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Sustainable Urban Lake Restoration

A Practitioner's Guidebook

south pole

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Abbreviations

DPR	Detailed Project Reports
ULB	Urban Local Bodies
GIS	Geographic Information System
DEM	Digital Elevation Model
GPS	Global Positioning System
WSUD	Water Sensitive Urban Design
CPCB	Central Pollution Control Board
pH	Potential of Hydrogen
DO	Dissolved Oxygen
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
TDS	Total Dissolved Solids
SER	Society for Ecological Restoration
NbS	Nature-Based Solutions
SDM	Structured Decision-Making
InVEST	Integrated Valuation of Ecosystem Services and Tradeoffs
RHS	River Habitat Survey
PRA	Priority Restoration Areas
STP	Sewage Treatment Plant
DEWATS	Decentralized Wastewater Treatment Systems
NGO	Non-Governmental Organization
HF	Horizontal Flow
VF	Vertical Flow

Executive Summary

The Sustainable Lake Management Training Guidebook is a practical resource designed to help urban local bodies (ULBs), planners, engineers, environmental experts, and community stakeholders in the restoration and sustainable management of urban lakes. It recognizes lakes as vital ecological assets that support urban resilience, water security, biodiversity conservation, climate resilience, flood management, and community well-being.

The guidebook provides a systematic framework for lake restoration, grounded in an understanding of the ecological value of lakes and their roles in urban drainage systems, stormwater management, habitat support, microclimate regulation, and ecosystem service provision. It also explores the root causes of degradation in urban water bodies and highlights the need for integrated restoration measures to address these challenges.

A key component of the guidebook is an overview of a preliminary assessment and baseline study, which comprises catchment area mapping, field observations, and water quality monitoring and assessment. These measures help determine the underlying causes of deterioration, sources of pollution, hydrological linkages, land-use pressures, and ecological conditions that impact lake health. Sustainable restoration requires addressing both in-lake concerns and catchment-level pressures.

The guidebook also presents a step-by-step Planning and Design Framework that includes defining restoration objectives, assessing ecosystem services, selecting appropriate interventions, using systematic decision-making processes, implementing restoration actions, and setting up monitoring and evaluation systems. The framework highlights the importance of community participation, stakeholder engagement and governance arrangements needed to sustain long-term lake management outcomes.

The final section outlines a range of lake restoration and management solutions, such as pollution control measures, wastewater treatment systems, ecological restoration techniques, phytoremediation, desilting and dredging, shoreline stabilization, habitat enhancement, and nature-based stormwater management interventions. These measures seek to enhance water quality, restore ecological functions, increase biodiversity, and build resilience to climate impacts.

In conclusion, the guidebook provides a comprehensive pathway for the restoration and management of urban lakes through science-based assessment, integrated planning, ecosystem-based interventions and participatory governance. It aims to support urban areas in protecting and restoring water bodies as critical natural infrastructure that contributes to resilient, sustainable, and climate-adaptive urban development.

LAKE RESTORATION & MANAGEMENT FRAMEWORK

CHAPTER 01: INTRODUCTORY MODULE

LAKES AND ECOLOGICAL SIGNIFICANCE

- Drainage
- Storm Water Management
- Urban Biodiversity
- Microclimate
- Ecosystem Services
  - Clean Water
  - Recreation
  - Carbon Sequestration

CHAPTER 02: PRELIMINARY ASSESSMENT AND BASELINE STUDY

CATCHEMENT AREA MAPPING → **WATER QUALITY PARAMETERS** → **IDENTIFY PROBLEMS**

CATCHEMENT AREA MAPPING

- Watershed Delineation
- Inflows Identification
- Land Use Analysis

WATER QUALITY PARAMETERS

- **Physical** (Temp., pH, Turbidity)
- **Chemical** (DO, 80D, COD, Nutrients)
- **Biological** (Plankton, Benthic, Coliforms)

IDENTIFY PROBLEMS

- **Pollution** (Point/ Non-Point)
- **Algal Blooms** (Harmful/ Eutrophication)
- **Siltation** (Sediment Accumulation)
- **Invasive Species** (Flora and Fauna)

CHAPTER 03: PLANNING AND DESIGN

- **Identify Solutions**
- **Define Restoration Objectives**
- **Identify Solutions**
- **Implementation**
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- **Impact Assessment**

CHAPTER 04: LAKE RESTORATION SOLUTIONS

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ECOLOGICAL RESTORTION

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- Phytoremediation (Floating wetlands, Constructed Wetlands)
- Bio-manipulation (Fish Stocking, food web management)
- Bioremediation (Microbial cultures)

SHORELINE & HABITAT RESTORATION

- Bank Stabilization (Bioengineering, gabions)
- Vegetative buffer zones
- Artificial reefs & habitat structures
- Wildlife Corridor Creation

SUSTAINABILITY & COMMUNITY INVOLVEMENT

- Public Awareness & Education Programs
- Citizen Science Monitoring
- Stakeholder engagement & partnerships
- Long-term funding mechanisms
- Policy advocacy & enforcement

01 Lakes and Their Ecological Significance in Urban Areas

Urban lakes are valuable natural resources. Historically, many cities developed around lakes and other water bodies because they provided water for drinking, irrigation, and other livelihoods. The functions of lakes are not limited to water storage; they also include influencing the local microclimate, enhancing biodiversity and providing other ecosystem services. Urban lakes play a vital role in maintaining environmental balance, managing urban water systems, flood control and improving the quality of life for urban residents.

However, rapid urbanization and other anthropogenic factors have resulted in pollution, degradation, and encroachment of several lakes. Recognizing and restoring the ecological functions of lakes is important to ensure sustainable urban growth and climate resilience.

1.1 | Drainage

Urban lakes form a crucial component of natural drainage systems. They function as "receptors for surface runoff," collecting excess water from adjacent catchment areas. Sometimes, lakes are interconnected with canals, channels, or drainage networks that regulate stormwater in the terrain. Isolated lakes facilitate the water cycle in their vicinity and improve groundwater recharge. Properly designed and maintained lakes help:

- control the movement of water throughout the terrain;
- collect excess rainwater, thereby preventing pooling in low-lying regions;
- help groundwater recharge by letting water seep in; and
- regulate the natural water balance in the urban watershed.

Urban flooding frequently occurs after heavy rainfall when drainage channels are obstructed or when lakes are inadequately integrated into urban planning. Therefore, effective urban water management requires protecting natural drainage systems that connect to lakes.

1.2 | Stormwater Management

Urban lakes serve as natural reservoirs for stormwater retention. Some Indian cities have cascading lake structures that store rainwater and direct the excess overflow into the next lake. This interconnected system of lakes and drainage channels serves as a barrier against flooding and provides water security for regions located away from perennial rivers. The storage volume of lakes also reduces pressure on urban drainage infrastructure. Key benefits of water sensitive planning through lakes include:

- mitigating flood risk in cities;
- controlling runoff and preventing erosion;
- allowing debris and contaminants to settle before water moves downstream; and
- improving groundwater recharge.

Lakes are increasingly recognized as "nature-based solutions for flood management," especially as climate change causes more frequent and intense rainfall events and increases the temperature in urban areas.

1.3 | Urban Biodiversity

Lakes support diverse ecosystems that provide habitats for several species that depend on freshwater for survival. Even small urban lakes can sustain diverse species of plants and animals including:

- Fishes
- Reptiles and amphibians
- Phytoplankton and aquatic plants
- Birds, including migratory species
- Bugs, insects and pollinators

These ecosystems contribute to the preservation of urban biodiversity and establish essential ecological corridors within cities. Healthy lake ecosystems maintain ecological balance and support urban food webs. They also provide opportunities for environmental education and research. With diverse biota and physicochemical processes, lake systems possess a delicate natural environment that is very sensitive to external influences. For example, the proliferation of invasive species can irreversibly alter lake conditions, impacting its physicochemical composition and biota.

1.4 | Microclimate

Water bodies have a significant influence on local weather conditions. Urban lakes help regulate local microclimates by moderating temperature and humidity levels in the surrounding areas. The combination of greening, shade, and urban cooling provided by lakes helps reduce urban heat island (UHI) effects. Research studies have shown temperature reductions of up to 2°C within 30m of lake boundaries.

Key benefits of urban lakes include:

- Reducing the effects of UHIs
- Cooling neighborhood areas through evaporative cooling
- Improved air quality and humidity levels
- Enhancing thermal comfort for residents in densely populated urban areas

1.5 | Ecosystem Services

Ecological services are the direct and indirect benefits that lakes provide to human beings. While some ecological services are quantifiable, e.g., income from boating, several benefits are difficult to model. Urban lakes provide an array of ecosystem services, which can be categorized as shown in Figure 1.

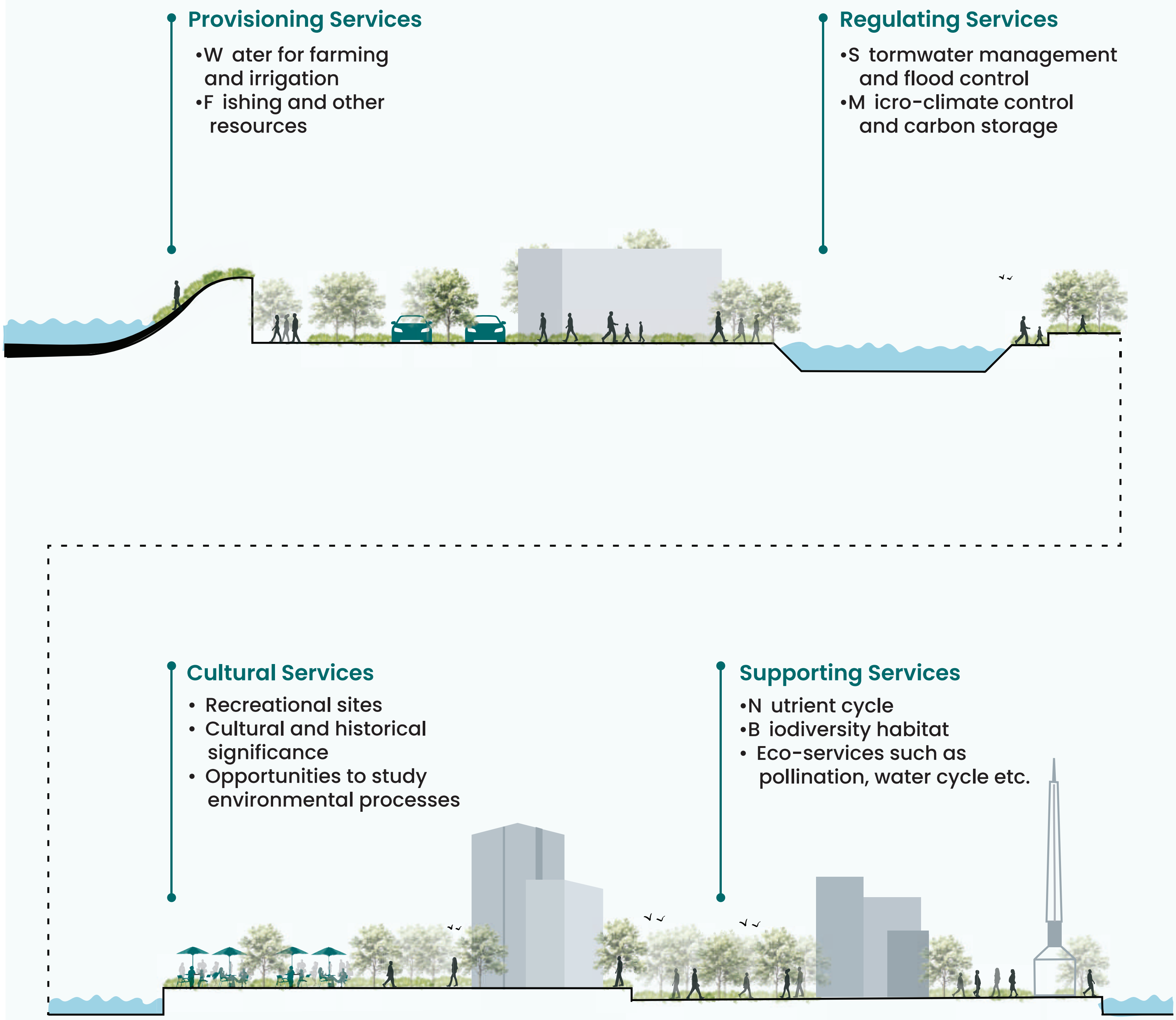

Figure 1: Categories of Ecosystem Services

When managed sustainably, urban lakes significantly contribute to environmental health, urban resilience, and community well-being. However, ecological services are often overlooked in land-use planning and environmental management in cities, owing to the ambiguity of quantifiable benefits.

1.6 | Historical Significance of Lakes in India

- Bengaluru was once called the city of a thousand lakes. According to historical records, Kempe Gowda, the founder of Bangalore, constructed artificial lakes for irrigation, fishing and the supply of drinking water. These lakes were connected with intricate channels, known as Rajakaluves, to drain excess stormwater. As the city expanded, subsequent rulers continued to expand the lakes, which favorably influenced the city's local climate and groundwater levels. The lakes also served important social and economic roles, such as supporting dhobis and temples, and providing fodder for cattle.

However, in recent years, lakes have dwindled significantly due to real estate development, encroachments, and land acquisition for development projects, adversely affecting the city's climate, water availability and biodiversity.

- Udaipur, renowned as the City of Lakes, has a network of water bodies that has supported the city for over 500 years. These lakes store monsoon water, control stormwater flows, and are an important part of the city's tourist attractions. They are interconnected through sluices, canals, and overflow channels, supporting a self-sustaining water cycle. However, the lakes face significant challenges due to unregulated sewage inflow, plastic waste, eutrophication, and other anthropogenic factors. Restoration activities were undertaken by the Jheel Samvardhan and Vikas Society (JSVS) to restore the lakes and improve their ecological condition.

The following chapters present an overview of the steps, as depicted in Figure 2, to be undertaken to develop a comprehensive lake restoration plan.

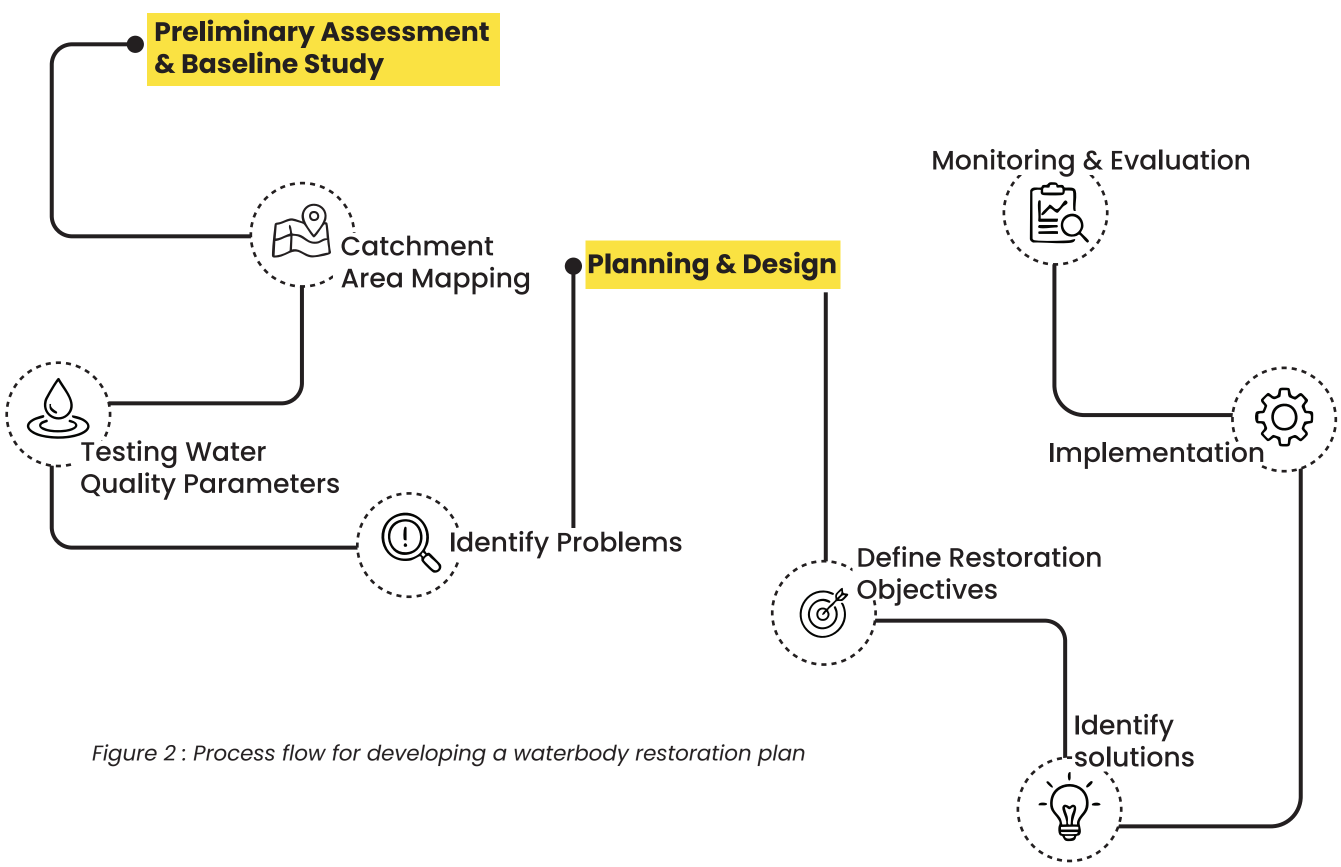

Figure 2 : Process flow for developing a waterbody restoration plan

02 Preliminary Assessment And Baseline Study

The effectiveness of lake restoration and sustainable waterbody management depends largely on the quality of the preliminary assessment and baseline study. Isolated in-lake measures or beautification-focused measures often fail because they do not address the fundamental causes of degradation within the catchment and drainage network.

The findings provide the basis for restoration planning and decision-making processes, including the preparation of restoration plans, Detailed Project Reports (DPRs), investment prioritization, monitoring frameworks and long-term governance mechanisms. This assessment helps Urban Local Bodies (ULBs), planners, engineers, environmental experts, and decision-makers transition from reactive restoration measures to integrated and sustainable lake management practices.

This chapter presents a framework for conducting a preliminary evaluation and baseline analysis of urban lakes and water bodies. Figure 3 shows key components of the assessment.

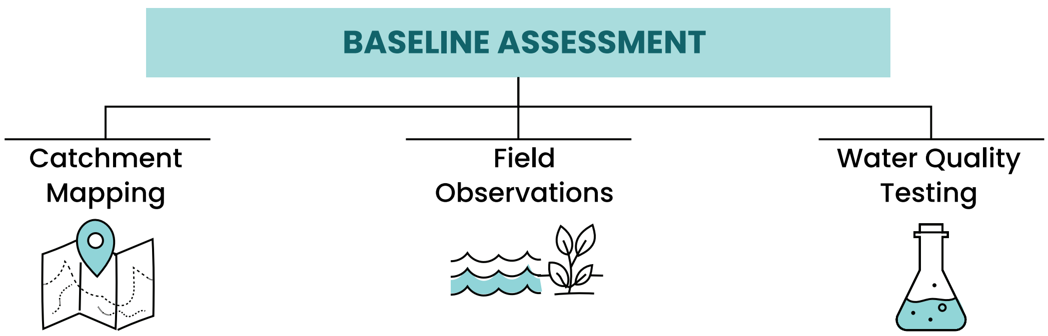

Figure 3 : Baseline assessment components

2.1 | Catchment Area Mapping

The catchment area is the total land area from which water flows into a lake. Its characteristics and associated issues directly affect the lake.

The catchment is a major component of the baseline assessment and requires mapping of water sources, flows, and factors influencing lake conditions.

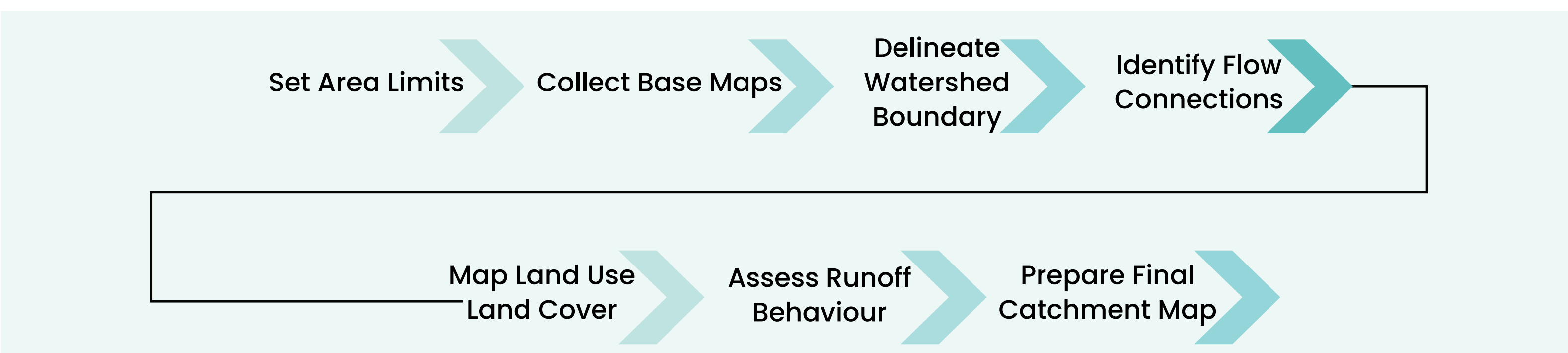

Figure 4 : Steps for Catchment Area Mapping

Step 1: Demarcate the Study Area

Demarcate the catchment area and understand its topography, drainage patterns and related features. Catchment assessment helps map surface and groundwater flows into the lake. The study boundary may include:

- the entire lake catchment,
- a smaller catchment, or
- the immediate area around the lake.

The boundary should include all land draining into the lake. This Water Resource Assessment process allows the study boundary to be set at the catchment, micro-catchment, city, or district level, depending on the study objectives[1]. A clearly defined boundary enables identification of pollution sources, drivers of lake degradation, and appropriate solutions.[2]

Step 2: Collect base maps and background data

Collect relevant toposheets or contour maps, satellite imagery, Geographic Information System (GIS) base maps, polygon files for spatial analysis, and Digital Elevation Model (DEM) data for understanding topography and drainage patterns. Ward maps, drainage maps, land-use maps, rainfall and hydrological data should be gathered to assess water flow, flood-prone zones, and infrastructure conditions.

Historical lake maps available in municipal records, land surveys, and satellite images can be used to understand changes in lake boundaries and catchment areas. These maps and records could help map historic drainage patterns, flood and drought events, and human interventions that have influenced the lake's present condition.

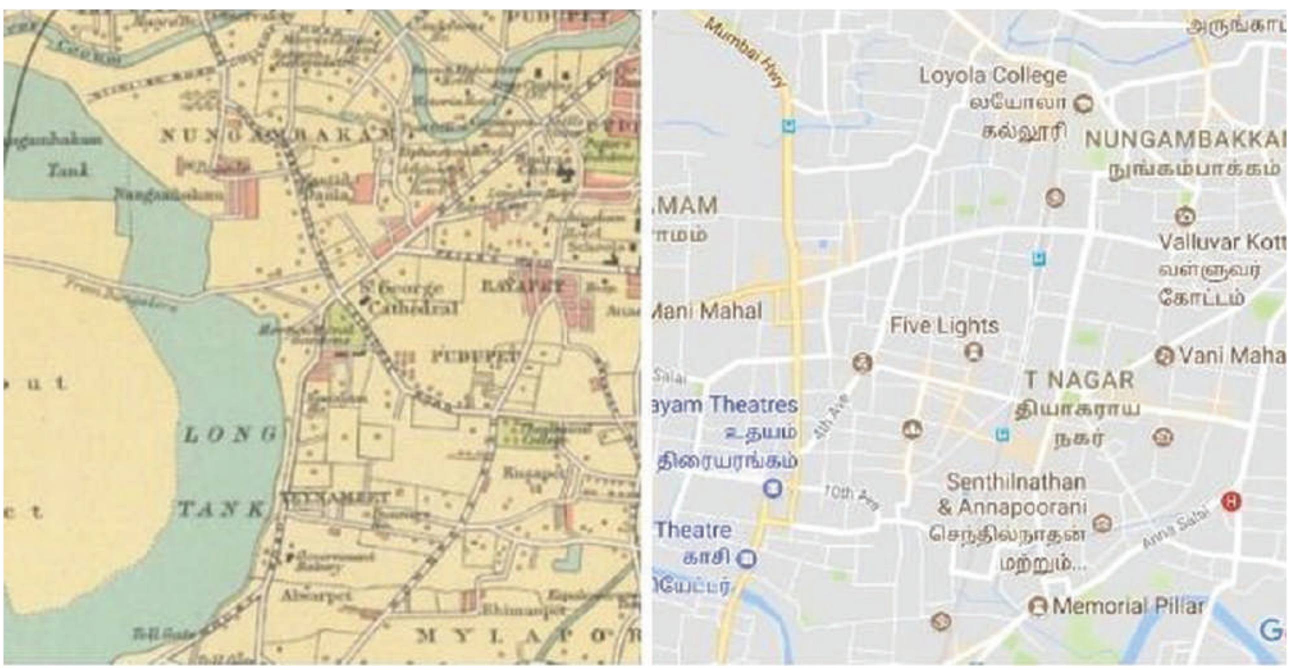

Figure 5 : Comparison of the 1909 and 2015 maps showing the disappearance of lakes in Chennai. Historical reference can help understand the evolution of land-use and development patterns and their impacts on water bodies.

1 Central Pollution Control Board (CPCB). (2019). Guidelines for restoration of water bodies. Ministry of Environment, Forest and Climate Change, Government of India, New Delhi.
2 (Noordam, G. (2026). What is Watershed Delineation? Spatial-Eye. Available at: https://spatial-eye.com/blog/spatial-analysis/what-is-watershed-delineation/)

Using GIS datasets, Google Earth imagery, DEM data, land-use and climate data, and waterbody records, the hydrological characteristics of the catchment can be analyzed. This step establishes the basis for identifying drainage direction, slopes, inflows, and land-use impacts.

Step 3: Delineate the watershed boundary

Using contour maps, DEM data, slope patterns, and drainage flow directions, delineate the watershed boundary that contributes runoff to the lake. This helps identify the settlements, roads, agricultural fields, and open spaces that affect the lake environment, and estimate the catchment area contributing to runoff. Where GIS tools are available, the watershed boundary can be drawn digitally to improve accuracy. Where they are unavailable, manual delineation can be undertaken using contour maps and field verification.

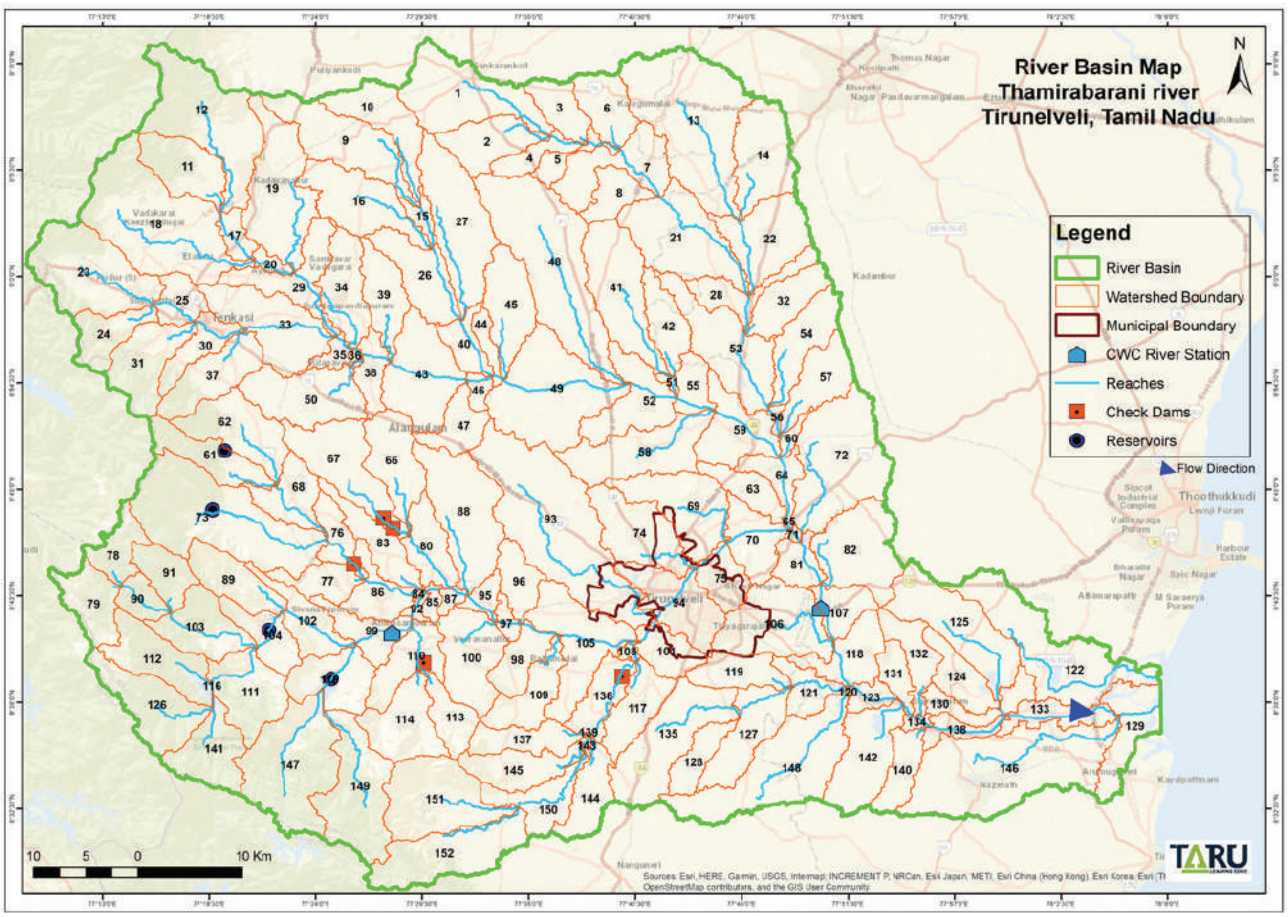

Figure 6 : Watershed delineation of the basin using the CARTOSAT 30 m Digital Elevation Model. A total of 152 sub-basins has been identified. [3]

Step 4: Identify inflows, outflows, and drainage connections

The watershed should be surveyed to identify and map all physical water connections to the lake. These links include feeder channels, stormwater drains, natural streams and nalas, culverts, overflow sites and outlet structures. Mapping these features helps in understanding water movement and assessing the lake's hydrological functioning.

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3 Taru Leading Edge, ICLEI South Asia.2023. Feasibility Report Watershed Assessment and River Flood Warning System for Tirunelveli City

The natural drainage network and the artificial stormwater network supply water to lakes. But urbanization, infrastructure development, and changes in local topography can interrupt natural flow routes by obstructing, diverting or contaminating inflow channels with sewage and other pollutants. The study should therefore delineate drainage zones, identify all inflow and outflow channels, and evaluate barriers affecting runoff.

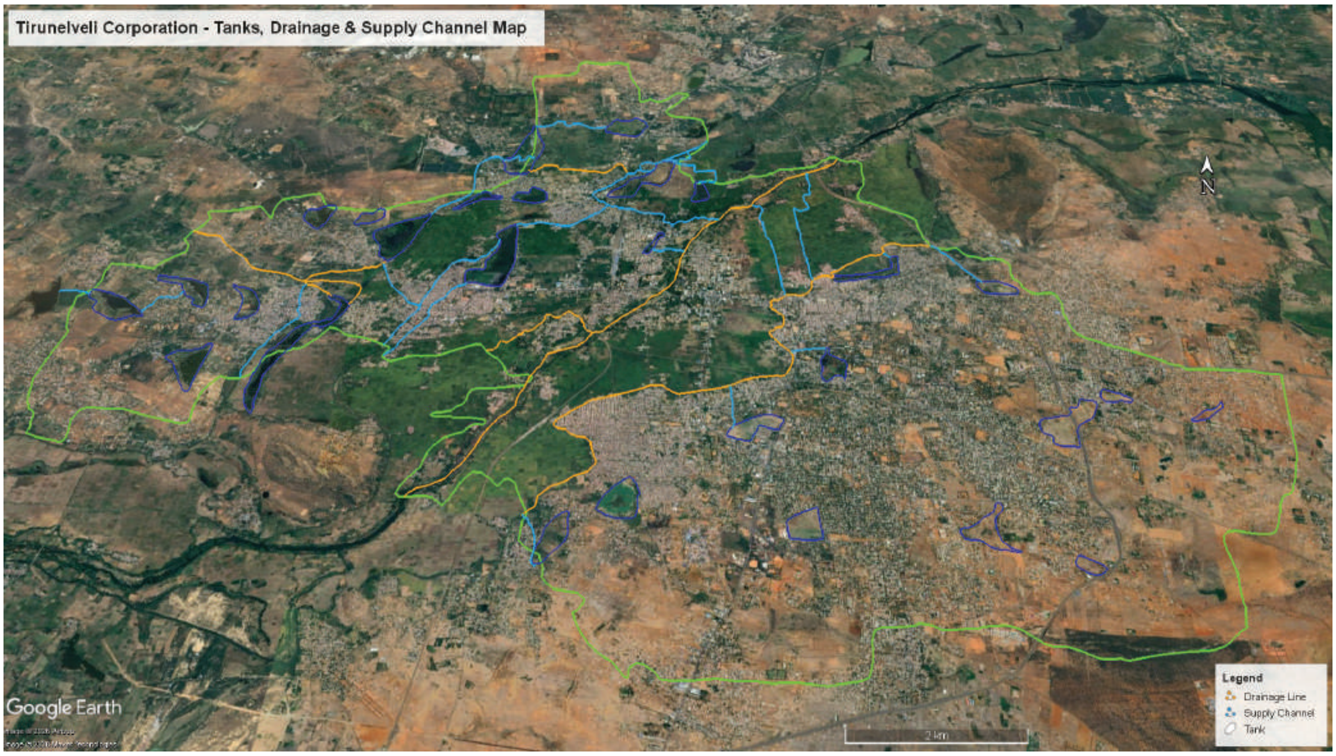


Figure 7 : Google Earth image showing drainage and supply channels between lakes in Tirunelveli.

Step 5: Map land use and land cover in the catchment

Land use in the catchment should be classified into residential, commercial, industrial, institutional, agricultural, open land, roads and paved surfaces, and green cover. Understanding these land-use categories is essential as they directly influence the quantity and quality of runoff into the lake.

Residential, commercial, and paved surfaces typically increase surface runoff and reduce groundwater infiltration. Industrial areas may contribute chemicals, oils, and heavy metals, while agricultural land can contribute fertilizers, pesticides, and sediments. Open or barren land often accelerates soil erosion and siltation, reducing the lake's storage capacity and impacting water quality.

In contrast, green spaces and vegetation promote infiltration, slow runoff rates and help filter contaminants before they reach the lake.

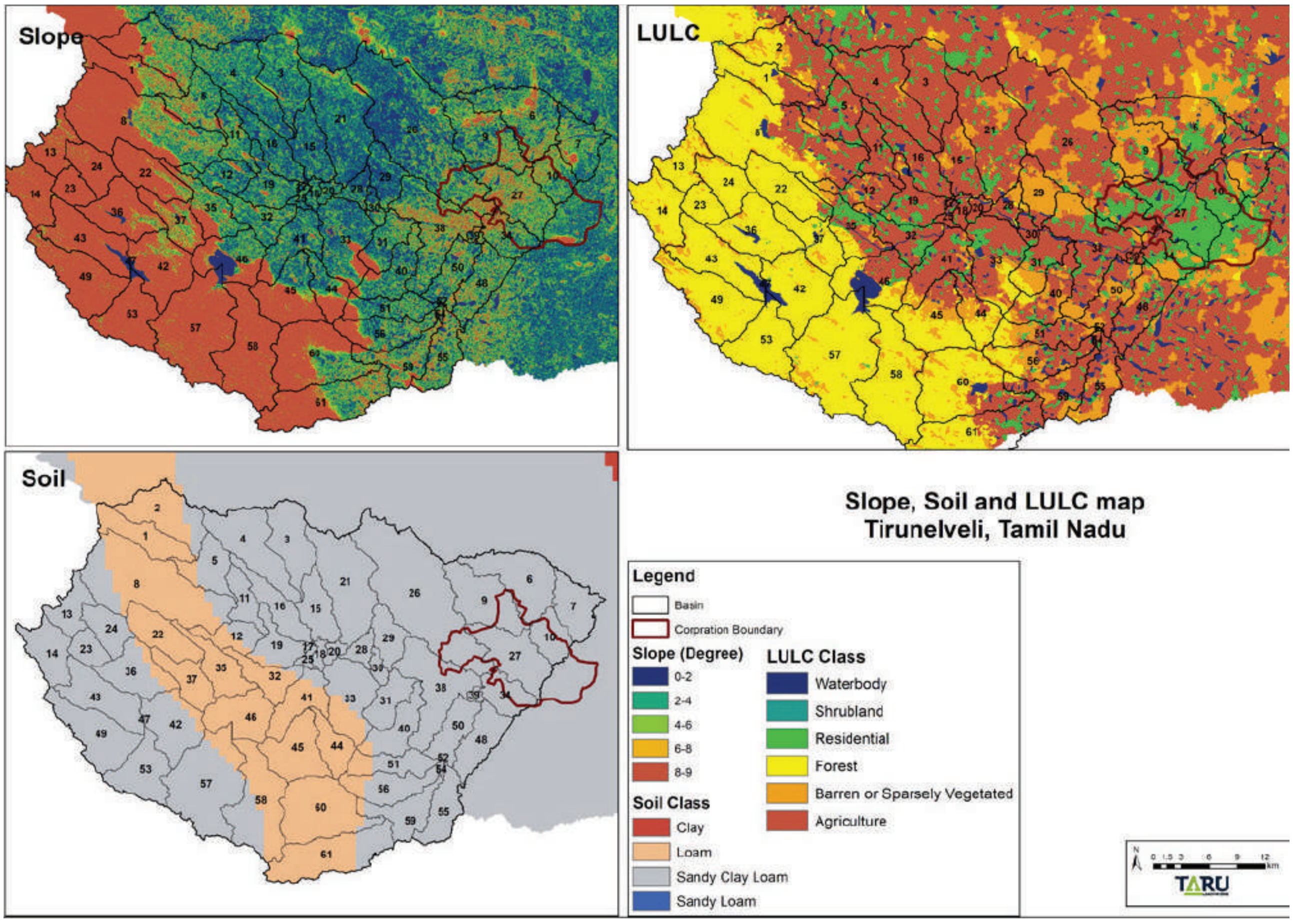


Figure 8 : Slope, Land Use, Land Cover and soil profile map for Tirunelveli [4]

Step 6: Assess Runoff Behavior, Hydrological Problems, and Field Verification

In this step, the catchment should be studied to understand runoff behavior and related hydrological issues. This assessment should identify areas of rapid runoff, high runoff generation, stagnant water, canals that transport combined stormwater and sewage, and areas that produce excessive sediment loads.

As map-based analysis may not capture all ground realities, field verification is necessary to assess drainage conditions, illegal discharge points, damaged or clogged drains, recent land-use changes, and encroachments. Field visits should be carefully documented with photographs, GPS coordinates, field observations, and stakeholder inputs.

Step 7: Prepare Final Catchment Map

A complete final catchment map should be developed after detailed map analysis and field verification, integrating all findings. The map should clearly show watershed boundaries, lake boundaries, inflow and outflow points, drainage networks, land-use zones, pollution sources, encroachments, blocked channels, and important risk areas. This integrated map is a key technical document for lake restoration planning, providing a clear understanding of the hydrological and environmental factors influencing the water body.

4 Taru Leading Edge, ICLEI South Asia.2023. Feasibility Report Watershed Assessment and River Flood Warning System for Tirunelveli City

It can also show sites where land-use restrictions, stormwater management systems, or Water Sensitive Urban Design (WSUD) initiatives are required.

2.2 | Field Observations

Step 1: Visually assess the water body

A visual inspection provides a rapid assessment of the lake condition before further technical investigations are done. Check the color, clarity, and odor of the water. Clear water generally indicates better water quality. Dark, green, black, or very turbid water may indicate pollution, algal blooms or excessive sediment loads. Foul odors may suggest sewage contamination, stagnant conditions or decomposition of organic matter.

The water surface should also be observed for floating waste, oil films, foam, plastics, or other pollutants. The amount of aquatic vegetation and algal growth should be checked as excessive growth may indicate nutrient enrichment and ecological imbalance. Photographs and field notes should be taken to support analysis and reporting.

Step 2: Identify pollution sources

Identify pollution sources contributing to water quality degradation by examining the lake environs, inflow channels, and catchment area.

- Locate greywater discharges, sewage inflows, open drains and wastewater outlets.
- Document solid waste dumping, construction debris, religious waste, or industrial waste.
- Trace upstream drainage networks to identify contamination sources.
- Inspect agricultural areas for runoff carrying fertilizers, pesticides, and sediments during rainfall events.

Mapping pollution sources helps identify likely contaminants and inform pollution-control strategies.

Step 3: Assess siltation (sediment build-up)

Siltation reduces water-storage capacity and ecological function. Assess whether the lake appears shallower than its historical condition, particularly near inflow channels where sediments tend to accumulate. Indicators include mud deposits, sand bars and plants growing on freshly formed sediment beds. Discussions with local communities can also help assess whether the lake has lost its water-holding capacity over time. Observations after rainfall can help assess whether additional runoff packed with sediment is accelerating siltation. Identifying silted zones is important for planning desiltation and catchment treatment measures.

Step 4: Check for algal blooms

Algal blooms can indicate fertilizer contamination and poor water quality. Check the water surface for green, blue-green or brown layers, thick algal mats, surface scum, and foul odors. Other indicators include reduced water quality, reduced aquatic biodiversity, fish kills, and depletion of DO. Algal blooms can damage aquatic ecosystems, recreational value, and public health. Understanding the causes and extent of eutrophication is critical for selecting appropriate restoration measures such as nutrient control, aeration, and nature-based treatment systems.

Figure 9 : Algal blooms in waterbodies

Step 5: Identify invasive species

Assess the extent of invasive aquatic species such as water hyacinth, salvinia, and other similar vegetation. These species can reduce light penetration, lower DO, restrict water flow, and disrupt aquatic biodiversity. Dense vegetation can also block inflow and outflow channels, causing stagnation and flooding. Map and document infestations through field observations and photographs to support appropriate management measures, including their removal, biological control or habitat modification.

Step 6: Map problem areas

Map all identified problem areas to support prioritization of interventions. Key locations include pollution sources, sewage discharge points, solid waste dumping zones, silted areas, algal bloom zones, invasive weed infestations and stagnant water pockets. Where possible, capture GPS coordinates and integrate them into a base map or GIS platform. Spatial analysis can reveal relationships between pollution sources and impacted areas, while supporting restoration planning, monitoring and stakeholder engagement.

Figure 10 : Pollution sources to the lake in Tirunelveli

Physical disturbances affecting the natural inflow and outflow of water should also be considered. These include blocked feeder channels, constricted or damaged drains, filled low-lying areas, erected structures that block drainage courses, encroachments on lake edges and road embankments that interrupt natural flow.

Figure 11 : Encroachments include illegal religious sites, fencing and drains blocked by silt and solid waste

Step 7: Validate with the local community

Community consultations are an important part of lake evaluation, as residents often possess useful knowledge of historical and seasonal changes in the water body. Discussions with residents, fishers, farmers, lake users, and local institutions can provide insights into changes in water quality, water levels, biodiversity, and lake use over time. Comparing local observations with field findings helps identify long-term trends and core causes of degradation and validate technical findings. Integrating scientific assessments with local knowledge supports more effective and community-supported restoration solutions.

2.3 | Water Quality Assessment

Water quality analysis helps determine the general health of a lake, the sources of contamination, and the necessary restoration, conservation, or treatment actions. A lake may appear healthy or contain sufficient water, yet still be polluted or environmentally degraded. Water quality monitoring helps identify contaminants, track changes over time, and support evidence-based lake restoration and management measures. It also enables ULBs to comply with standards, such as those prescribed by the Central Pollution Control Board (CPCB).

Step 1: Define the purpose of water quality assessment

The assessment may aim to:

- determine the overall health of the lake;
- identify the level and type of pollution;
- locate the major contamination spots;
- assess suitability for lake restoration;
- compare inlet and outlet water quality; and
- establish baseline data for long-term monitoring.

A site visit should be undertaken to identify inflow sources and trace inlet drains within a radius of at least 500 m of the lake boundary. Particular attention should be paid to industries, tanneries, or other pollution sources, as these observations can help prioritize parameters for testing.

Step 2: Identify sampling locations

Sampling sites should represent overall lake conditions and the influence of different pollution sources. Sites should include inlets, outlets, sewage or industrial discharge areas, stormwater inputs and representative open-water sites. Samples may be collected from central areas to determine overall water quality, particularly in larger lakes.

Additional sampling should be conducted in stagnant zones where pollutants, nutrients, algal blooms, sediments, and floating debris accumulate, as well as in areas affected by bathing, washing, religious activities, livestock access or waste disposal.

Step 3: Determine the timing and frequency of sampling

Water quality varies seasonally and in response to weather conditions. The assessment should determine whether sampling is a one-time exercise or part of a longer monitoring program. Seasonal sampling helps capture fluctuations in pollutant concentrations, sediment loads, nutrient loads, and dilution effects. For example, pre-monsoon sampling may suggest concentrated pollutants, while monsoon monitoring may capture increased sediment loads, stormwater runoff, and contamination from the neighboring watershed. Post-monsoon sampling can reveal dilution effects, fresh contamination or ecological changes.

Where seasonal monitoring is not feasible, historical water quality records, laboratory reports and local knowledge should be reviewed to get qualitative insights.

Step 4: Select parameters for testing

Water quality parameters are commonly classified as physical, chemical and biological indicators. Selection should be based on site conditions, pollution sources, and assessment objectives.

A. Physical parameters

Physical parameters provide a preliminary indication of lake condition and include temperature, turbidity, color, odor, and suspended solids.

Many of these can be assessed during field visits. For example, dark color, foul odors, and excessive turbidity may indicate sewage contamination, erosion, stormwater runoff, or untreated wastewater discharge. Basic field equipment, such as portable temperature sensors, turbidity meters, and water quality kits, can be used for on-site measurements.

B. Chemical parameters

Chemical parameters are used to determine pollution levels, nutrient enrichment, oxygen depletion, and overall water quality.

- **pH:** indicates whether water is acidic or alkaline. Healthy freshwater systems generally have a pH between 6.5 and 8.5.

- **Dissolved oxygen (DO):** Measures oxygen available for aquatic life. Low DO may indicate sewage contamination, high organic waste, stagnation, or eutrophication, and can result in fish kills, unpleasant odors, anaerobic conditions, and biodiversity loss.
- **Biochemical oxygen demand (BOD):** Measures oxygen required by microorganisms to decompose organic matter and is a key indicator of organic pollution.
  - **Chemical oxygen demand (COD):** Measures the oxygen required to chemically oxidize pollutants. High COD indicates increased contamination from sewage, industrial discharge, chemical waste or organic matter.
- **Nutrients:** Excessive nutrient levels can cause eutrophication, algal blooms, oxygen depletion and fish mortality.
- **Ammonia:** Its presence usually indicates sewage contamination and decomposition of organic waste. High concentrations can be toxic to fish and other aquatic species.
- **Total dissolved solids:** Measures dissolved salts and minerals in water. High TDS levels may indicate contamination from industrial discharge and urban runoff.

Figure 12 : pH test strips (litmus paper) are used for simple on-site estimation of pH levels in a water body.

Figure 13 : Portable water meters are used for quick, on-site measurement of water quality parameters such as pH, electrical conductivity, and temperature.

C. Biological parameters

Biological parameters help evaluate the ecological health of a lake and identify biological contamination, eutrophication and nutrient enrichment. Common indicators include total coliforms, E. coli, algal growth and plankton abundance.

Step 5: Prepare for field sampling

Before fieldwork, ensure that all materials and equipment are available and functional. Basic items include clean sampling bottles, labels, gloves, a GPS device or mobile phone, a field notebook, portable water-testing kits (if available) and an ice box for sample storage and transport. All sample vials should be clearly labelled with the site name, date, time, sample identification code and sampling location (e.g., inlet, mid-lake, outlet, or stagnant zone). Accurate labelling, handling, and documentation are vital to maintain sample integrity and ensure reliable results.

Step 6: Collect water samples properly
Water samples should be collected using standard procedures:

- Avoid disturbing the bottom sediments unless sediment samples are needed. For a specific sediment analysis, use tools like Ekman grabs or core samplers.
- Collect samples from a representative depth below the surface.
- Avoid contamination from hands or containers.
- Seal the bottles immediately after collection.

If specific tests require distinct containers or preservation methods, the relevant protocols should be followed. Samples should be transported to the laboratory promptly.

Step 7: Test in-situ parameters immediately
Some parameters are best measured on-site because they change quickly after collection. These include temperature, pH, DO, and electrical conductivity in some cases. Immediate on-site testing yields more reliable results than delayed analysis.

Step 8: Laboratory analysis
Samples that require detailed testing should be sent to an NABL-accredited laboratory. Laboratory testing is usually required for:

- BOD
- COD
- nutrients
- microbial contamination
- chemical pollutants
- detailed suspended or dissolved solids analysis

This step establishes the scientific basis for evaluating the severity of pollution and selecting appropriate treatment measures.

Step 9: Compare results across locations
Compare water quality values at inlet, outlet, mid-lake, and wetland outlet locations (where applicable). Differences between sampling points can help identify pollution hotspots and contamination sources in the catchment area.

Where historical data are available, compare the test results to identify trends and assess whether the lake's conditions are improving or deteriorating. The test results should also be assessed against CPCB water quality criteria, designated best-use classifications and other relevant environmental requirements. This comparison helps to establish whether the water quality is adequate for aquatic life, recreation, groundwater recharge or other designated purposes.

Step 10: Interpret the causes of poor water quality

Laboratory results should be compared with field observations, land-use patterns, drainage characteristics, inflow conditions and identified pollution sources. Understanding these linkages helps identify root causes of degradation and supports targeted interventions for lake restoration and management. For example, excessive turbidity may indicate soil degradation, construction activity, or sediment-laden runoff, while high BOD and COD levels often indicate sewage inflows, organic waste, or decaying vegetation.

The assessment results should be used to prioritize interventions, establish monitoring frequencies, identify key monitoring locations, and evaluate restoration actions. Water quality assessment is not only a technical activity but also an important planning and decision-support tool for sustainable lake management.

03 Planning And Design

3.1 | Define Restoration Objectives

Ecological restoration is the process of assisting the recovery of degraded, damaged, or destroyed ecosystems. Effective restoration requires clearly defined and measurable objectives that address both environmental and social dimensions.

Restoration goals typically focus on improving ecosystem health and ecosystem services for people and nature.

- **Water Quality:**

Pollutant Reduction
Reduce pollutant loads to improve water quality.

Nutrient Control
Limit nitrogen and phosphorus inputs to prevent eutrophication and algal blooms.

Natural Filtration
Improve wetlands and forests that naturally filter water.

- **Biodiversity:**

Habitat Restoration
Restore and improve habitats for native species.

Species Conservation
Protect habitats of threatened or endangered species.

Ecological Integrity
Restore natural ecosystem structure, composition, and processes.

- **Recreation:**

Cultural Services
Improve conditions for activities such as fishing, boating, camping, and walking.

Aesthetic Improvement
Improve the visual quality of the lake by reducing pollution and restoring vegetation.

Community Access
Promote sustainable livelihood opportunities and accessible natural spaces.

Tiruchirappalli Restores
Chettikulam Lake

Under the Swiss Agency for Development and Cooperation-funded CapaCITIES (Capacity Building Project on Low Carbon and Climate Resilient City Development in India) project, ICLEI South Asia supported the restoration of Chettikulam Lake in Tiruchirappalli, benefiting over 36,000 residents.

The city adopted an integrated catchment-based approach. The lake's hydrology was assessed in the context of flood mitigation within the Koraiyar River basin. A defunct irrigation channel between Kalinga Nagar, Ayyappan Nagar and the lake was restored and connected to the Koraiyar River to divert excess flows. Restoration measures included bund strengthening, improvement of water inlets and outlets, restoration of storage capacity, desiltation, and prevention of sewage pollution.

The project significantly reduced urban flooding in Kalinga Nagar and Ayyappan Nagar by improving drainage and increasing storage capacity. Covering a catchment area of 6.4 sq.km, the intervention revitalized a 2.5-acre lake, resulting in an additional storage capacity of 404.684 m3, improving flood resilience during heavy rainfall events.

Figure 14 : Chettikulam Lake, Tiruchirappalli

3.2 | Identifying Solutions

A. The Restorative Continuum: This model, standardized by the Society for Ecological Restoration (SER), views restoration as a continuum and helps identify which "stage" of repair a project belongs to, from simply reducing harm to achieving full recovery.

- **Initial Stage:** Reduce pressures such as pollution and invasive species.
- **Intermediate Stage:** Rehabilitate specific functions through measures like planting native vegetation for water filtration.
- **Final Stage:** Restore a self-sustaining ecosystem that mimics its historical or "best possible" natural state.

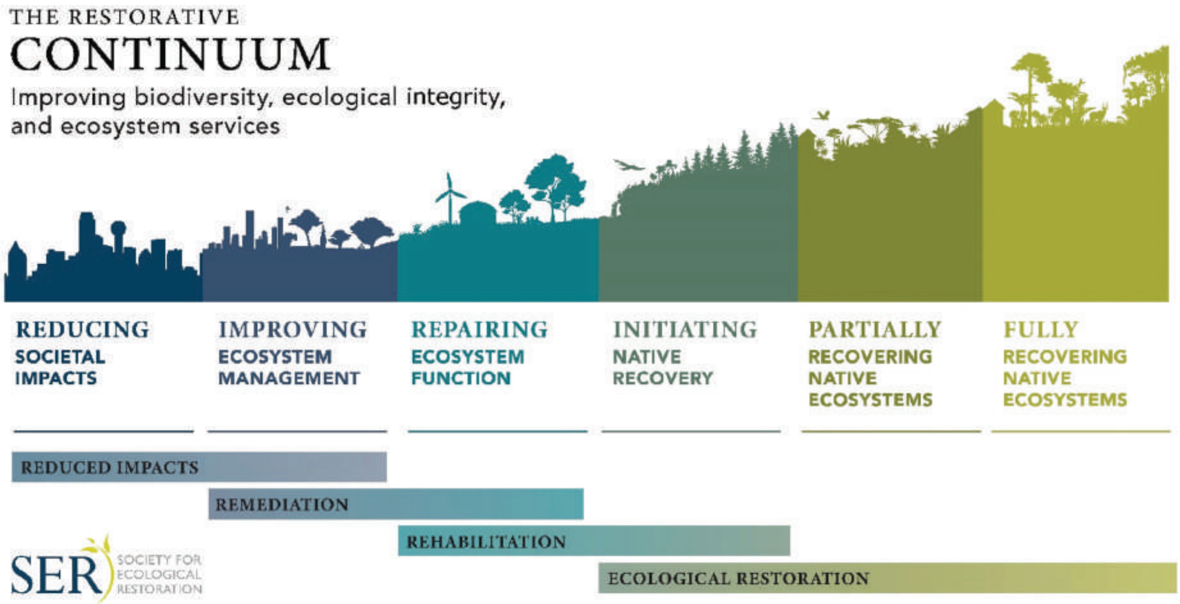


Figure 15 : The Restorative Continuum[5]

Solutions range from minimal intervention to intensive engineering, often categorized along a restorative continuum.

Hydrological and Morphological Interventions:

- **Flow Restoration:** Re-establish natural flow regimes and river channel structures.
- **Dam Removal and Modification:** Reconnect river segments to allow for species migration and sediment transport.

Vegetation-Based Actions:

- **Revegetation:** Establish native vegetation to stabilize soils and create wildlife corridors.
- **Vegetated Buffers:** Create vegetated buffers along water bodies to reduce pollutant and sediment runoff.

Nature-Based Solutions (NbS):

- **Constructed Wetlands:** Treat wastewater and enhance aeration and biodiversity.
- **Bioengineering:** Use vegetation with inorganic materials to stabilize banks and reduce erosion.

Management and Policy:

- **Passive Restoration:** Reduce or eliminate sources of degradation (e.g., stopping pollution) to enable natural recovery.
- **Agri-Environment Programs:** Implement environmentally friendly farming practices and crop diversification to reduce nutrient runoff.
- **Invasive Species Control:** Remove non-native species that threaten local biota.

The principles of these treatment interventions are elaborated further in Chapter 4.

5 Gann, G. D., McDonald, T., Walder, B., Aronson, J., Nelson, C. R., Jonson, J., Hallett, J. G., Eisenberg, C., Guariguata, M. R., Liu, J., Hua, F., Echeverría, C., Gonzales, E., Shaw, N., Decleer, K., & Dixon, K. W. 2019. International principles and standards for the practice of ecological restoration. Second edition. Restoration Ecology 27(S1): S1–S46. https://doi.org/10.1111/rec.13035

3.3 | Ecosystem Services and Objectives

Restoration solutions should be aligned with ecosystem services and project objectives.

Objective	Solutions	Restoration Benefit
Water Quality	**Constructed Wetlands, Riparian Buffers**	**Regulating:** Natural Filtration and flood control
Biodiversity	**Reforestation, removing migration barriers**	**Supporting:** Habitat Creation and species resilience
Recreation	**Ecological parks, boardwalks and cleaner lakes**	**Cultural:** Mental well-being and eco-tourism

Table 1: Ecosystem Services and Objectives

3.4 | Solution Identification Cycle

A Solution Identification Cycle typically includes:

- Identify the problem and its root causes (e.g., damming, runoff).
- Define restoration objectives.
- Evaluate alternative solutions (e.g., compare active planting and passive restoration [nature takes over] options).
- Finalize and implement the chosen technical solution.
- Monitor outcomes and adapt strategy over time.

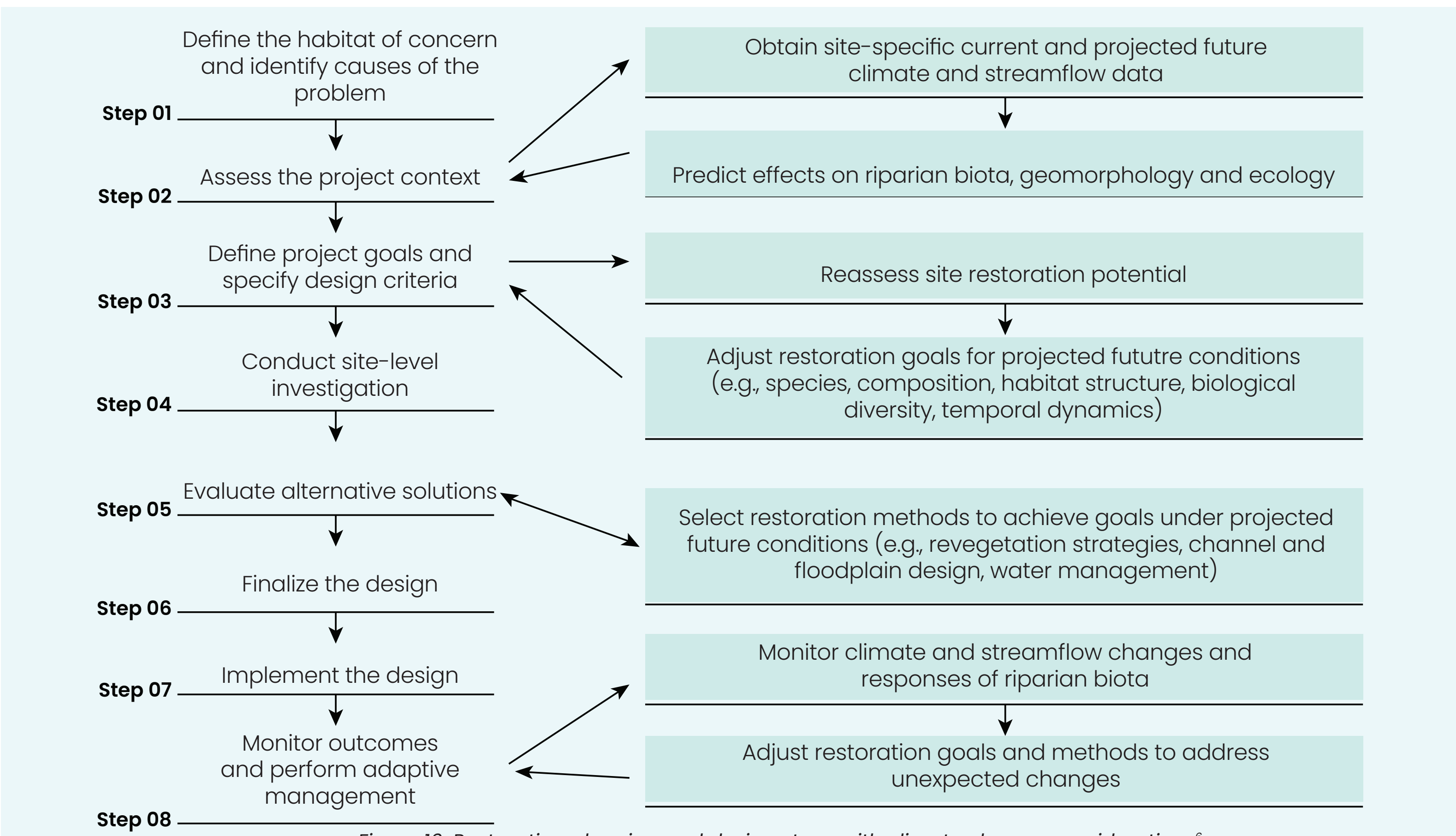


Figure 16: Restoration planning and design steps with climate change considerations[6]

6 G Perry, Laura & Reynolds, Lindsay & Beechie, Timothy & Collins, Mathias & Shafroth, Patrick. (2015). Incorporating climate change projections into riparian restoration planning and design: Riparian Restoration for a Changing Climate. Ecohydrology. 8. n/a-n/a. 10.1002/eco.1645.

3.5 | Structured Decision-Making (SDM) Framework

SDM is useful where multiple objectives and stakeholders are involved. The framework includes:

- **Define the Problem:** Establish scope and constraints (e.g., budget, funding/grant availability, and institutional capacity).
- **Set Objectives:** Use the **"WITI Test"** (Why Is That Important?) to separate fundamental goals (e.g., biodiversity) from "means" objectives (e.g., planting trees).
- Identify Alternatives: Develop a range of potential solutions, such as active vs. passive restoration.
- **Estimate Consequences:** Predict how each solution impacts project objectives using models like the **InVEST** (Integrated Valuation of Ecosystem Services and Tradeoffs) tool.
- **Evaluate Trade-offs:** Compare solutions to see which offers the best "return on investment" for both nature and the community.
- **Decide and Monitor:** Select the optimal solution and use a **Monitoring Plan** to track progress and adjust as needed.

3.6 | Specialized Technical Frameworks

For specific environments, specialized tools help pinpoint solutions:

- **River Habitat Survey (RHS):** A standardized field method that identifies "morphological quality" and specific problems like silting or channel modification.
- **Marxan:** uses algorithms to identify **Priority Restoration Areas (PRAs),** helping locate low-cost, high-benefit intervention zones.
- **Source-Flow-Sink Model:** identifies pollutant sources and where natural filtration (sink) is most needed.

3.7 | Implementation

Implementation translates restoration plans into on-ground interventions, integrating engineering solutions, ecological restoration, and institutional coordination. A well-structured process ensures that interventions are executed efficiently, address root causes of degradation, and lead to long-term sustainability of the lake ecosystem.

In the pre-implementation phase, undertake detailed site investigations such as topographic, hydrological, and bathymetric surveys (see Chapter 2) to help refine technical designs, estimate sediment volumes, understand inflow–outflow dynamics, and minimize technical gaps. Obtain the necessary statutory approvals, finalize schedules, and mobilize contractors or implementing agencies.

Controlling pollution at its source is a priority and the most crucial step. Measures may include diverting sewage and wastewater away from the lake, installing treatment systems such as STPs or decentralized wastewater treatment systems (DEWATS), and constructing silt traps and oil/grease separators at inlet points. This step is essential for long-term restoration success.

Following this, core interventions are undertaken, including desilting and dredging; strengthening embankments; constructing inlet and outlet structures for improved water circulation; planting native aquatic and riparian vegetation; development of littoral zones; removal of invasive species; and, in some cases, development of walkways and buffer zones in an environmentally sensitive manner.

Once the major interventions are completed, systems are evaluated and fine-tuned in the stabilization phase. This includes ensuring proper functioning of aeration systems, monitoring plant survival, and making necessary adjustments to hydrological or ecological components.

Successful implementation also requires a strong institutional framework, with clearly defined roles and responsibilities among Urban Local Bodies, technical experts, contractors, NGOs, and community stakeholders. Establishing operation and maintenance protocols, along with dedicated financial and human resources, is important for long-term sustainability.

Overall, implementation is a phased and coordinated process that bridges planning and long-term management. Its success depends on proper sequencing, integration of technical and ecological interventions, and continuous monitoring.

3.8 | Sustainability and Community Involvement

Lake restoration requires effective stakeholder engagement supported by proper identification of relevant stakeholders. Identifying stakeholders with responsibilities, interests, and decision-making authority is essential for developing feasible and sustainable restoration strategies. Stakeholder mapping frameworks can be used to identify relevant stakeholders, define engagement processes, and understand institutional gaps. Key steps include:

- Identifying stakeholders involved with the lake, drainage network, infrastructure, wastewater treatment, agriculture, etc. This exercise, ideally undertaken in the preliminary stages, should identify:
    - i. Who drives decisions;
    - ii. Who can influence or oppose decisions;
    - iii. Key community stakeholders or decision makers; and
    - iv. Stakeholders involved in past initiatives.

- Assessing stakeholder interests and influence in the decision-making and implementation process.

Stakeholder mapping reveals governance structures, relationships and interests. While participation levels may vary, all stakeholders need to be informed and engaged throughout the restoration process to avoid potential conflicts at critical stages.

POTENTIAL INFLUENCE			
HIGH	INVOLVE/ ENGAGE	INVOLVE/ ENGAGE	PARTNER
MEDIUM	INFORM	CONSULT	CONSULT
LOW	INFORM	INFORM	CONSULT
	LOW	MEDIUM	HIGH

POTENTIAL INTEREST

Figure 17 : Relation between potential influence and potential interest

Following restoration, efforts should focus on improving community ownership and stewardship of the lake, especially among local residents. Community stewardship can transform lakes into thriving socio-ecological hubs and support their long-term sustainability and conservation.

3.9 | Monitoring and Evaluation

Monitoring and evaluation provide a systematic and continuous assessment of the lake's ecological, hydrological, and socio-economic performance. Key monitoring areas include water quality, biodiversity, hydrology, infrastructure performance, and community engagement. Regular monitoring of parameters such as DO, nutrient levels, species diversity, water levels, and sedimentation patterns at defined intervals helps track lake health and identify early signs of degradation.

The monitoring process should not be ad hoc but embedded within the institutional structure of the ULB and supporting departments and agencies. Regular field measurements, laboratory analysis, remote sensing, and community-based observations together create a robust evidence base. This data-driven approach supports informed decision-making, such as adjusting aeration systems, modifying maintenance schedules, or strengthening pollution control measures.

Equally important is integrating maintenance monitoring and impact assessment to ensure that restoration gains are sustained over time. Routine activities such as invasive species removal, desilting, and infrastructure maintenance are tracked alongside broader outcomes, including improved water quality, enhanced biodiversity, reduced flooding, and groundwater recharge. By linking monitoring results with adaptive management, cities can refine interventions, optimize resource allocation, and sustain restoration gains. A suggested monitoring and evaluation framework is presented below, organized into seven categories:

A. Water Quality Monitoring

Table 2 : Water quality monitoring parameters

Parameter	Method	Frequency	Responsible Agency	Benchmark/ Target
Dissolved Oxygen (DO)	Field meter	Monthly	ULB / Lab	> 5 mg/L
Biochemical Oxygen Demand (BOD)	Lab testing	Monthly	PCB / Lab	< 3 mg/L
Chemical Oxygen Demand (COD)	Lab testing	Monthly	Lab	Decreasing trend
pH	Field testing	Monthly	ULB	6.5 – 8.5
Nutrients (Nitrogen, Phosphorus)	Lab testing	Quarterly	Lab	Reduced levels
Turbidity	Field testing	Monthly	ULB	Low/clear water

B. Biodiversity Monitoring

Table 3 : Biodiversity monitoring indicators

Indicator	Method	Frequency	Responsible Agency	Expected Outcome
Aquatic vegetation	Field survey	Quarterly	ULB / Experts	Increase in native species
Fish diversity	Sampling/ observation	Bi-annual	NGOs / Experts	Healthy population
Bird population	Visual survey	Seasonal	NGOs / Experts	Higher species richness
Macroinvertebrates	Sampling	Annual	Research Institutions	Presence of indicator species

C. Hydrology and Sediment Monitoring

Table 4: Hydrology and sediment monitoring parameters

Parameter	Method	Frequency	Responsible Agency	Expected Outcome
Water levels	Gauge monitoring	Monthly	ULB	Stable seasonal variation
Inflow / Outflow	Flow measurement	Seasonal	ULB/Engineers	Efficient drainage
Sediment accumulation	Bathymetric survey	Annual / 2–3 yrs.	Technical Agency	Controlled siltation
Water spread area	GIS / Remote sensing	Annual	GIS Team	No shrinkage

D. Infrastructure Performance Monitoring

Table 5: Infrastructure performance monitoring components

Component	Method	Frequency	Responsible Agency	Expected Outcome
Aerators	Physical inspection	Monthly	ULB/Contractor	Fully functional
Constructed wetlands	Visual + water testing	Quarterly	Experts	Effective treatment
Inlet / Outlet structures	Inspection	Monthly	ULB	No blockage
Stormwater drains	Field inspection	Pre-monsoon	ULB	Free flow

E. Maintenance Activities

Table 6: Maintenance activities

Activity	Method	Frequency	Responsible Agency	Target
Invasive species removal	Field inspection	Monthly/ Seasonal	ULB / Contractor	No invasive spread
Desilting requirement	Survey/ Inspection	Annual	ULB	Timely action
Plantation survival	Field survey	Quarterly	ULB / NGO	> 80% survival
Solid waste removal	Visual inspection	Weekly	ULB	No waste disposal in the lake

F. Socio-Economic Monitoring

Table 7: Socio-economic monitoring indicators

Indicator	Method	Frequency	Responsible Agency	Expected Outcome
Public usage	Observation / counts	Quarterly	ULB	Increased footfall
Community participation	Activity records	Quarterly	ULB / NGOs	Active engagement
User satisfaction	Surveys	Annual	ULB	Positive feedback

G. Impact Assessment Monitoring

Table 8: Impact assessment monitoring indicators

Indicator	Method	Frequency	Responsible Agency	Expected Outcome
Water quality improvement	Before–after comparison	Annual	ULB / Experts	Improved standards
Biodiversity index	Comparative study	Annual	NGOs/Experts	Increased diversity
Flood reduction	Incident tracking	Seasonal	ULB	Reduced waterlogging
Groundwater recharge	Monitoring wells	Annual	Groundwater Dept/ Board	Improved levels

04 Lake Restoration And Management Solutions

In many Indian cities, lakes and water bodies receive sewage and stormwater due to inadequate drainage systems. Sewage from unplanned settlements often drains into local water bodies, degrading water quality. Interception and diversion structures help separate wastewater from stormwater by diverting wastewater for treatment, while allowing stormwater to enter during rainfall events.

4.1 | Primary Treatment Methods

- **Screening chambers:** Coarse screens (typically with openings of 50mm and 20 mm) remove large and small debris and plastic waste, respectively, at the lake entry points. Regular maintenance is required to prevent clogging.
- **Grit chambers or silt traps:** Grit or silt traps remove coarse particles through gravitational separation. The chambers have a hydraulic retention time of 1-2 minutes to capture large particles before they enter the lake. The chamber could be a concrete structure or a small pond, depending on site conditions.
- **Interception and diversion structures:** Interception and diversion structures divert sewage flows while allowing stormwater inflows during rainfall events. These structures include weirs and screening systems to manage stormwater surges during heavy rainfall. As this method may still allow diluted wastewater containing trace pollutants to enter the lake, it is often combined with wetlands to improve water quality.

Figure 18: Primary treatment methods
Source: Down to Earth, 2025[7]

7 Parsad, J. (2025, March 17). Interception and diversion-based wastewater management can conserve Indian rivers and lakes. Down To Earth https://www.downtoearth.org.in/water/interception-and-diversion-based-wastewater-management-can-conserve-indian-rivers-and-lakes

4.2 | Secondary Treatment Methods

DEWATS for lake restoration

DEWATS provide localized wastewater treatment and opportunities for water reuse and can help sustain the lake's water balance and ecology, particularly during dry periods. DEWATS systems need to be designed to meet the discharge standards set by state or local pollution control boards. The quantity of treated wastewater entering the lake can be determined from water balance studies. Treated water can be used for tree plantations and other maintenance activities.

Commonly, DEWATS modules combine aerobic and anaerobic systems, such as septic tanks, baffled reactors, and planted filters. Increasingly, nature-based technologies are being adopted for their ecological benefits. Figure 19 illustrates the basic treatment sequence:

Primary Treatment: Sedimentation/ Floatation

↓

Secondary treatment: Baffled upstream reactors or anaerobic filters

↓

Tertiary aerobic treatment in sub-surface flow filters

↓

Tertiary aerobic treatment in polishing ponds

Figure 19: Sequence of treatment methods

4.3 | Ecological Restoration

Aeration (floating fountains, diffused or solar aerators): Aeration systems improve DO levels and help reduce eutrophication, foul odor, and algal blooms. They can be broadly categorized into mechanical or diffusion methods.

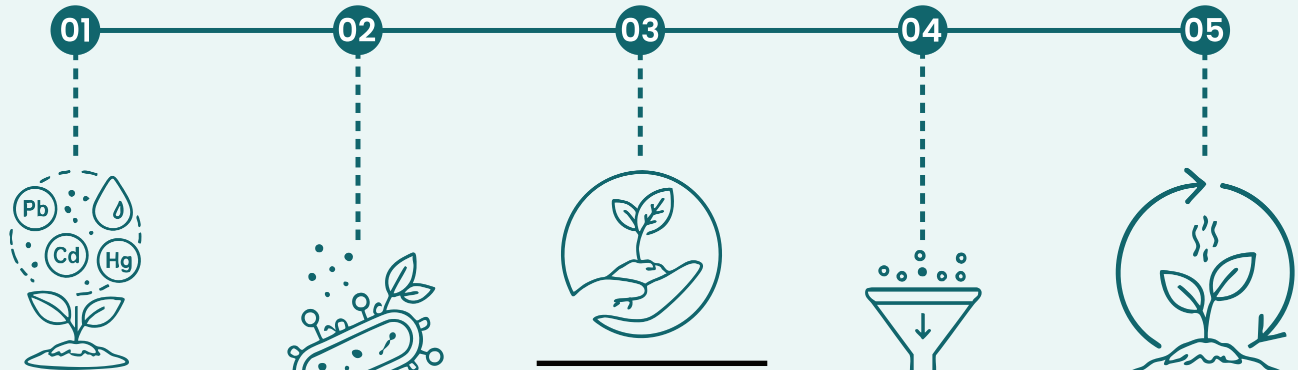
Mechanical aeration: Includes paddlewheel aerators, floating surface aerators, fountains or cascades. These systems enhance oxygen transfer by churning and agitating the water surface, increasing air–water contact.

Diffused aeration: Introduces air through submerged diffusers that generate fine and coarse bubbles. This form of aeration mixes thermal and chemical stratification in the water and promotes nutrient decomposition that causes algal and weed growth.

Phytoremediation (floating and emergent plants): Phytoremediation is an environmentally friendly technique that uses selected vascular plants to remove pollutants, especially heavy metals. Certain plant species can accumulate high levels of heavy metals within their tissues without major adverse effects. Phytoremediation refers to different plant-based mechanisms that remove contaminants from water, thereby reducing their impact on lake ecosystems.

Phytoremediation Techniques

Phytoremediation techniques harness the natural capabilities of plants to remediate environmental contaminants.



Phytoextraction involves using platns to absorb and accumulate pollutants, particularly heavy metals, from the soil.

Phytodegradation harnesses the enzymatic activity of plants and associated microbes to break down organic contaminats into simpler, less harmfull moleculess.

Phytostabilization leverages plants exceptional ability to absorb and immobilize pollutants, preventing their dispersion and offering and economical and ecologically benign approach to soil restoration

Rhizofiltration is a water remediation technique where plants, particularly those with extensive root systems, absorb and filter contaminants from polluted water

Phytovolatilization is a phytoremediation method in which plants absorb contaminants from soil or water, transform them into volatile substances, and release them into the atmosphere through stomatal processes

Figure 20: Phytoremediation techniques
Source: Sharma, Rawat, & Rautela, 2024[8]

Constructed Wetlands (surface/subsurface flow)

Constructed wetlands are shallow basins filled with substrate (such as sand or gravel) and planted with specific vegetation. Depending on their type and flow patterns, they can be broadly classified into surface or substrate systems.

- **Horizontal Flow (HF) wetland:** HF wetlands consist of an inlet and an outlet with a standpipe (for maintaining water level) along with layers of coarse and fine substrate, as shown in Figure 21. Wastewater flows through aerobic, anaerobic, and anoxic zones where organic pollutants are removed through a combination of filtration and biological processes. Wetland macrophytes form a network of aerobic zones that facilitate microbiological degradation, while selected plant species can enhance nutrient removal.

8 Sharma, M., Rawat, S., & Rautela, A. (n.d.). Phytoremediation in sustainable wastewater management: An eco-friendly review of current techniques and future prospects. School of Advanced Engineering, University of Petroleum and Energy Studies.

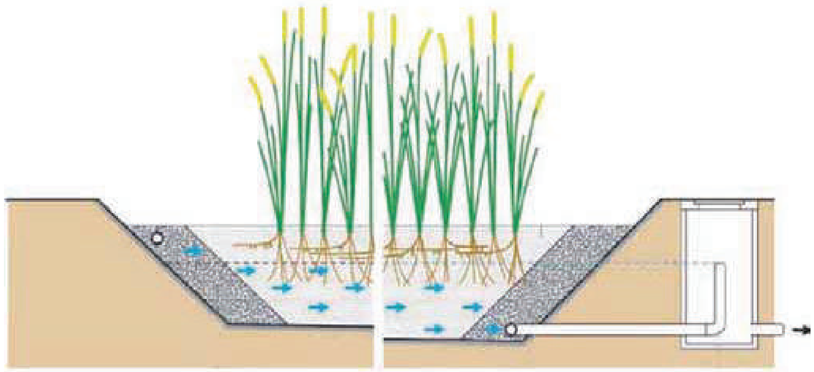


Figure 21: Horizontal wetland

- In Vertical Flow wetlands, wastewater is fed at the surface and percolates to the bottom. Intermittent inflow, supported by pumping mechanisms that allow each batch to drain completely before the next batch is pumped, maintains aerobic treatment conditions. VF systems are typically smaller in area than HF systems.

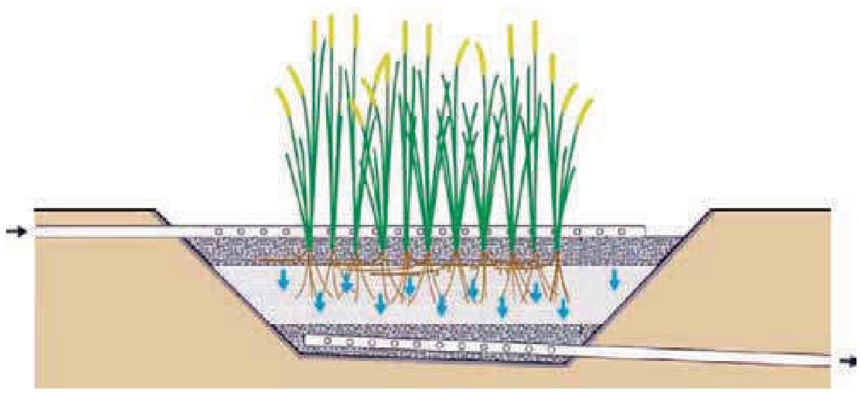


Figure 22: Vertical wetland

Biomanipulation (native fish introduction and invasive species control)
Biomanipulation involves managing aquatic food chains to effectively tackle invasive species such as algal blooms, and control eutrophication caused by overuse of fertilizers, excessive feeding, untreated sewage discharge, and industrial effluents. This technique is proposed as a low-cost, effective treatment mechanism for small lakes.

Major components include:

- **Fish management:** Introducing selected fish to prey on phytoplankton blooms. In some cases, predatory fish are introduced to reduce zooplanktivorous fish numbers, allowing zooplankton (algal-feeding) populations to increase and suppress algal blooms. The lake's food web is hence altered with human intervention.

- **Chemical control:** Additives such as aluminum sulfate or sodium aluminate are used to precipitate phosphorus, reducing phytoplankton growth.

4.4 | Desiltation and Dredging

Bathymetric Survey (depth mapping, sediment volume)
Prolonged sedimentation reduces lake depth and storage capacity. Bathymetric surveys are hydrographic surveys that help map the depth and underwater topography of a waterbody, supporting dredging, flood management, lake restoration, navigation safety, and other development activities.

The process involves using echo sounders, GPS systems, multi-beam sonar, LiDAR, and unmanned survey vessels for an accurate and comprehensive assessment. The methods may include single-beam or multi-beam sonar surveys, depending on the scale and application of the mapping.

Dredging Process (mechanical/hydraulic, sediment disposal, aquatic life protection)
Dredging refers to freshwater lake sediment removal to:

- increase storage capacity
- remove nutrient-rich or toxic sediments
- remove rooted macrophytes from the lake.
- improve groundwater recharge by removing sludge

Before undertaking dredging, the following should be assessed:

- Sources of sedimentation and degradation
- Sediment characteristics and depth
- Associated environmental impacts
- Sediment removal methods
- Sediment disposal area

The sediments removed from a lake should be stored, dried, and transported to an appropriate disposal facility. Depending on sediment characteristics, it may be used as manure or for other purposes.

4.5 | Shoreline and Habitat Restoration

Healthy shorelines provide habitat, filter runoff before it enters the lake, and help maintain the lake's health. Shoreline degradation results from erosion, loss of natural habitat, encroachment and biodiversity loss. To preserve this natural habitat, 'soft' interventions are recommended for shoreline stabilization, wherever feasible.

- Plant deep-rooted native species to stabilize banks and control erosion.
- Maintain riparian vegetation to provide necessary shade.
- Use gentle slopes and natural materials such as stone blocks, rip-rap, and vegetation mats.
- Maintain vegetated buffer zones of at least 50 feet to intercept sediments and nutrients, helping prevent eutrophication.
- Apply green-grey measures, such as vegetated gabions or riprap, or hard measures such as rock mattresses

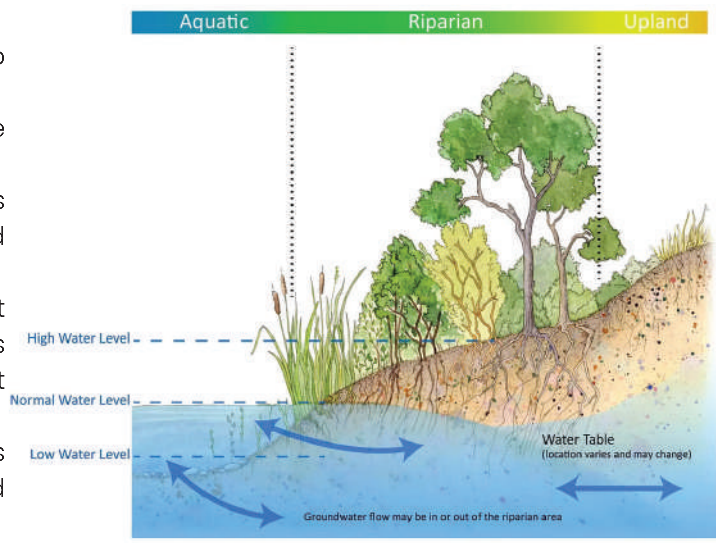


Figure 23: Transition from upland to riparian to aquatic zones
Source: https://www.riparianresourcesab.info/riparian-101

or geotextile, where erosion risks and structural damage are high.
- Use artificial floating wetlands to increase filtration and biodiversity along lake edges.

4.6 | Stormwater Management

Stormwater runoff can carry oils, hydrocarbons, fecal load, and heavy metals into lakes. Effective stormwater management is therefore necessary to prevent clogging of stormwater drains and lake inlets, and to reduce pollutant loads entering the lake.

Water intake and outlet structures
These structures help regulate and divert water flow into and out of lakes. Intake structures may include screens or pre-screening chambers to remove grit and floating waste. The levels of the structures need to be carefully determined to ensure proper drainage and operation. Intake structures need to operate effectively in all-weather conditions. The important levels to consider are:

- Maximum lake storage level
- Relative levels of inlets and outlets: Inlet levels should be fixed appropriately to avoid upstream backflow during high-flow events. Weirs or sluice gates can be installed to regulate inflows. Similarly, outlets may be equipped with weirs or sluice gates to control lake water levels. Flow rates can be determined using the depth of flow over the weir or sluice gate and the flow width.

Sediment basins:
Sediment basins slow water velocity, enabling the settling of coarse and medium-sized particles, limiting their deposition in the lake. They also absorb high flows, protecting lake systems from scouring. They can be constructed within lake boundaries or before the lake inlet.
Baffle walls are used within sediment basins to lengthen flow paths and also reduce short-circuiting and dead storage.

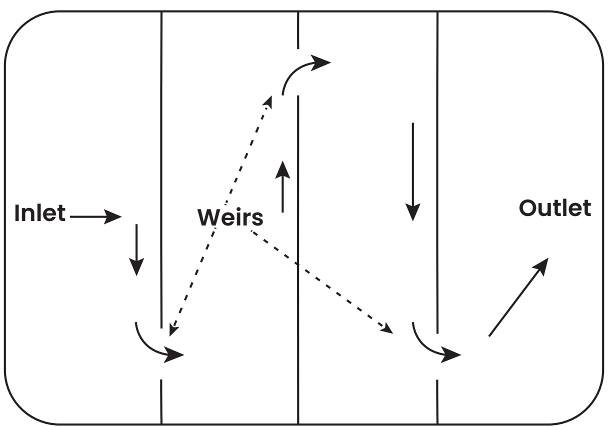


Figure 24: Baffle walls to slow the water velocity

Rain gardens:
Rain gardens are shallow landscape depressions that allow stormwater to bio-retain and seep into the ground. Rain gardens are designed with a shallow depth of 10-30cm, with soil engineered to have high infiltration capacity. They support groundwater recharge, mitigate heat effects, and reduce the risks of waterlogging and pollution. Rain gardens help reduce the nutrient load entering load by intercepting stormwater runoff at the source, thereby reducing the possibility of eutrophication.

Sustainable Urban Lake Restoration
A Practitioner's Guidebook

2026

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