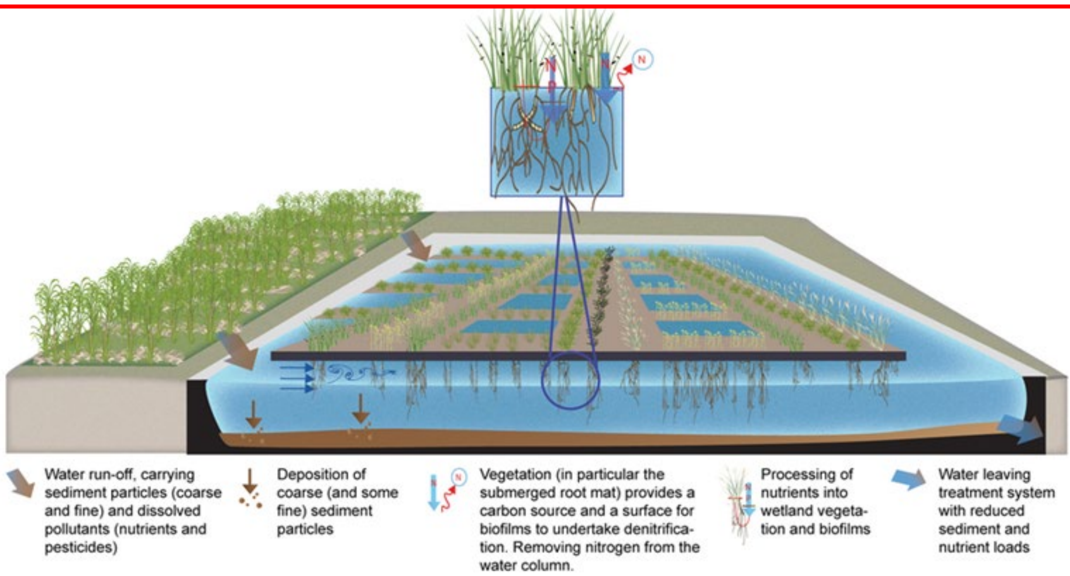

Figure 37. Schematic of a floating treatment wetland (Source: Department of Environment and Science, Queensland Government, Australia).

Figure 38. Application of floating macrophyte bed at Neknampur Lake, Hyderabad (Source: The Hindu).

Planning and design considerations

Several design aspects must be taken into consideration such as the functionality, durability, anchoring system, weight, buoyancy, and plant species selection. The ability to keep the asset anchored during high flow velocities, wave action or strong winds needs consideration to protect the asset and prevent damage to other infrastructure. Consideration should be given to the plants' ability to withstand variation in water quality as floating wetlands cannot be placed offline during a severe pollution event. Plant species selection should consider pollutant removal effectiveness, aesthetics, endemicity and robustness (noting that issues can arise from excessive bird grazing and nesting). *Phragmites australis* (common reed) has been found to be highly effective at uptake of nitrogen and phosphorus in floating wetland systems. There are products available on the market currently, however floating wetland systems can also be constructed from locally available material.

Operation and maintenance considerations

Low-skilled personnel are required for key maintenance activity including weed removal, plant cutting back and thinning, pest control and plant replacement. Harvesting plant material may be required so that they do not release nutrients back into the water column when they senesce (particularly in eutrophic waterbodies where nutrient mitigation and removal is the objective). Studies suggest that biofilms that form on plant roots continue to remove nutrients after plants start to senesce.

Useful resources

Niti Ayog. (2022). Urban Used water Scenario in India–. *Water Security*, *16*, 100119. Government of India (GOI). https://www.niti.gov.in/sites/default/files/2022-09/Waste-Water-A4_20092022.pdf

D2.3 – In-situ drain treatment

In-situ drain treatment measures have been developed to target treatment of used water in drains. Examples include microbial dosing, horizontal flow filters, floating wetland cells, and vertical flow filters. These measures can assist with improving water quality before it enters downstream waterbodies or downstream treatment assets (e.g., constructed wetlands).

Application level		Beneficial effect on waterbody health	
Catchment		Hydrology and hydraulics	
Incoming channel	✓	Physical form	
Buffer zone		Water quality	✓
Waterbody		Aquatic and riparian ecosystems	

D2.3.1 – Microbial dosing

Microbial dosing refers to the application of naturally occurring microbes in the drain to degrade organic matter generally from untreated used water thus reducing concentration of organic pollutants entering downstream waterbodies or treatment assets. The microbes delivered into the drain use the nutrients in the water for their growth and digest the organic matter (i.e., food source) using oxygen to produce carbon dioxide and water. Microbes are usually applied to flowing water with contact created at barriers of stones and boulders to ensure uniform mixing and oxygenation of the water. A key advantage of this technique is that it can be applied without disturbing the drain structure.

Microbial dosing has been implemented as several sites in India and has shown successful reduction in BOD. Expertise is required in designing the dosing system, selecting the right product, determining the dosing program, and monitoring performance. However low-skilled personnel are required to operate the system once installed. Capital cost is required upfront for setting up the dosing facility as well as on-going costs from regular application. Because they are naturally occurring microbes, they are safe to the environment and people.

D2.3.2 – Horizontal flow filter

This technique refers to installation of “bridges” constructed across the drain or in a zig-zag manner using locally available material (gravel, sand, and soil) with plants grown within the upper layer of the bridge (**Figure 38**). Flow and pollutant removal processes are similar to a sub-surface horizontal flow wetland (see D2 – Constructed wetland). Screens are installed upstream of the “bridges” to capture suspended and floating materials and litter. Pollutant removal processes at the bridges include sedimentation, filtration, adsorption, plant assimilation, nitrogen transformation, and microbial degradation. The length of bridges can be optimised for pollutant removal depending on the characteristics of the pollutants and pollutant loading. Disadvantages of this technique are the impact of the barriers on the flow carrying capacity of the drains and potential scouring of the upper soil layer and vegetation from high flow velocities (noting that application in India have often excluded the vegetation and upper soil layer). Other similar horizontal flow filter products which are modular, mobile and available in portable units have also been developed such as the PhytoTrap by NEERI.

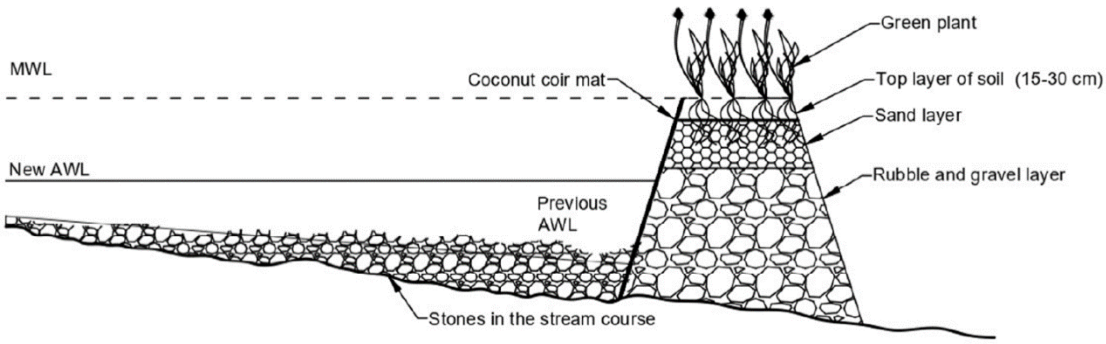

Figure 39. Schematic of a horizontal flow filter installed in a drain (Source: Satyendra et al., 2023).

Figure 40. Application of horizontal flow filter in canal leading to Udai Sagar Lake in Udaipur (Source: Vikalpsangam)

D2.3.3 – Floating wetland cell

This technique refers to devices purpose-built for installation in drain that have the same features, benefits, advantages and pollutant removal processes as floating wetland (see D3-Floating wetland). Products have been developed that are modular and available in portable units such as Phyto-floraft by NEERI (**Figure 40**).

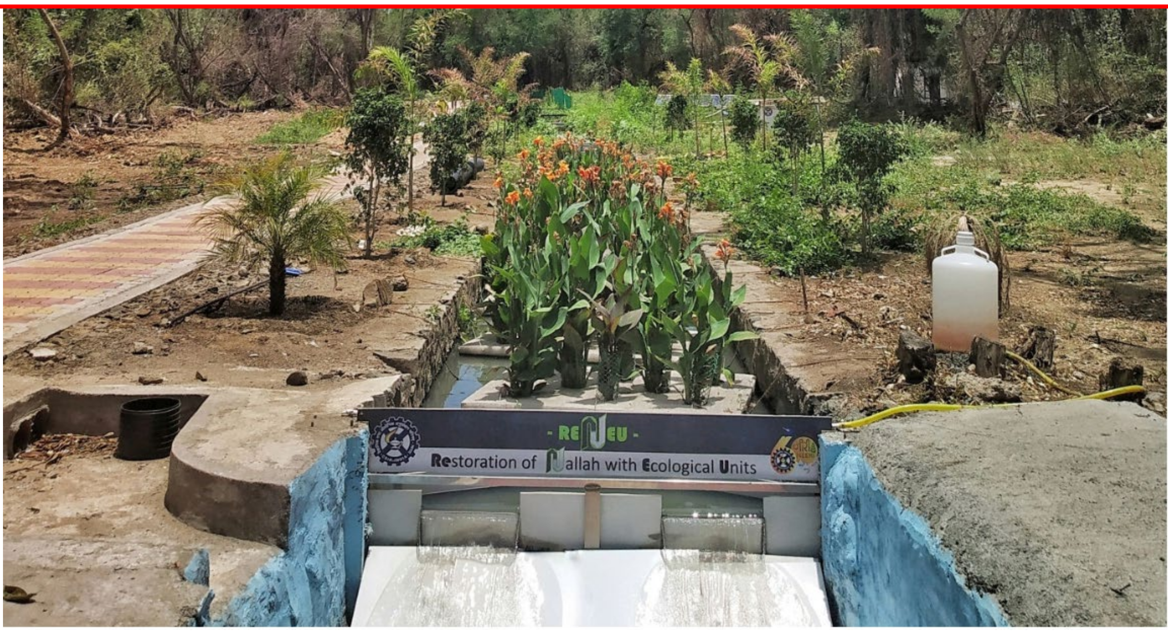

Figure 41. Installation of floating wetlands cells in a drain (Source: NEERI)

D2.3.4 – Vertical flow filters

This technique relies on diversion of water from a drain to a vegetated filter media with water passing through the biologically active filter media in a vertical direction (**Figure 41**). Gravity fed systems are generally low cost and require low skilled personnel to perform routine operation and maintenance such as removal of accumulated material at the surface of the filter. Vertical flow filters are generally installed adjacent to the drains to stay offline during high flows (to prevent scouring and damage).

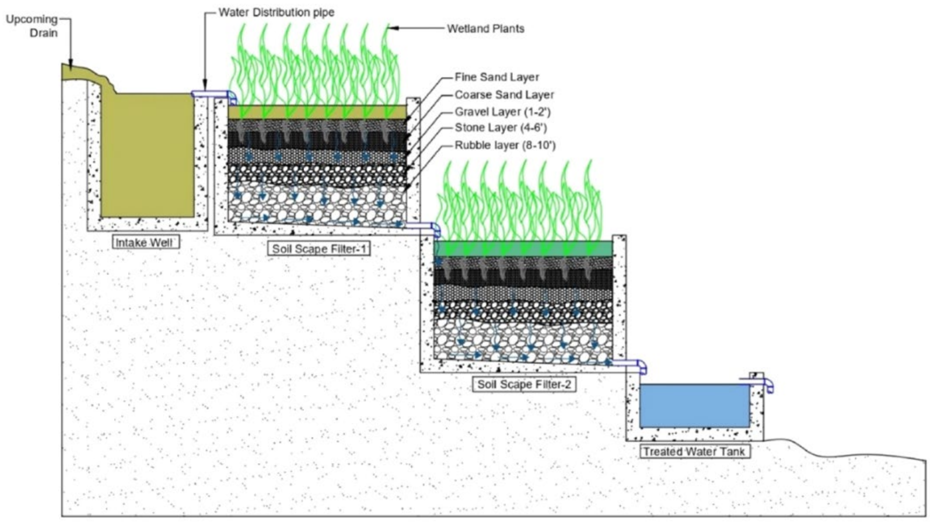

Figure 42. Schematic of a vertical flow filter (Source: NEERI Satyendra et al., 2023)

D2.4 – Biofiltration system

Application level		Beneficial effect on waterbody health	
Catchment	✓	Hydrology and hydraulics	
Incoming channel		Physical form	
Buffer zone	✓	Water quality	✓
Waterbody	✓	Aquatic and riparian ecosystems	

Application

Biofiltration system forms the secondary stage for treatment of stormwater. It targets removal of suspended solids, organics, nutrients (nitrogen and phosphorus) and to some extent pathogens in stormwater. A typical biofiltration system consists of a vegetated sand-based filter media which receive stormwater at the surface with water flowing vertically down the filter media and collected in a drainage pipe or allowed to infiltrate into the surrounding soils for groundwater recharge (**Figure 42**).

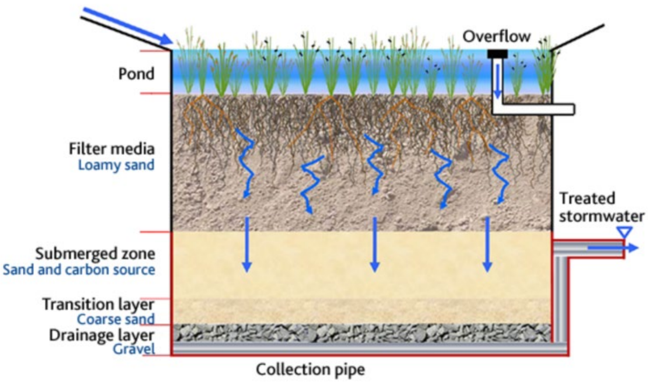

Figure 43. Application and schematic of a biofiltration system

Biofiltration system is a well-established technique for stormwater treatment and are applicable for all types and sizes of waterbodies where stormwater runoff is a primary cause of poor water quality in the waterbody. It can be applied at the inflow points to a waterbody, within a waterbody (attractive when land availability is a constraint), or at any location in the waterbody buffer zone or catchment for treatment of stormwater runoff. They require smaller footprint than stormwater constructed wetlands for the same pollutant removal performance and are highly flexible and scalable and therefore suitable for dense urban spaces.

- Small biofiltration systems applied at the street scale or lot-scale are referred to as 'raingardens'
- Linear biofiltration systems are referred to as "biofiltration swales'
- Larger biofiltration systems applied at end-of-pipe or at inflow points of waterbodies are referred to as 'biofiltration basins'

Figure 44. Application of biofiltration technology – Street scale raingarden (left), street scale linear swale (middle) and end-of-pipe biofiltration basin (Source:Spiire)

Processes

The following treatment processes take place in biofiltration systems:

- As stormwater enters the biofiltration system, soil particles and particulates to settle out on the surface of the filter media by sedimentation process. In addition, particulates are filtered from the water as it percolates down through the filter media (mechanical straining).
- The filter media contains clay minerals and other chemically active compounds that bind dissolved pollutants (sorption)
- Decomposition of organics
- Adsorption of ammonium and phosphorus to soil particles and organic matter
- Transformation of ammonium to nitrates under aerobic conditions (nitrification process) and subsequently from nitrates to nitrogen gas under anaerobic conditions (denitrification process) by bacteria
- Vegetation and the associated microbial community assimilate nutrients and some other pollutants (e.g. plant and microbial uptake)

Design and planning considerations

Key design considerations include pre-treatment measures for removal of coarse solids such as sand, plastics and litter to protect the biofiltration system from accumulation of solids. Construction activities in particularly can generate high sediment loads which can clog the biofiltration system. Pre-treatment measures can include sediment ponds (see D1.2 – Sedimentation pond), swales and sediment forebays (**Figure 44**).

A key design consideration is sizing the system appropriately for the catchment flows. A starting point is sizing the biofiltration system with a surface area that is 2% of the impervious area of the contributing catchment. However, sizing needs to also take into consideration ponding depth, infiltration rate and vegetation health in the long term. Oversizing may not provide sufficient flows to sustain vegetation health.

It is important to select a filter media that provides a balance of adequate infiltration rate and adequate moisture retention to support plant health during the dry season. It is also important to plant the biofiltration system densely to enhance pollutant removal.

It is also worth considering a submerged zone in the design (by raising the outlet) to provide anaerobic conditions for permanent removal of nitrogen (via denitrification process) and water storage to sustain plants during the dry season (**Figure 42**).

Figure 45. Pre-treatment measures for biofiltration system and other stormwater treatment assets – Sediment ponds (left) and swales (right)

Operation and maintenance considerations

Typical maintenance activities should focus on health and coverage of vegetation, the filter media, and hydraulic aspects of the system:

- A strong healthy growth of vegetation is critical to the treatment performance. The most intensive period of maintenance is during the plant establishment period when weed removal and replanting may be required. Care during this period will reduce long-term maintenance requirements.
- The surface of the biofilter is vulnerable to erosion, scour, sediment, and litter accumulation, clogging and moss growth. These compromise the function of the system, in terms of the infiltration rate and the capacity to treat stormwater volumes. Repair minor accumulation of sediment by scarifying the surface between plants and if feasible, manual removal of accumulated sediment. Repair erosion and infill using filter media and add features for energy dissipation (e.g., rocks and pebbles at inlets). Litter removal should be undertaken regularly and manual scraping to remove moss may also be required.

Useful resources

Central Public Health and Environmental Engineering Organisation (CPHEEO). (2019). Manual on Storm Water Drainage Systems, Volume – I, Part A: Engineering Design (First edition). *Ministry of Housing and Urban Affairs (MoHUA). Government of India*. Retrieved from: https://cpheeo.gov.in//cms/manual-on-storm-water-drainage-systems---2019.php

CPHEEO. (2019). Manual on Storm Water Drainage Systems, Volume – II, Part B-Operation & Maintenance and Part C-Management. *MoHUA. GOI.* Retrieved from: https://cpheeo.gov.in//cms/manual-on-storm-water-drainage-systems---2019.php

Adoption Guidelines for Stormwater Biofiltration Systems (https://watersensitivecities.org.au/wp-content/uploads/2016/09/Adoption_Guidelines_for_Stormwater_Biofiltration_Systems.pdf)

Appendix C – Data sources

C1 – Establishing watershed characteristics

Land use and land cover

Data type	Source
Land use	Municipal corporation, regional development authority BHUVAN Portal (https://bhuvan.nrsc.gov.in/home/index.php) Procured satellite images from National Remote Sensing Centre (NRSC)
Land cover	

Hydrogeology

Data type	Source
Hydrogeological	Central Groundwater Board (http://cgwb.gov.in/aquifer-atlas) *Aquifer Atlas and Maps – Aquifer Systems of India* *State wise Aquifer Atlas and Maps (as on Sep 23) – Chhatisgarh, Karnataka, Kerala, Himachal Pradesh, Meghalaya, Goa, Andhra Pradesh, Madhya Pradesh, Tamil Nadu*
Soil Map	Soil & Land Use Survey of India

Catchment and topography

Data type	Source
Drainage network	Municipal corporation, regional development authority Primary data – collected through topography survey
Watershed/Micro-watershed	Soil & Land Use Survey of India *Watershed delineation and corresponding natural drainage pattern can also be derived through Arc GIS using Digital Elevation Model (DEM). The gridded tiles for DEM downloaded from Bhuvan has a vertical accuracy of 8m at 90% confidence.* *Higher resolution DEM can be purchased from NRSC.*

Incoming flow to waterbody

Data type	Source
Flow from the catchment	Chapter 4: Runoff Estimation, Manual on Storm Water Drainage System, Volume -I (Part A: Engineering Design), 2019. Published by Central Public Health and Environment Engineering Organisation (https://mohua.gov.in/publication/manual-on-storm-water-drainage-systems--2019.php) Using tools such as Arc Hydro (https://www.esri.com/en-us/industries/water-resources/arc-hydro), SWAT (https://swat.tamu.edu/), BASINS (https://www.epa.gov/ceam/better-assessment-science-integrating-point-and-non-point-sources-basins), PCSWMM (https://www.pcswmm.com/).
Other sources of flow	Incoming flow from upstream Used water treatment plants discharging into the waterbody. Collect the outflow discharges from the utility/organisation operating the plant. Untreated used water from areas not connected with network discharging into the drains leading to waterbody. Install flow meters at the inlet of the waterbody.

C2 – Establishing waterbody and meteorological characteristics

Bathymetry with waterbody inlet and outlet survey

Data type	Source
Waterbody bathymetry	Primary data collection. It is recommended to collect the data at 10 m × 10 m grid. It will include surveying of the waterbody inlet and outlet.

Water and Sediment Quality

Data type	Source
Physico-chemical data of lake water and sediment quality	Kindly refer to **Appendix A – Recommended quality parameters**

Meteorological Data

Data type	Source
Rainfall and Evaporation Data	Indian Meteorological Department Rainfall – recommended data is at hourly resolution preferably for the rain gauge with long duration (30 years or more) data availability. Evaporation – daily evaporation data. If the nearest available rain gauge station from the waterbody does not have long term data, consider closest gauge station with long meteorological data record.

Credits

This Advisory on Waterbody Rejuvenation is an outcome of dedicated efforts by individuals who were part of creating this document under the aegis of AMRUT 2.0 Mission of Ministry of Housing and Urban Affairs (MoHUA).

Team's heartfelt thanks to Ms D Thara, Addl. Secretary and Mission Director AMRUT 2.0 (MoHUA) whose vision and commitment has made it possible to incorporate Waterbodies as an integral part of thriving Urban Water Ecosystem. Mr. Lavnya Kumar, Director (IC), MoHUA, and Ms Tanvi Garg, Dep. Secretary, MoHUA, who provided their unwavering support and valuable guidance through preparation of this advisory.

Dr Harry Virahsawmy, Urban Water Specialist at Alluvium, and to the project team – Advait Madav, Aksheyta Gupta, Tony Weber, Parth Gohel and Shivani – for the guidance, research and inputs in preparing this advisory.

Mr. Gaurav Bhatt, Water Lead – ARUP's AIWASI Team, for his technical inputs and writing of the report.

The Australian Department of Foreign Affairs and Trade (DFAT), and the team from Australian High Commission New Delhi – Ms Belinda Costin, First Secretary (AHC), and Mr. Nagasreenivas Kanchi, Senior Technical Advisor, for their support through the preparation of this advisory.

It is hoped that this Advisory on Waterbody Rejuvenation will serve as a valuable guidance document for cities to embark on a transformative journey of sustainable and resilient Urban Waterbody Management.

THIS PAGE IS INTENTIONALLY BLANK