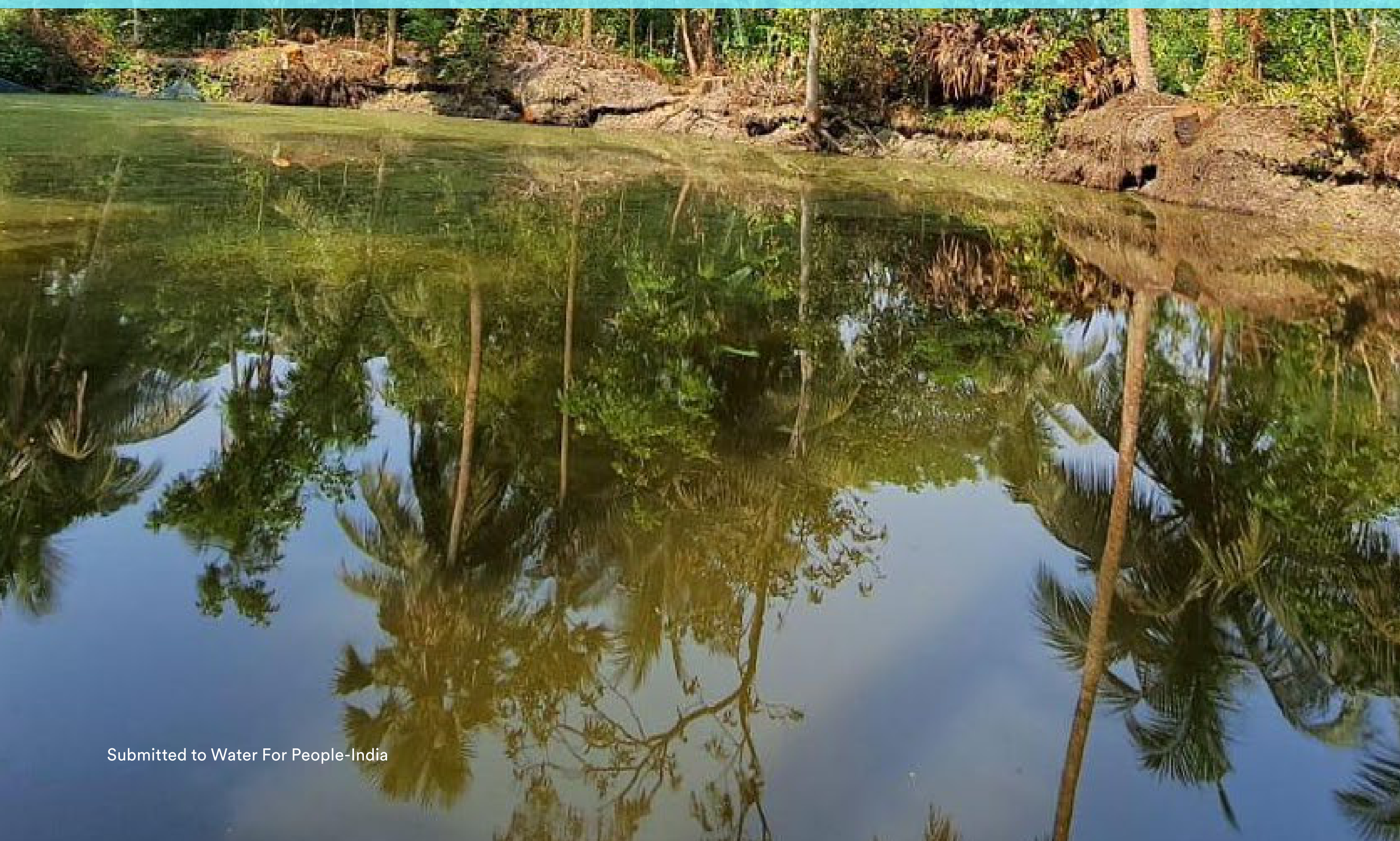
30 September 2024

TECHNICAL MANUAL ON REJUVENATION OF WATER BODIES

Developed By Walter P Moore



Submitted to Water For People-India

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List of Abbreviations

S. No	Acronym	Full form
1	BASINS	Better Assessment Science Integrating point and Nonpoint Sources
2	BOQ	Bill of Quantities
3	CETP	Captive Effluent Treatment Plant
4	CGWB	Central Ground Water Board
5	CPCB	Central Pollution Control Board
6	CSV	Comma-Separated Values
7	DEM	Digital Elevation Model
8	DOS	Department of Space
9	EC	Electric Conductivity
10	FTW	Floating Treatment Wetlands
11	GEDSI	Gender Equality, Disability, and Social Inclusion
12	GIS	Geographic Information System
13	GOI	Government of India
14	GPS	Global Positioning System
15	HEW	Horticulture Extension Workers
16	IDF	Intensity Duration Frequency
17	IMD	India Meteorological Department
18	ISRO	Indian Space Research Organisation
19	IWMP	Integrated Watershed Management Program
20	KML	Keyhole Markup Language
21	LiDAR	Light Detection and Ranging
22	MLA	Member of the Legislative Assembly
23	MOHUA	Ministry of Urban Development
24	MPLADS	Member of Parliament Local Area Development Scheme
25	NGO	Non-Governmental Organization

S. No	Acronym	Full form
26	NRSC	National Remote Sensing Centre
27	PCSWMM	Personnel Computer Storm Water Management Model
28	PCC	Pollution Control Committee
29	PDF	Portable Document Format
30	SCEW	Soil Conservation Extension Worker
31	SPCB	State Pollution Control Board
32	STPs	Sewage Treatment Plants
33	SWAT	Soil & Water Assessment Tool
34	SWC	Soil Water Conservation Engineering
35	TIN	Triangulated Irregular Network
36	US EPA	United States Environmental Protection Agency
37	UWTP	Urban Wastewater Treatment Plant
38	UWTP	Used Water Treatment Plant
39	VAW	Village Agriculture Workers
40	WRIS	Water Resources Information System

1.0 Executive Summary

The objective of the technical manual is to prepare a document meant to help the practitioners, field engineers, front-line workers, local government officials, service providers, etc. to plan and implement the rejuvenation and construction of waterbodies in the different typologies and geographies in a scientific way. The manual includes relevant government guidelines, norms, regulations, existing government programs, design criteria, site selection criteria, and guidelines about drawings and estimation, operation and maintenance, water quality, etc.

Surface waterbodies like lakes, ponds, reservoirs, tanks, and rivers were treated as community resources or assets for centuries. In urban areas also such waterbodies played an important role as a source of drinking water, absorption of flood water, and a conduit for groundwater recharge. They were being nurtured, protected, conserved, and managed by the active participation of the local community without any code of conduct or rule. In turn, these waterbodies have been catering to the local human and livestock populations. With the introduction of public water supply and groundwater development through tube wells and hand pumps in modern times, coupled with urbanization and industrialization-induced pollution, a tectonic shift in the attitude of the people towards these waterbodies have been witnessed resulting in lesser conservation of these community resources. Mushrooming urban, industrial, and infrastructure development has further changed the status of these waterbodies from community resources to mere dumping ground or sinks for solid wastes, construction debris, domestic sewage, industrial effluents, religious offerings, etc. resulting in severe degradation in the quality of such resources.

Tanks and waterbodies form an important surface water storage system. The existing ponds and tanks in the area have been silted over the years, making the waterbodies less functional for recharging. Hence, there is an urgent need for the waterbodies to be de-silted, the inlet and outlet to be cleaned from obstruction and the bunds to be strengthened. Apart from available rainwater and reuse of treated wastewater, waterbodies (lakes, ponds) especially in rural areas have enormous value in terms of resource provision (for drinking or irrigation), regulating services (climate mediation, flood, and drought management), and cultural services (religious, historic value). However, these lakes and ponds are extremely sensitive to environmental stress caused by anthropogenic activities in the basin or catchment, which reduces the natural capacity of the waterbody to restore itself and results in its deterioration. Hence, implementing an effective waterbody restoration plan and technique is the need of the hour. This manual intends to contribute to this cause by formulating a pond rejuvenation process and methodology that can be used by all possible stakeholders for a project.

The objective/scope of the manual is listed below:

- Review and documentation of various state and centrally sponsored water conservation schemes and convergence opportunities in force at the time of issue of this report.
- Review and documentation of existing guidelines for farm pond construction/rejuvenation.
- Develop a strategy /or framework for a standard operating procedure for the farm pond/waterbodies rejuvenation based on existing government guidelines.
- To include various phases for waterbody rejuvenation framework viz. Recognition phase, Restoration phase, Protection phase, Improvement phase, and Sustenance phase.
- The manual will provide guidelines for understanding the current status of the waterbodies, their suitable use, and their need for management and conservation so that they may serve as a good resource for future, potential strategies for long-term water management.

In this manual, the term "WATERBODY" refers specifically to POND / SMALL LAKE.

1.1 Waterbody Construction/Rejuvenation Flowcharts

The section provides the flowcharts for the Construction and/ or Rejuvenation of Waterbody Manual. The flowchart is designed to streamline the process of constructing or rejuvenating the waterbodies, such as ponds, lakes, etc. This user-friendly flowchart presents a series of step-by-step procedures, guiding users through the various stages of pond construction or rejuvenation. From assessing current site conditions to the documentation of the project, each step is given with the respective section of the manual, allowing users to navigate the process with ease. Figure 1.1 and Figure 1.2 represent the waterbody construction/rejuvenation flowcharts.

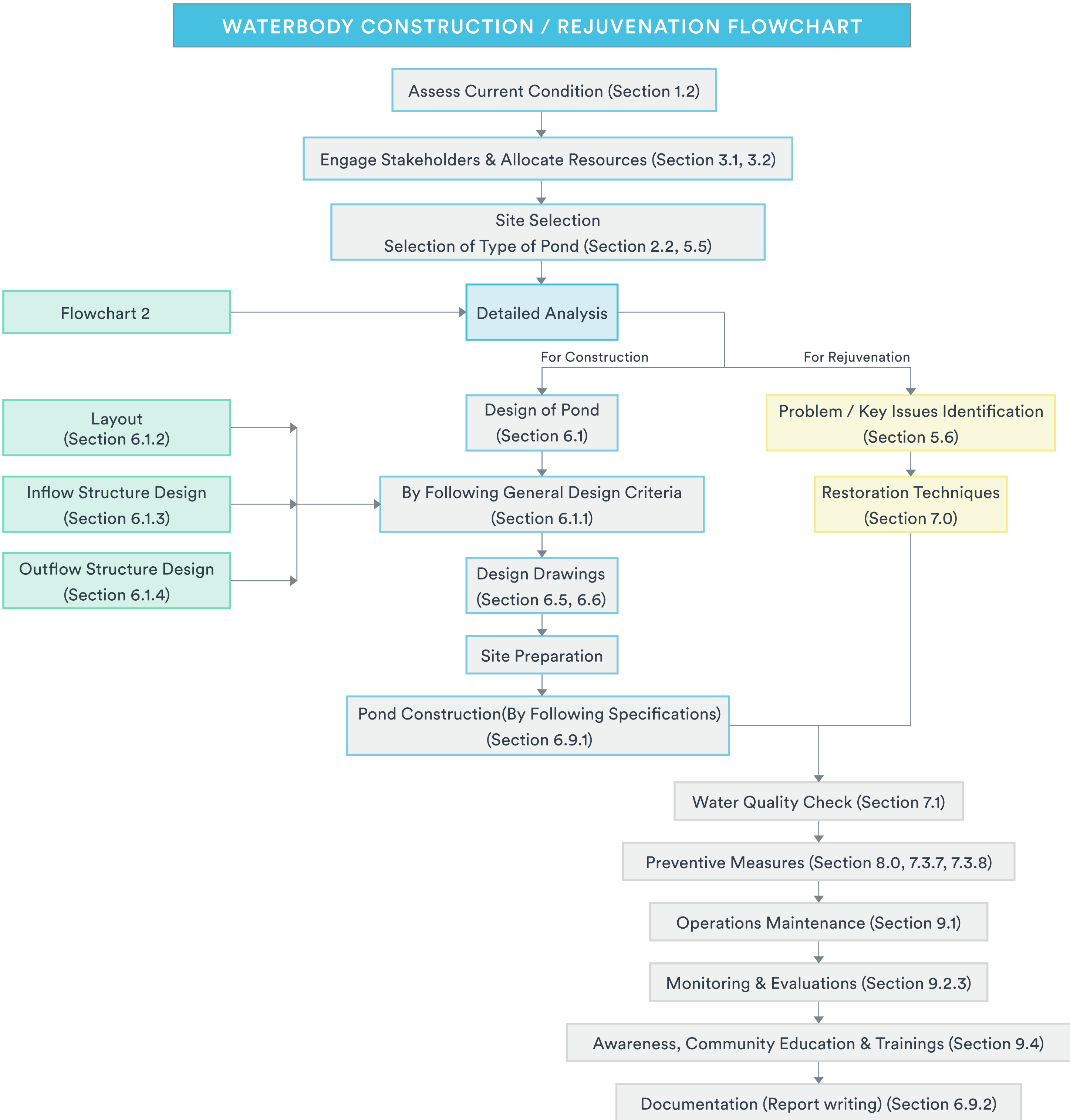

Figure 1.1 Waterbody Construction/Rejuvenation Flowchart 1

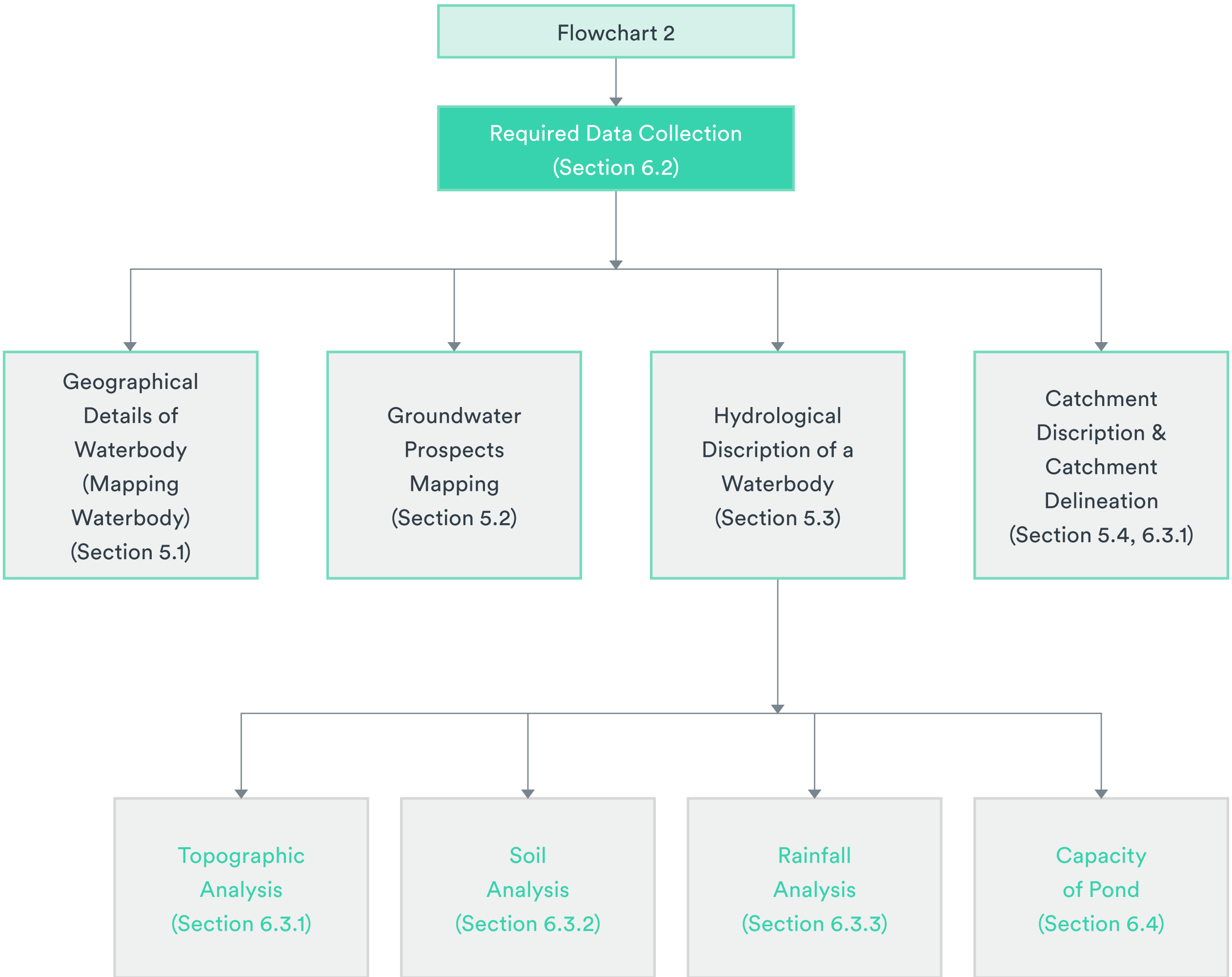

Figure 1.2 Waterbody Construction/Rejuvenation Flowchart 2

Checklist

1.2

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The waterbody checklist can serve as the foundational step for initiating a project aimed at waterbody construction or rejuvenation. It provides a cumulative overview of the current condition of the waterbody, identifying issues such as pollution sources, silting, weeding, etc. This assessment is essential for understanding the waterbody's surroundings and determining the feasibility of on-site interventions collectively. By adopting a scientific approach, the checklist can evaluate both the present status and the historical and future significance of the waterbody to the local community and environment. It can guide project technical teams in designing and implementing appropriate interventions aligned with community needs and environmental considerations, thereby laying the groundwork for successful waterbody construction or rejuvenation efforts. Table 1.1 shows the blank sample of the waterbody checklist [1]. This checklist will provide necessary input information to understand the stage of the waterbody construction or rejuvenation framework. After identification of the stage, the flowchart will further guide on procedures to be followed.

Table 1.1 Waterbody Checklist [1]

Location and surroundings:	
Name of waterbody	
Location	Village, District, State, etc.
Latitude and Longitude (Lat-Long)	Degree Minutes Seconds or Decimals
Region	
Ownership/land of waterbody	
Current status of the waterbody and current season	Dry, monsoon, etc.
Type of waterbody	Natural or Man-made/constructed
Area of pavement around the waterbody (if any)	
Urban/ Rural, surrounding land use	Urban, Agricultural, Forested, etc. (Accordingly C value should be chosen Table 6.7, Equation 6.11)
Any waterbody or stream passing nearby	If Yes, Which, Where
Use of waterbody	Agriculture, fisheries, drinking, groundwater recharge, for animals, flood mitigation, tourism, any other, etc. (one or more)
Total population using the waterbody	Example: Village population
Geo-tagged pictures of the waterbody (covering Lat-Long details)	
Physical characteristics: (For the construction of the new waterbody – Layout/drawing with specifications)	
Size of the waterbody (surface area)	acre
Depth of the waterbody	meter
Shape of the waterbody	Rectangular, Oval, Irregular
Substrate type / Soil type	Sand, Mud, Rocks, etc. Clay, Silty, Loam, etc.

Shoreline vegetation (if any)	Grasses, Shrubs, Trees
Catchment area of the waterbody	Hilly, Flat, etc.
Water sources	Rainfall, Streams, Rivers, Runoff, Drains, Treated Wastewater, etc.
Inflow details	Weir, pipe inflows, etc. (size, shape, existing condition)
Outflow details	Weir, pipe outfalls, etc. (size, shape, existing condition)
Does the waterbody dry out completely?	If yes, months, years
Groundwater level	meter
Aquifer mapping	Required/ not required based on the purpose of waterbody rejuvenation
Problem identification:	
Proximity to sources of pollution	Roads, industrial sites, agricultural fields
Sedimentation	Reduction in area/depth/capacity
Algal Bloom	
Weeding	
Encroachments or blockages	
Discharges or waste disposal or washing activity	Type of waste domestic/industrial, etc.
Eutrophication	
Uncontrolled inflow/outflow	Damaged inlet/ outlet structures
Emerging contaminants and heavy metals	Sources
Water quality parameters: For test sample location, refer to Table 9.3, for test procedures, refer IS 10500. Refer to Table 7.1 for water quality criteria based on the designated best use of the waterbody.	
Temperature	
pH level	
Dissolved oxygen	
Turbidity (clarity)	
Conductivity (salinity)	
Nutrient levels (nitrogen, phosphorus)	

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Presence of pollutants (heavy metals, pesticides)	
Rejuvenation required: (Yes/No)	
Desiltation/Deweeding	Manual/ Mechanical
Water quality improvement activities	
Chemical treatment	
Biological treatment	
Removal of encroachments and blockages	
Implementation of flood control measures	
Addressing pollution sources	
Data collected for detailed analysis/ construction/ rejuvenation of waterbody: (Yes/No)	
Meteorological data (Rainfall and Evaporation)	
Hydrogeological data (Aquifer maps, Soil maps)	
Topography (DEM)	
Land use and land cover	
Design requirements/ criteria	
Catchment analysis **(Section 6.3.1)**	Catchment or Drainage Area (hectares)
Soil analysis **(Section 6.3.2)**	Side slope (based on soil type)
Rainfall analysis, IDF curves **(Section 6.3.3)**	
Design frequency **(Section 6.1.1)**	1 in 25 year
Runoff coefficient **(Table 6.7, Equation 6.11)**	Based on the type of catchment area
Time of concentration **(Section 6.3.4, Equation 6.12)**	minutes
Design flow/catchment runoff **(Section 6.3.4, Equation 6.10)**	m^3/hr or m^3/sec
Capacity of the pond (if required)	

2.0 Introduction

Water on Earth is found within the hydrosphere, spanning approximately 15 kilometers upwards into the atmosphere and around 1 kilometer downwards into the lithosphere, which is the Earth's crust. This water moves through a complex network of pathways known as the hydrologic cycle, which is the main focus of hydrology. This cycle is perpetual, lacking a distinct beginning or end, with its various processes occurring continuously [2].

Outlined in Figure 2.1, the hydrologic cycle involves water evaporating from both the oceans and land surfaces, joining the atmosphere as water vapor. This vapor is then transported through the atmosphere, where it may condense and fall as precipitation onto land or back into the oceans. Upon reaching the surface, precipitation can take several paths: it may be intercepted by vegetation, flow overland, infiltrate into the ground, travel through the soil as subsurface flow, and eventually discharge into streams as surface runoff. Much of the intercepted water and surface runoff returns to the atmosphere through evaporation. Water that infiltrates the ground may percolate deeper, replenishing groundwater, and may later resurface through springs or seep into streams, contributing to surface runoff. Ultimately, this water either flows back into the sea or evaporates into the atmosphere, thus perpetuating the hydrologic cycle [2].

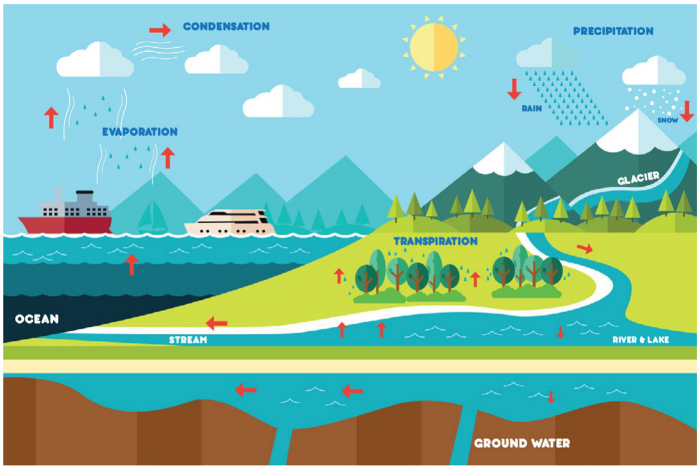

Figure 2.1 The Global Hydrologic Cycle

While the overall amount of water in the global hydrologic cycle remains relatively stable, its distribution undergoes constant fluctuations across continents, regions, and local drainage basins. The hydrology of a particular area is shaped by its climatic conditions and various physical elements like terrain, geology, and plant life. Moreover, as societies advance, human interventions increasingly impact the natural water ecosystem, disrupting the delicate balance of the hydrologic cycle and introducing novel processes and occurrences [2].

India has had an abundant supply of water resources. However, as a result of population increase, urbanization, and uncontrolled growth, India is progressively moving from being a country with plenty of water to one with scarcity [3]. The country has 18 percent of the world's population, but possesses merely 4% of the world's water resources, rendering it one of the most water-stressed nations globally [4]. As a consequence, waterbody management has become extremely important. The availability of water resources is currently our nation's biggest problem. The availability of water resources is a significant problem and a serious challenge that our country is currently confronting [3]. Therefore, it is essential to take steps to restore these waterbodies and improve their health. Restoring waterbodies can also help mitigate climate change by reducing the risk of flooding and erosion, increasing water storage capacity, and promoting vegetation growth. The restoration is a critical step in ensuring the sustainability and resilience of our environment [5].

Pond rejuvenation is a process aimed at restoring the ecological health, functionality, and aesthetic appeal of a pond that has degraded over time due to various factors such as sedimentation, nutrient runoff, invasive species, poor water quality, or pollution. This process typically involves a combination of management practices such as dredging to remove accumulated sediment, controlling nutrient inputs through vegetative buffers or constructed wetlands to improve water quality, and implementing measures to enhance habitat diversity and biodiversity, such as adding submerged aquatic vegetation or creating shallow areas for wildlife. Pond rejuvenation efforts also often include community engagement and education to raise awareness about the importance of preserving and managing ponds sustainably. By rejuvenating ponds, not only can their ecological balance and biodiversity be restored, but they can also provide valuable recreational, aesthetic, and ecosystem services to surrounding communities.

This manual provides guidelines aimed at enhancing the sustainability and productivity of crucial waterbodies, such as ponds, lakes, etc. It lays down procedures for waterbody management, ecological considerations, and strategies for preserving and restoring waterbodies to optimize their role in agricultural and environmental ecosystems. It provides steps from an initial assessment of pond health to the implementation of sustainable operation and maintenance practices. Each chapter unfolds processes for waterbody management. It covers identification criteria, assessment methodologies, and practical steps for rejuvenation measures, emphasizing community engagement and integration into broader water management frameworks for long-term sustainability.

2.1 Different Types of Waterbodies

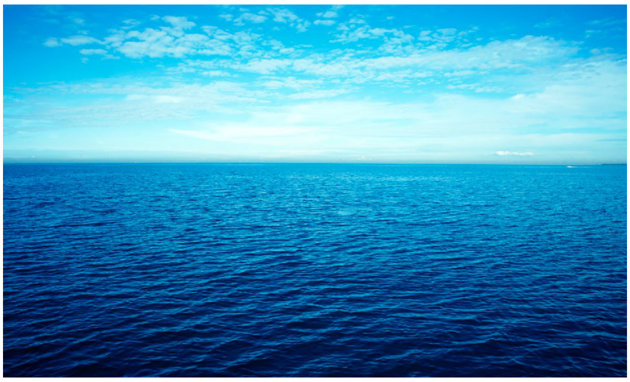

Figure 2.2 Ocean

Ocean:

Oceans are the most extensive and linked bodies of water on Earth, encompassing approximately 71% of the planet's surface. Oceanic bodies serve as the ultimate destination for the entirety of marine saltwater that exists on our planet. Ocean physical properties, including temperature, salinity, and density, exhibit variations based on depth and location. The oceanic water cycle encompasses the processes of evaporation, condensation, and precipitation, which play a substantial role in shaping worldwide weather patterns. Oceans play a critical role in regulating climate and supporting diverse marine life (Figure 2.2).

Figure 2.3 Sea

Sea:

The sea is a sub-section of the ocean (Figure 2.3). These are vast, interconnected bodies of saltwater that cover large expanses of the earth's surface, connecting to oceans but partially enclosed by land. Hydrologically, seas exhibit similar dynamics to oceans. Salinity levels, temperature variations, and nutrient distribution influence the unique characteristics of different seas. Human activities, including shipping, fishing, and resource extraction, impact the hydrological and ecological balance of these expansive marine environments.

Figure 2.4 Ganga River Kolkata

River:

Rivers are dynamic waterbodies that play a crucial role in the hydrological cycle. Originating from various sources (such as springs, lakes, or melting glaciers), rivers flow downhill, transporting water, sediments, and nutrients across landscapes. Their hydrological characteristics include discharge measured in cubic meters per second, which reflects the volume of water passing a specific point. Additionally, rivers exhibit seasonal variations influenced by precipitation, snowmelt, and human activities. The interconnectedness of rivers with their watersheds emphasizes their significance in maintaining ecosystems and providing essential resources for communities. Figure 2.4 depicts the Ganga River, which is situated in Kolkata.

Figure 2.5 Pawna Lake situated in Maharashtra, India

Lake:

Lakes are inland waterbodies that contain either freshwater or saltwater. These are static in nature, non-moving exhibits varying in both size and depth. Lakes are formed by various processes, ranging from glacial erosion and volcanic eruption to river damming (obstructions/blockages; natural or anthropogenic). These are usually fed by a combination of rivers, streams, and precipitation. The residence time of water in lakes, influenced by their size and exchange rates (rates at which water enters and exits the waterbodies), impacts water quality. Lakes act as vital reservoirs, storing water for various uses, and their ecosystems are sensitive to changes in nutrient levels and human interventions. Figure 2.5 depicts the Pawna Lake situated in Maharashtra, India.

Figure 2.6 Sardar Sarovar Dam, Narmada district, Gujarat, India

Reservoir:

Reservoirs are artificial waterbodies created by damming rivers to store and manage water for various purposes such as irrigation, drinking water supply, and hydropower generation. Hydrologically, reservoirs experience fluctuations in water levels based on inflows, outflows, and human management practices. Seasonal variations influenced by precipitation and snowmelt can impact reservoir storage capacity. The creation of reservoirs alters natural river flow patterns and sediment transport, influencing downstream ecosystems. Balancing water management needs with environmental considerations is crucial for sustaining the hydrological health of reservoirs and the ecosystems they affect. Figure 2.6 shows Sardar Sarovar Dam, Narmada district, Gujarat, India.

Figure 2.7 Lagoon at Tilaya Dam Reservoir in Poraia, Jharkhand India

Lagoon:

Lagoons are coastal or inland bodies of water characterized by their shallow depths, typically separated from larger bodies of water by barrier islands, sandbars, or coral reefs. These dynamic ecosystems exhibit a unique blend of marine and freshwater influences, supporting a diverse array of flora and fauna. Lagoons play vital roles in coastal protection, acting as buffers against storm surges and erosion, while also serving as important habitats for various species, including fish, birds, and aquatic plants. Additionally, lagoons often hold cultural and recreational significance for surrounding communities, providing opportunities for fishing, boating, and ecotourism. However, lagoons face numerous threats such as pollution (including but not limited to industrial discharges, agricultural runoff, urban wastewater, and littering., etc), habitat degradation, and climate change impacts, necessitating careful management and conservation efforts to ensure their ecological integrity and continued provision of ecosystem services. Figure 2.7 depicts the Lagoon at Tilaya Dam Reservoir in Poraia, Jharkhand India.

Figure 2.8 The Estuary in the Middle of the City, Chennai

Estuary:

Estuaries are dynamic and biodiverse ecosystems where freshwater rivers meet and mix with salty ocean water, creating a unique blend of habitats and ecological processes. These transitional zones are characterized by fluctuating salinity levels, influenced by tidal fluctuations and freshwater inputs, resulting in diverse habitats ranging from marshes and mudflats to tidal channels and open water. Estuaries serve as vital nurseries for numerous marine species, providing abundant food and shelter, while also supporting migratory birds and other wildlife. Estuaries are increasingly threatened by water pollution, habitat destruction, and overexploitation. Figure 2.8 shows the estuary in the middle of the Chennai city.

Figure 2.9 Pond Located in Chikhaldara, Amravati, Maharashtra

Pond:

Ponds are small, shallow waterbodies characterized by their still or slow-moving water, often man-made or naturally occurring. Hydrologically, ponds are influenced by factors such as precipitation, runoff, and local topography. They often have a relatively simple water balance, with inputs mainly from direct rainfall and occasional inflows from small streams. Ponds play a vital role in local ecosystems, supporting a variety of plants and wildlife. Their water levels can be sensitive to climate fluctuations, making them valuable indicators of environmental changes in their immediate surroundings. Figure 2.9 depicts A Pond Located in Chikhaldara, Amravati, Maharashtra.

In this manual, the term "WATERBODY" refers specifically to POND / SMALL LAKE.
Ponds are further categorized according to their intended use in the next section.

2.2 Types of Ponds

TYPES OF PONDS

COMMUNITY POND

Figure 2.11 Community Pond, India

SUNKEN POND

Figure 2.12 Sunken Pond

FISH POND

Figure 2.13 Fish Pond

FARM POND

Figure 2.14 Farm Pond

Figure 2.10 Flow Chart for Types of Ponds

2.2.1 COMMUNITY POND

Community ponds are vital communal resources that serve multiple purposes within neighborhoods and towns. These artificial bodies of water are typically created and maintained by local authorities or community organizations for various reasons, including recreational activities such as fishing and boating, ecological conservation efforts, stormwater management, and aesthetic enhancement of public spaces. Community ponds often foster a sense of belonging and social cohesion by providing gathering spots for residents to engage in leisure activities, socialize, and connect with nature. Additionally, they can contribute to the overall well-being of the surrounding ecosystem by supporting diverse aquatic life and mitigating the effects of urbanization on water quality and biodiversity. Overall, community ponds play a crucial role in enhancing the quality of life and fostering a sense of community among residents. Figure 2.11 depicts the Community Pond.

2.2.2 SUNKEN POND

Sunken ponds, also known as sunken gardens or sunken water features (Figure 2.12), are unique landscape elements that add both aesthetic beauty and functional benefits to outdoor spaces. These ponds are designed to be partially or fully recessed into the ground, creating a visually striking focal point while seamlessly blending into the surrounding environment. Sunken ponds often feature lush vegetation, rock formations, and cascading waterfalls, providing a tranquil oasis for relaxation and contemplation. Beyond their ornamental value, sunken ponds serve practical purposes such as stormwater management, groundwater recharge, and habitat creation for aquatic and semi-aquatic species. By integrating seamlessly into the landscape and offering both visual appeal and ecological benefits, sunken ponds contribute to the overall sustainability and beauty of outdoor environments.

2.2.3 FISH POND

Fish ponds, whether natural or man-made, serve as invaluable aquatic ecosystems that support the breeding, rearing, and harvesting of various fish species. These ponds are carefully designed and managed to provide optimal conditions for fish growth and reproduction. Fish ponds (Figure 2.13) are not only utilized for recreational fishing but also play a significant role in aquaculture, providing a sustainable source of protein for human consumption. Additionally, they contribute to ecosystem health by promoting biodiversity and serving as habitat for aquatic plants and animals. With proper management practices, fish ponds can be a lucrative venture for farmers and a valuable asset for communities seeking to enhance food security and economic development while conserving natural resources.

2.2.4 FARM POND

Farm ponds are typically constructed as small tanks or reservoirs designed to collect and store water originating from surface runoff [6]. Farm ponds serve various purposes such as irrigation, providing water for cattle, facilitating fish production, and recharging groundwater. Designing and building these ponds necessitates a deep understanding of site conditions and specific requirements. Optimal locations for ponds should be identified, capitalizing on natural advantages whenever possible [7]. Figure 2.14 depicts a typical farm pond.

TYPES OF FARM PONDS:

Farm ponds are categorized into four types based on their water source and their relative positioning with respect to the land surface. These are (1) Dugout ponds (2) Surface ponds (3) Spring or Creek fed ponds and (4) Off-stream storage ponds [7]. Figure 2.15 depicts the various types of farm ponds.

TYPES OF FARM POND

- DUGOUT PONDS
- SURFACE WATER PONDS
- SPRING OR CREEK-FED PONDS
- OFF-STREAM STORAGE PONDS

Figure 2.15 Types of Farm Pond

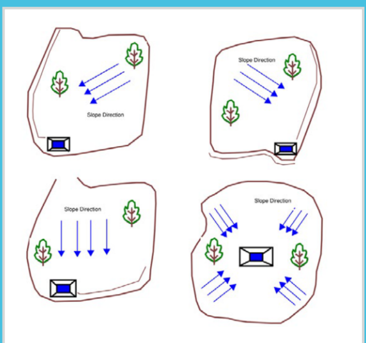

Figure 2.16 Planning and Selection of Site for Dugout Ponds [8]

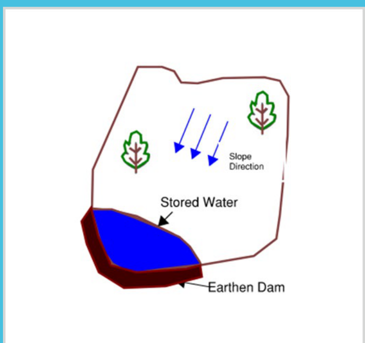

Figure 2.18 Planning and Selection of Site for Surface Water Ponds [8]

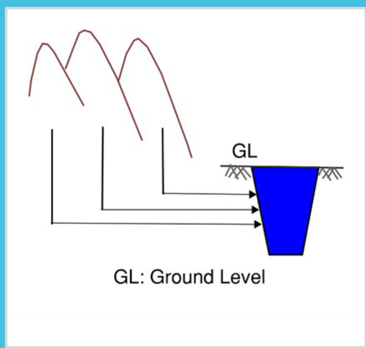

Figure 2.20 Planning and Selection of Site for Spring or Creek Fed Pond [8]

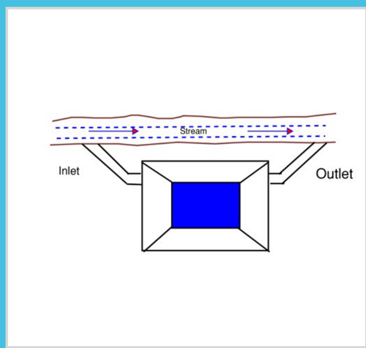

Figure 2.22 Planning and Selection of Site for Off-stream Storage Ponds [8]

Figure 2.17 Dugout Pond

Dugout Ponds:

Dugout ponds are created by excavation at the site, and the soil obtained is then used to form an embankment around the pond. These ponds can be filled either by surface runoff or groundwater, particularly in areas where aquifers are present. When the stored water is intended for irrigation purposes, it typically needs to be pumped out [7]. The selection of a site for a Dugout Pond should consider the average slope direction of the field. Figure 2.16 illustrates different locations for dugout ponds based on the prevailing land slope. In areas with multiple slopes in various directions, it's advisable to excavate the pond in a location where it can effectively collect the maximum amount of water draining into it from the surrounding area [8]. Figure 2.17 shows an example of a dugout pond.

Figure 2.19 Surface Water Ponds

Surface Water Ponds:

Surface water ponds are the most common types of farm ponds. These are partially excavated with an embankment constructed to retain water. Typically, these ponds are constructed in areas where a natural depression already exists on the site [7]. Surface ponds are feasible in farm areas characterized by undulating topography. Unlike other types of ponds, surface ponds do not necessarily need a formal inlet provision; however, it's essential to have a formal outlet provision to manage water levels effectively [8]. Figure 2.18 depicts the planning and selection of a site for surface water ponds. Figure 2.19 gives an idea about the surface water ponds.

Figure 2.21 Spring or Creek Fed Water Pond

Spring or Creek-Fed Ponds:

These ponds are dependent on natural springs or creeks as their primary water source. Their construction relies on the availability of these natural water sources in the area [7]. Hence, this type of pond is typically built at the foothills of sloping catchments, as shown in Figure 2.20. Following excessive rainfall, soil saturation triggers subsurface flow within the catchment, gradually emerging at the foothills as base flow [8]. Figure 2.21 displays a spring or creek-fed water pond.

Off-Stream Storage Ponds

These ponds are constructed alongside streams that flow only during specific seasons. The purpose is to capture and store water from these streams during their seasonal flow periods [7]. These types of ponds are suitable for adoption in sloping catchments where upstream storage volume is insufficient to maintain high flow velocity. If stream flows serve as the storage source, the pond should be situated off the stream, with water properly diverted through pipes or channels [8]. Appropriate arrangements must be made to convey water from the stream to the storage ponds as shown in Figure 2.22 [7].

The integration of farm ponds with diverse activities such as fish farming, duck rearing, and agricultural or horticultural crops plays a vital role in enhancing food production, income, nutrition, and employment opportunities for rural communities. Additionally, the provision of lifesaving irrigation during critical growth stages of crops ensures sustainable agricultural practices and promotes consistent income generation while safeguarding crops.

3.0 Project Details

This chapter provides details regarding the minimum resources required for a typical pond rejuvenation project to initiate. It involves the roles and responsibilities of stakeholders, the involvement of the stakeholders at each stage, setting up the team, and building the environment for the execution of the project, norms, rules, and regulations of the conservation of waterbodies, funds, and financing.

Figure 3.1 Flowchart of Project Details

3.1 Stakeholders

The success of rejuvenating a waterbody hinges on cooperation among all stakeholders, each with potentially differing objectives for its management. Therefore, early engagement of key stakeholders to identify their respective drivers is crucial. To determine appropriate engagement strategies, it is essential to classify all stakeholders based on various characteristics, such as ownership, geographical proximity, influence, and their potential financial contribution to the project. Moreover, interventions for waterbody rejuvenation should be viewed through a Gender Equality, Disability, and Social Inclusion (GEDSI) lens, particularly during stakeholder engagement. As emphasized in the AMRUT 2.0 operational guidelines, projects should ensure that households from informal settlements and low-income groups are duly considered [9]. Stakeholders can generally be grouped into two categories: Primary stakeholders and Secondary stakeholders.

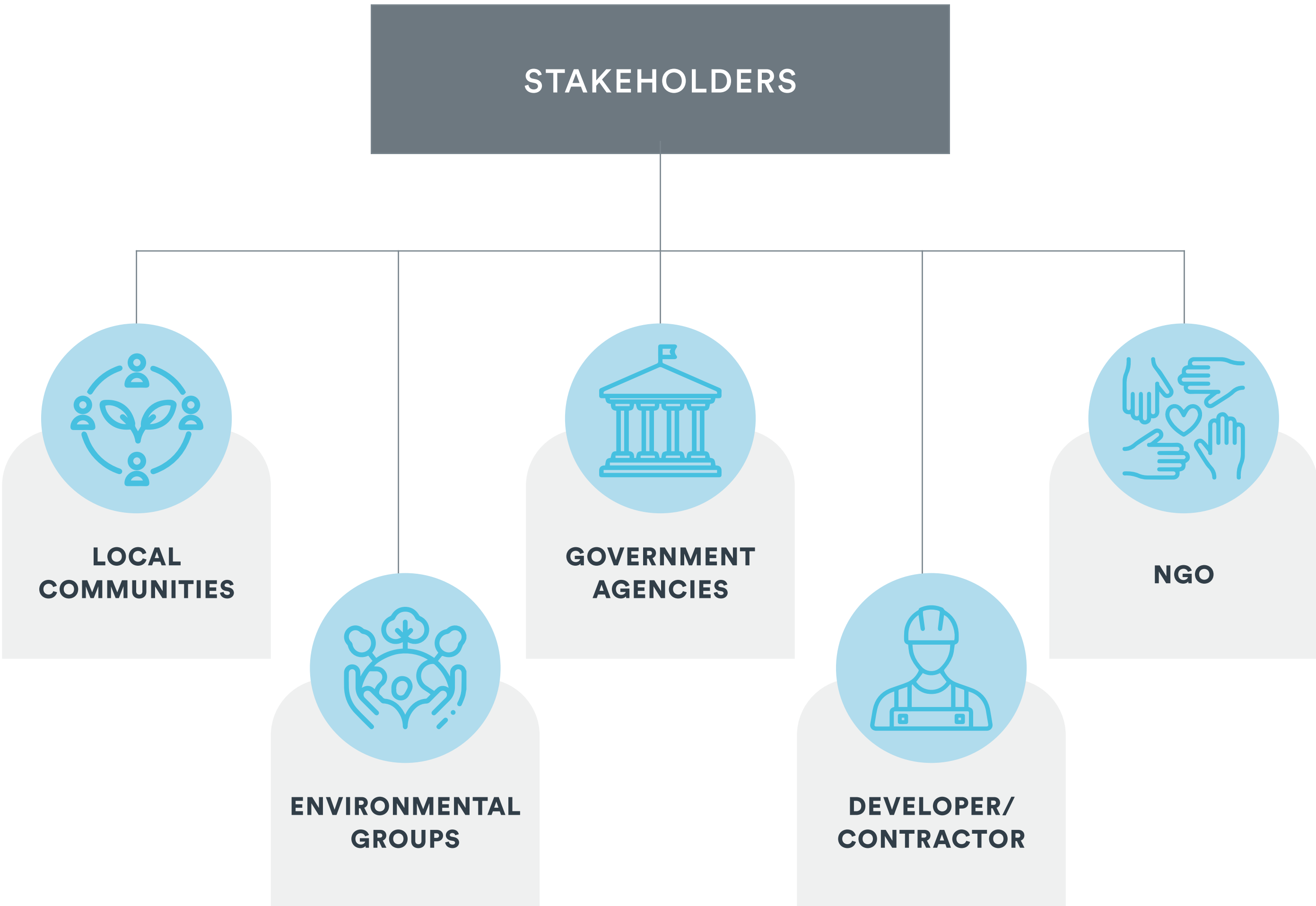

Figure 3.2 Flowchart of Stakeholders

The stakeholders can be grouped into two categories:

- **Primary Stakeholders**
  The primary stakeholders are those with a direct interest or influence on waterbody management. This category encompasses municipal organizations, land/building development authorities, regional development authorities, water board/utility companies, water resources conservation/management authorities, pollution control boards, central and state governments, the general public, and communities. It also includes women or women's groups dependent on the waterbody for their water needs or those residing in close proximity to the waterbody [9].

- **Secondary Stakeholders**
  Secondary stakeholders do not have direct responsibility for managing specific waterbody activities, but they do have an indirect interest in the waterbody. This group includes state agriculture/horticulture/aquaculture/energy departments, research institutes, Non-Governmental Organizations (NGOs), suppliers, contractors, the Director of Soil Conservation and Watershed Development, Directorate of Horticulture, Directorate of Agriculture and Food Production, Department of Panchayatiraj and Drinking Water, etc. [9].

Figure 3.2 illustrates the flow chart of the stakeholders.

- **Local Communities:**
  Communities provide insights into local needs, preferences, and concerns regarding the pond project. The responsibilities of local communities are to participate in consultations, provide feedback on design and implementation plans, and collaborate with project organizers.
- **Environmental Groups:**
  This group is an advocate for environmentally sustainable practices and the protection of natural habitats. It offers expertise on ecological considerations, monitors project impacts, and ensures compliance with environmental regulations.
- **Government Agencies:**
  Their role is to regulate and oversee the project to ensure compliance with laws and regulations, issue permits, provide technical guidance, and enforce environmental and construction standards.
- **Developers/Contractors:**
  They execute the construction and rejuvenation work according to the project specifications, design and implement construction plans, adhere to timelines and budgets, and address concerns raised by stakeholders.
- **Non-Governmental Organizations (NGOs):**
  NGOs advocate for social and environmental justice and provide support to marginalized communities. NGOs raise awareness about the project, facilitate community involvement, and advocate for equitable outcomes.

3.2 Building Environment and Setting Up Restoration Team

The restoration phase includes declaring the 'designated best use' of the waterbody, which serves as a foundation for formulating strategies and determining the extent of treatment required for its restoration. The most appropriate solutions and their application will vary depending on the specific characteristics of each case, aiming to achieve the designated best-use water goals for the subject waterbody. The goal of restoration is to reverse adverse ecological impacts and improve water quality. The initial step in pond restoration involves creating the necessary environment and building a restoration team tasked with taking responsibility for the pond [10].

The crucial initial step in waterbody restoration is to establish the appropriate environment and assemble a restoration team tasked with assuming responsibility for the waterbody. This team should ideally include representatives from the local community, technical experts, government officials, and NGOs. The composition of the team may vary based on the skills required for the restoration task, which can evolve over time [10]. Figure 3.3 represents various roles required in the restoration team. The team's roles and responsibilities are explained below:

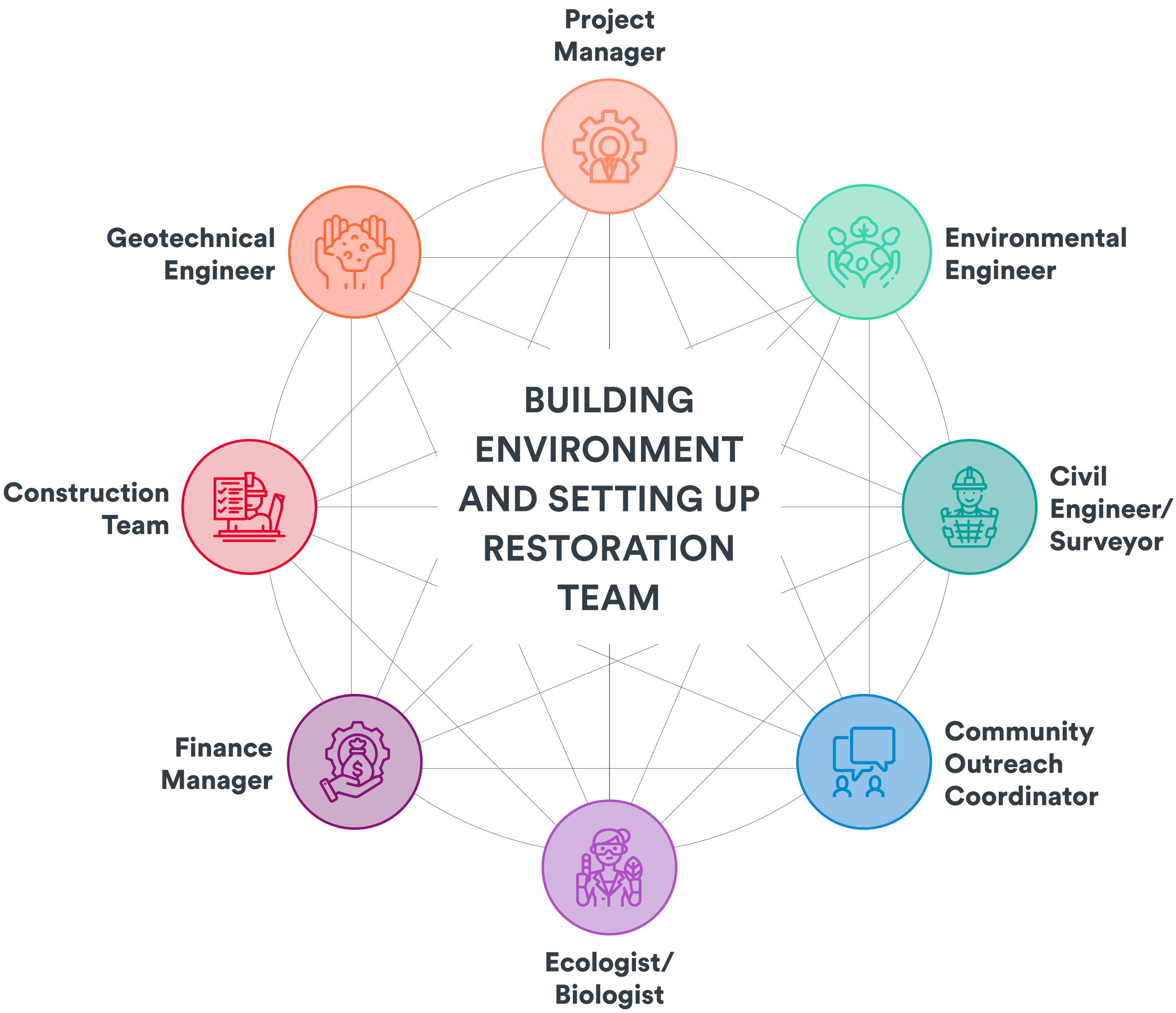

Figure 3.3 Flowchart of Various Roles in the Restoration Team

Project Manager:

- Oversee all aspects of the pond restoration project from planning to implementation.
- Develop project plans and timelines.
- Coordinate team efforts and resources.
- Monitor progress and adjust strategies as needed.
- Oversee the authorization process and regular monitoring of compliance with government guidelines.

Environmental Engineer:

- Ensure that restoration efforts comply with environmental regulations and sustainability principles.
- Assess environmental impacts.
- Design restoration plans with minimal ecological disturbance.
- Monitor water quality and habitat restoration progress.

Civil Engineer:

- Design and oversee the construction aspects of the restoration project.
- Develop pond infrastructure plans (e.g., embankments, spillways).
- Ensure structural integrity and safety. Supervise construction activities.
- Estimation and costing that involves accurately predicting project expenses and preparing budgets to ensure efficient resource allocation and cost control throughout the project lifecycle.

Geotechnical Engineer:

- Conduct geotechnical site investigations to assess soil, rock, and groundwater conditions.
- Assess the stability of slopes and embankments to prevent landslides and slope failures.
- Geo-tagged still photographs of the projects at different stages of execution (Pre-During-Post) must be taken and be a part of the case record [11].
- Design foundations for structures based on soil conditions and structural requirements.

Surveyor:

- Conduct detailed surveys to gather data on topography, natural features, and soil conditions.
- Collaborate with engineers and architects to develop design plans, providing input on on-site layout and technical aspects.
- Mark precise locations and elevations of project components during construction to ensure compliance with design plans.
- Conduct surveys to verify the accuracy and integrity of constructed features, ensuring compliance with standards.

Community Outreach Coordinator:

- Engage with local communities and stakeholders to ensure their involvement and support for the project.
- Organize community meetings and outreach events.
- Facilitate communication between the project team and stakeholders.
- Address community concerns and gather feedback.

Ecologist/Biologist:

- Provide expertise on the ecological aspects of pond restoration and biodiversity conservation.
- Conduct ecological assessments.
- Identify native species for habitat restoration.
- Monitor wildlife populations and ecosystem health.

Finance Manager:

- Manage the project budget and financial resources.
- Develop budget forecasts and financial plans.
- Track expenses and ensure cost-effectiveness.
- Procure necessary materials and services within budget constraints.

Fund Management is the process of assessing larger resource requirements which can be bifurcated into Manpower, Material, and Machines. Often based on outcomes, fund management is an art form that emphasizes the usage of all resources wisely and removes the focus from the monetary exchange. The Member of Parliament Local Area Development Scheme (MPLADS), Member of the Legislative Assembly (MLA) Development fund, Mahatma Gandhi National Rural Employment Guarantee Act 2005 (MGNREGA), Forest Department, Horticulture Department, Swachh Bharat Mission (SBM), Integrated Watershed Management Programme (IWMP), and Irrigation are among the government departments and organizations that provide financial assistance, either directly or indirectly, for works falling within the scope of their authority [1].

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Construction Team:

- **Construction Supervisor:**
  Oversee daily construction activities at the site, manage crews and subcontractors, ensure safety compliance, coordinate with engineers, and facilitate job card processes while supervising labor attendance and providing first aid resources.
- **Contractor:**
  Manage the construction team, oversee project scheduling and budget, ensure quality and safety, solve issues, and communicate with the project owner.
- **Site Engineer:**
  - Provide technical guidance and ensures that the construction is in line with the design specifications.
  - Handle on-site measurements, adjustments, and quality control.
- **Mason:**
  - Construct any masonry elements such as retaining walls, pathways, or steps around the pond.
  - Perform stonework or brickwork required for the project.
- **Laborers:**
  Perform general manual tasks including moving materials, assisting other trades, and handling site cleanup. Support the heavy equipment operators and masons.
- **Excavator Operator:**
  Operate excavation machinery to dig out the pond area, shape the pond's depth and contours, and manage the removal of earth and debris.

3.3 Norms, Rules, and Regulation of Conservation of Waterbodies

The Government of India (GOI) has formulated several policies to support the efforts of state governments in conserving both natural and artificial waterbodies. Some of these policies include [12]:

1. National Water Policy 2012: The Ministry's National Water Policy 2012 mandates that encroachments and diversions of waterbodies (e.g., rivers, lakes, tanks, ponds) and drainage channels (including irrigation areas and urban drainage) must be strictly prohibited. In cases where such encroachments occur, restoration efforts should be undertaken to the extent possible, followed by proper maintenance.
2. Wetlands (Conservation and Management) Rules, 2017: The Ministry of Environment, Forest & Climate Change has notified the Wetlands (Conservation and Management) Rules, 2017, aimed at the protection, conservation, and management of wetlands across the country.
3. Water (Prevention and Control of Pollution) Act 1974: The provisions of the Water (Prevention and Control of Pollution) Act 1974 are enforced by the State Pollution Control Boards (SPCBs) /Pollution Control Committees (PCCs) to regulate the discharge of effluents and enforce standards regarding polluting sources.
4. Environment (Protection) Rules, 1986: The GOI has stipulated general discharge standards and industry-specific effluent discharge standards under the Environment (Protection) Rules, 1986, with the objective of preventing pollution in waterbodies.
5. Indicative Guidelines for Restoration of Waterbodies: The Central Pollution Control Board (CPCB) has issued "Indicative Guidelines for restoration of waterbodies" to provide guidance to stakeholders for ensuring the restoration and rejuvenation of waterbodies.
6. Revised Guidelines on Idol Immersion in Waterbodies: The guidelines for the immersion of idols in waterbodies, initially formulated in 2010, have been revised. The "Revised Guidelines on Idol Immersion in Waterbodies" have been implemented nationwide since January 1, 2021.

The GOI has initiated the first census of waterbodies in convergence with the sixth round of the minor irrigation census (the reference year 2017-18) under the centrally sponsored scheme “Irrigation Census.” The objective of the census of waterbodies is to develop a national database for all waterbodies by collecting information on various aspects such as size, condition, status of encroachments, use, and storage capacity [12].

There should be restrictions on building activity in the vicinity of waterbodies to protect the areas from flooding. The following guidelines are based on the Urban Flood Management Guideline (September 2010), and National Disaster Management Guidelines, (September 2017) [13]:

1. No building/ development activity shall be allowed in the bed of waterbodies like river or nallah/ stormwater drains and in the Full Tank Level (FTL) of any lake, pond, tank, or pond/ tank bed lands.
2. The above waterbodies and courses shall be maintained as recreational/green buffer zones, and no building activity other than recreational use, shall be carried out within:
    - 100 m from the river edge outside Municipal Corporation/ Municipal limits and 50 m within Municipal Corporation/ Municipal limits. No permanent constructions/structures will be permitted within the above-mentioned buffer zone.
    - 50 m from the boundary of ponds/lakes of area 10 Ha and above.
    - 30 m from the boundary of lakes of area less than 10 Ha/ponds/tank bed lands.

4.0 Pond Rejuvenation Framework

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The methodology framework for pond rejuvenation encompasses a structured approach consisting of five distinct phases aimed at systematically restoring deteriorated pond ecosystems. The detailed action plan for the restoration of ponds shall be prepared based on the Indicative Guidelines for Restoration of Waterbodies [3] prepared by the CPCB to ensure compliance with the order of the Hon'ble National Green Tribunal. The objectives of the action plan include ensuring pollution-free waterbodies that meet designated quality standards, preserving surplus water during monsoon seasons, and restoring and augmenting storage capacities of ponds, etc. Each phase plays a critical role in guiding stakeholders through the process, ensuring that interventions are well-informed, efficiently executed, and effectively monitored for long-term sustainability. Through a methodological flowchart, as shown in Figure 4.1, pond rejuvenation initiatives can be systematically orchestrated to achieve desired ecological, social, and environmental outcomes.

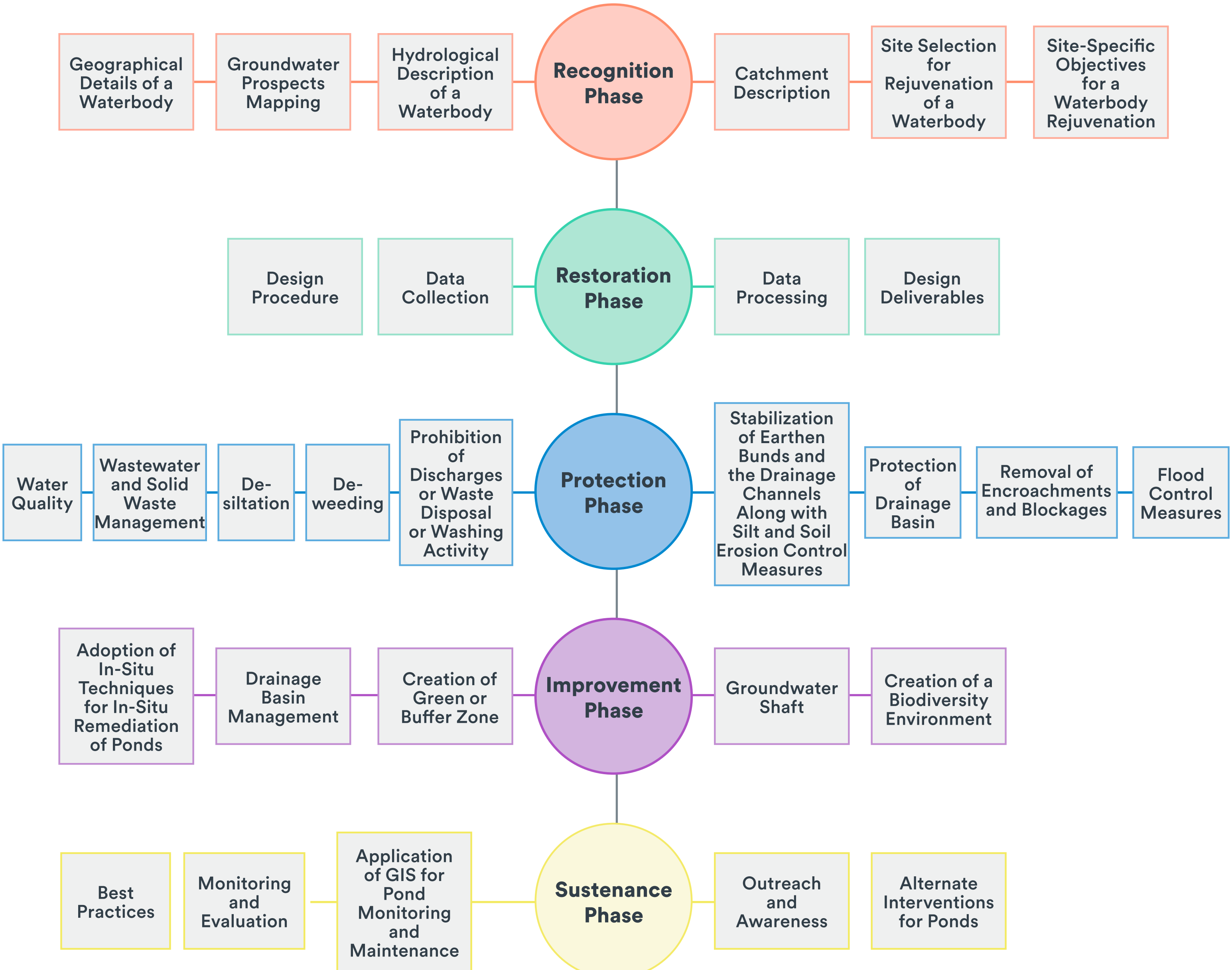


Figure 4.1 Methodological Flowchart

5.0 Recognition Phase

This phase mainly focuses on the identification and recognition of the problem. Understanding the status of the waterbodies, their suitable use, the need for management and conservation so that they serve as a good resource for the future, and potential strategies for long-term management especially in the areas, that are facing severe water shortage.

This phase involves collecting basic information such as historical information related to the waterbodies, existing natural resources around the project site, existing land use and land cover, geology, groundwater level assessment, and land availability for groundwater recharge. It also includes mapping administrative boundaries and their attributes with satellite imagery, collecting secondary and primary survey reports, and Geographic Information System (GIS) mapping of waterbodies (geographical details, hydrological description, catchment description, etc.). The phase also provides considerations for the selection of a site (waterbody) for its construction or rejuvenation. Figure 5.1 depicts the flow chart for the components of the recognition phase.

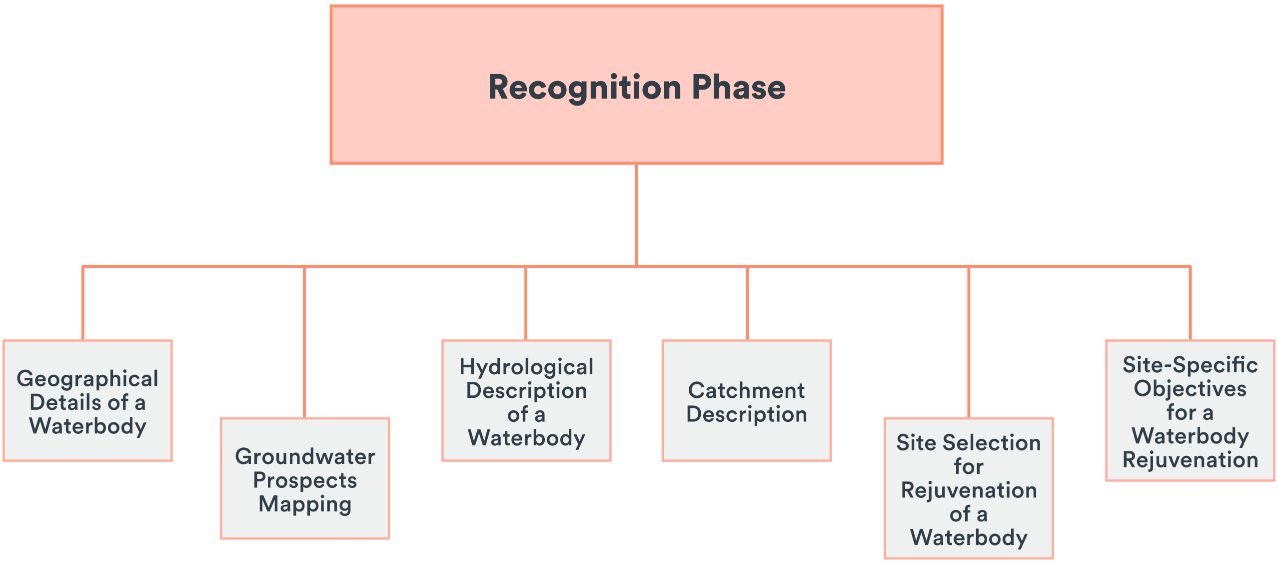


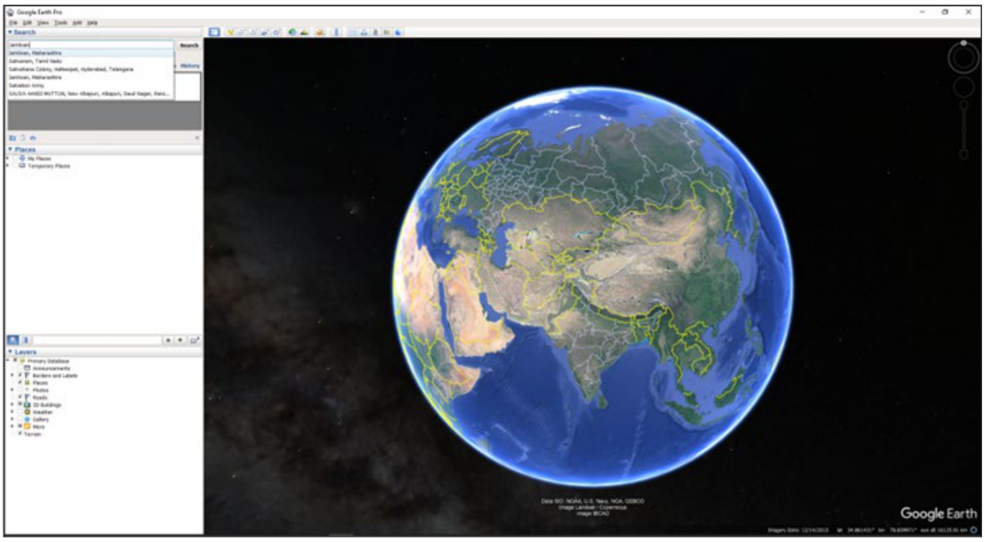
Figure 5.1 Flowchart of the Components of Recognition Phase

5.1 Geographical Details of a Waterbody

Global Positioning System (GPS) Location (latitude and longitude) of the waterbody can be identified using Google Maps, Google Earth Engine, National Remote Sensing Centre (NRSC) (geo-mapping), etc. The local government authorities can help in providing the secondary data such as address (Khasra No./ Plot No./ Survey No.), size or dimensions, area, elevation above the mean sea level (can be obtained from a survey), ownership of the waterbody, boundaries with earmarking, map of the pond (digital map, remote sensing or satellite map over the years/National Wetland Atlas) with salient features [3] [10]. Mapping waterbodies and open spaces plays a crucial role in understanding the efforts taken or required for their rejuvenation and conservation. Spatial information provided by maps facilitates water resources planning and enables monitoring of various indicators during and after the implementation of initiatives. Additionally, it assists in identifying potential threats and vulnerabilities, facilitating informed decision-making and resource allocation for effective conservation measures. Overall, mapping serves as a valuable tool in promoting sustainable management of waterbodies and open spaces for the benefit of present and future generations [14].

The following steps can be undertaken to map the waterbodies and open spaces to assess their location by using the Google Earth software [14]:
Here, for example, the Jamlivan Pond, Amaravati is used to illustrate the mapping process.

Step 1:
Search for a region/city.



Step 2:
Locate a waterbody or open space of interest and zoom in using the slider.

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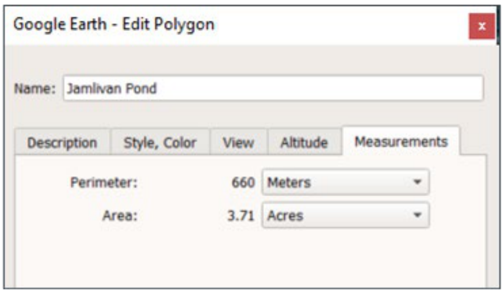
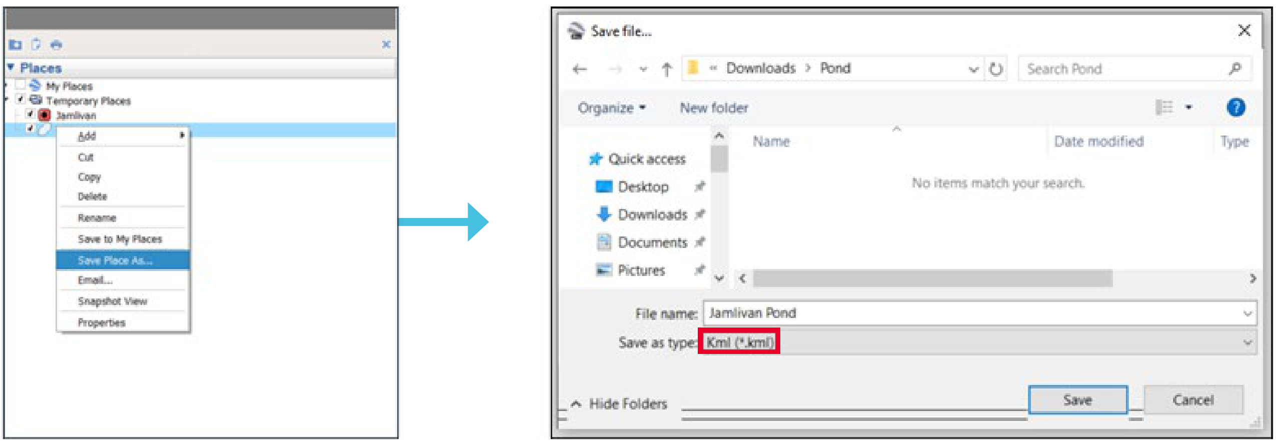
Step 3:
From the toolbar, click on ‘Add Polygon’ and edit the specification as per the requirements.

Step 4:
Select multiple points around the waterbody or open space and close the polygon/outline by selecting the starting point again.

Step 5:
In the dialog box, click on the ‘Measurement’ tab and note the area.

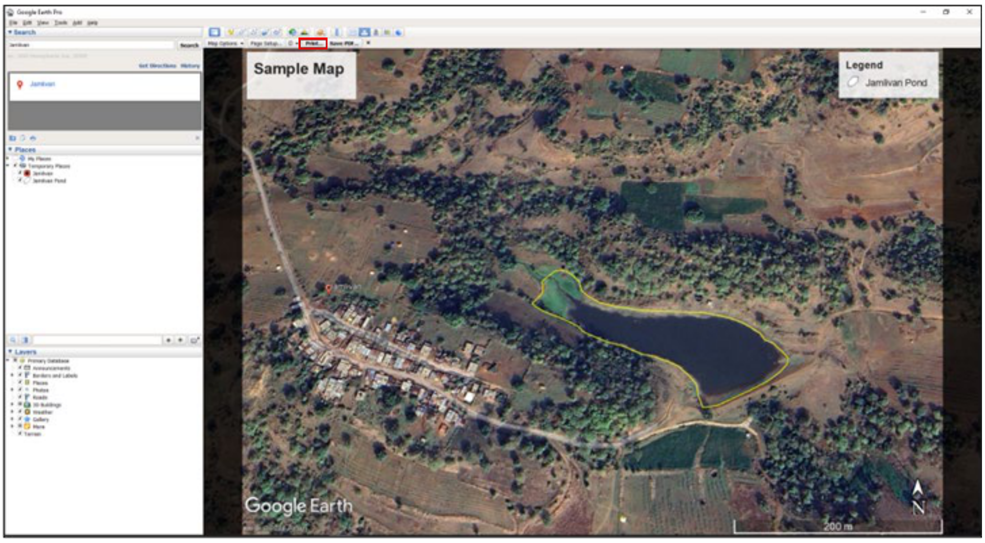


Step 6:
On the ‘Places’ window, right-click the name of the waterbody/open space and save the file as Keyhole Markup Language (.kml)



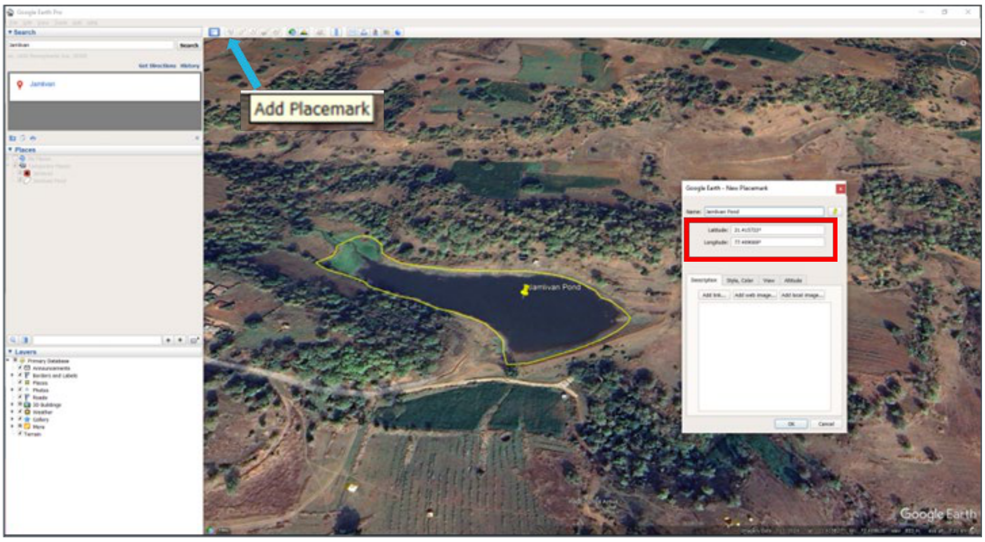
Step 7:

From the toolbar, select the option to print and save the file as a Portable Document Format (PDF).



Step 8:

From the toolbar, click on 'Add Placemark' and place the placemark on the pond location. On the dialog box, coordinates (Latitude, Longitude) of the pond location will be displayed. Placemark can also be saved as a KML file.



5.2 Groundwater Prospects Mapping

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During the past two decades, the methodology for creating groundwater maps using satellite imagery has undergone rapid evolution. Initially, remote sensing data such as aerial photographs and satellite images were primarily utilized to update and refine conventional hydrogeological maps derived from ground surveys. Subsequently, numerous organizations in the country, including the NRSC / Department of Space (DOS), the Central Ground Water Board (CGWB), groundwater departments of various states, research laboratories, and academic institutions, have also adopted the practice of preparing groundwater maps through systematic visual interpretation of satellite data, supplemented by limited field checks. These maps, bearing different titles, exhibit significant variation in terms of quality and information content [15]. CGWB **(Aquifer Atlas | CGWB)** and Aquifer Atlas and Maps – Aquifer Systems of India should be used to collect the maps and groundwater information [16].

5.3 Hydrological Description of a Waterbody

The basic hydrological information of a waterbody can be collected by interaction with the local community, from secondary data received from the local government authorities, and by aerial observations using the Google Earth Engine. The hydrological description should include the category of the waterbody (natural or man-made), area, average and maximum depth of stored water (during monsoon and non-monsoon periods), total storage capacity, the status of the waterbody in terms of percentage of open water and aquatic vegetation. Identify the main source of water – rainfall/groundwater, seepage/catchment, runoff/direct or indirect flow from any river, stream, or creek. Also, the water permanence (permanent or intermittent), and the destination of excess water from the waterbody should be identified. It should also include the intended water usage such as drinking water sources, fisheries, agriculture or cultivation of aquatic food plants, recreational and aquatic sports, groundwater recharge, whether the waterbody acts as a sink for sediments, or a habitat for noteworthy animals' species, migratory birds, or any other purpose, etc. [3]. The detailed procedure to obtain the hydrological information is explained in Section 6.2.

5.4 Catchment Description

The drainage or catchment area responsible for supplying surface runoff for pond storage is very important. It is essential for the structure to be filled at least once during the season to provide farmers with water for essential irrigation during dry periods. The characteristics of a catchment directly impacting runoff yield include the slope of the terrain, soil infiltration capacity, vegetation cover, land use patterns, and the shape of the catchment. These factors are interconnected and vary depending on the site, making them site-specific considerations [8]. For example,

- If the drainage area is disproportionately small compared to the size of the pond, it may result in inadequate filling or excessively low water levels during prolonged hot and dry periods.
- Intense rainfall events can lead to soil erosion, with runoff carrying sediment into the pond. These issues can be mitigated through effective soil and water conservation measures. To achieve the desired depth and capacity of the proposed pond, inflow should ideally be relatively free of sediment from an eroding catchment.
- The most effective protection against erosion is implementing proper erosion control measures such as in situ moisture conservation or land management practices (e.g., ridge and furrow, broad bed furrow, compartmental bunds, contour bunds, graded bunds) in the drainage contributing area.
- Land covered by trees or grasses provides optimal drainage area protection. If such land is unavailable, the watershed should be treated with appropriate conservation practices to mitigate erosion before pond construction.
- Catchments should be chosen to prevent drainage from farmsteads, feedlots, sewage lines, waste disposal sites, industrial and urban areas, and similar sources from reaching the pond [8].

The catchment description should also include the following points [3]:

- Detailed information regarding natural drains or flood channels and their respective flows contributing to water accumulation.
- Details on major towns surrounding the pond, including the total population residing in the vicinity, any sewage contributions from these towns, total sewage generation, the number of existing Sewage Treatment Plants (STPs), and their treatment capacities, if applicable.
- Identification of major industrial clusters or estates contributing to pollution in the ponds, including the total number of industries categorized by sector, sector-wise total industrial effluent generation, and existing industrial effluent treatment capacity (both Captive Effluent Treatment Plants –(CETPs) and Common Effluent Treatment Plants), if present.
- Assessment of total waste generation (e.g., municipal solid waste, plastic waste, industrial hazardous waste, construction, and demolition waste) and existing provisions for waste collection, transportation, treatment, and disposal practices in the vicinity.

Any additional relevant information such as the presence of declared Wetland Ramsar sites, biodiversity details encompassing flora and fauna diversity (including lists of plant and animal species, identification of species of conservation significance such as rare, endangered, threatened, and endemic species, identification of major plant invasive alien species and extent of invasion) [3]. Figure 5.2 portrays the catchment area of the Jamlivan Pond, Amravati.

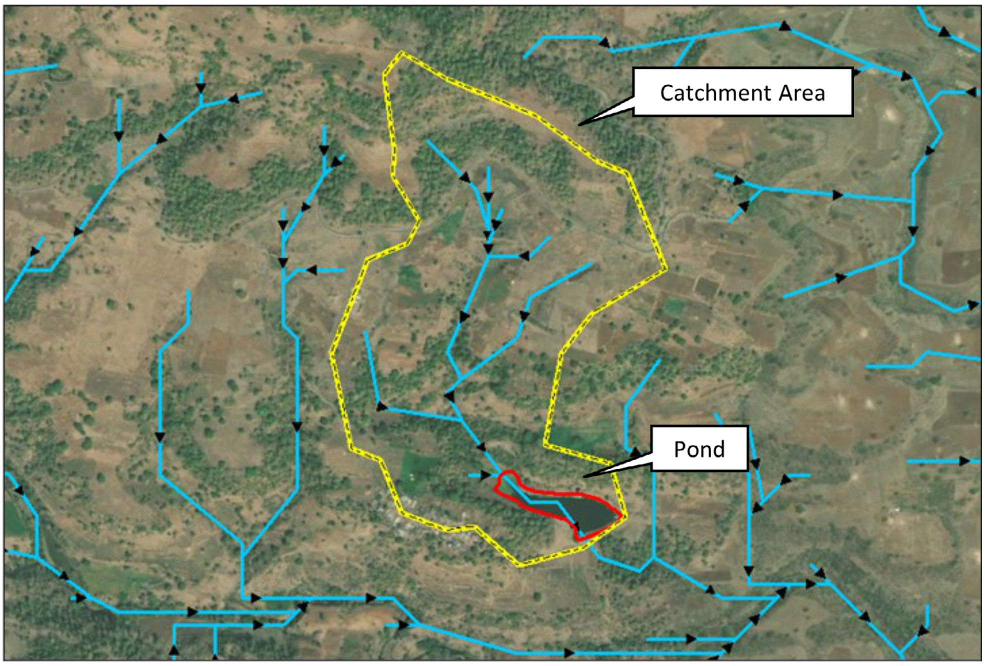

Figure 5.2 Catchment Area of the Pond

5.5 Site Selection for Rejuvenation of a Waterbody

Rejuvenation of the waterbody involves careful consideration of several factors to ensure the success and effectiveness of the restoration efforts. Rejuvenation work for a waterbody can begin once the water table in the surrounding area goes down. The summer season, allowing for complete drying of the waterbody, is ideal for this purpose, ensuring efficient and cost-effective rejuvenation [17]. However, removing silt from a partially dried pond bottom is challenging, labor-intensive, and expensive. Various considerations for site selection must be taken into account in this regard, which are as follows:

- Identify waterbodies that are ecologically important, serving as habitats for diverse plant and animal species.
- Waterbodies that support rare or threatened species, or those that contribute to local biodiversity, should be prioritized for rejuvenation.
- Assess the importance of the waterbody to local communities for irrigation, livestock watering, recreational activities, and cultural practices.
- Consider the social and economic significance of the waterbody and involve community stakeholders in the site selection process.
- Hydrological characteristics of the waterbody, including water flow patterns, depth, and connectivity to other waterbodies are also important factors for selecting waterbody rejuvenation sites.
- Waterbodies with natural or potential hydrological connections to rivers, streams, or groundwater sources may have greater ecological value and potential for restoration.
- Consider the accessibility of the site and the availability of infrastructure, and resources for implementing rejuvenation measures.
- Accessible sites with existing infrastructure for water quality monitoring, habitat restoration, and community engagement may be more feasible for rejuvenation efforts.
- Assess the extent of encroachments, pollution, sedimentation, and other threats affecting the waterbody's condition.
- Prioritize sites where rejuvenation efforts can address significant threats and contribute to meaningful improvements in water quality and habitat quality.
- Evaluate the potential for collaboration with government agencies, non-profit organizations, and community groups to leverage resources and expertise for successful site restoration.

5.6 Site-Specific Objectives for a Waterbody Rejuvenation

Waterbody rejuvenation is a set of actions to improve the health of a waterbody by 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 an understanding of the need to develop a waterbody rejuvenation plan.

5.6.1 SEDIMENTATION/SILTATION AND SOIL EROSION

Sediment deposition poses a significant challenge for small ponds, as the rate of siltation is notably higher compared to larger waterbodies. This accelerated siltation diminishes the useful life of the pond [18]. Besides geomorphological processes, soil erosion is heavily influenced by human activities in the catchment area. These anthropogenic modifications include the establishment of concrete drainage networks, deforestation, intensified agriculture practices, road construction, and unregulated grazing [19]. The rapid erosion of topsoil in India poses a significant threat to the ecological balance of receiving waterbodies, including ponds [20]. In India, the average rate of soil erosion is approximately 16.35 tons per hectare per year. Approximately 10% of this eroded soil is deposited in reservoirs and ponds, resulting in an annual reduction of storage capacity by 1 to 2% [21].

The reduction in the water retention capacity of ponds significantly impacts agricultural productivity and livestock in developing regions [18]. Renwick et al. (2005) conducted a study on the sediment budget of 2.6 million ponds in the USA and found that ponds serve as major sediment sinks, with a sedimentation rate ranging from 0.43 to 1.78 × 10^9 m^3 per year, compared to larger dams with a sedimentation rate of 1.67 × 10^9 m^3 per year across 43,000 reservoirs. Soil erosion and sediment transport not only contribute to sediment load but also transport sediment-associated nutrients, organic matter, heavy metals (Goyal et al., 2022), and other emerging contaminants (Riley et al., 2018) to the ponds (Oertli and Parris, 2019). Globally, erosion of nutrient-rich topsoil, estimated at 25–42 billion tonnes per year, results in increased transport of nitrogen (23–42 million tonnes) and phosphorus (15–26 million tonnes) (Ramsar Convention on Wetlands, 2018). Mukherjee et al. (2022) reported the partitioning of heavy metals in pond sediment (Pond in East Kolkata Wetland, India) in the order of Pb > Cr > Cd [21].

In India, many ponds are encircled by habitation and residential areas. Landlocked ponds in the country, especially those with narrow or no outlets, are particularly prone to sediment deposition and the accumulation of contaminants from vehicles and other discharges (Goyal et al., 2021) [21]. Figure 5.3 illustrates the sedimentation process in these ponds.

Figure 5.3 Sedimentation in the pond

5.6.2 WEEDING

It is natural to have a growth of aquatic vegetation in the waterbodies. They help in increasing the nutrient levels in the water. However, weeds are the excessive growth of aquatic plants, such as water hyacinth and algae, which can lead to decreased oxygen levels in the water and increased foul odors. They can also choke out native aquatic plants and disrupt the natural balance of the pond ecosystem. In regions where ponds are used for irrigation or drinking water supply, excessive aquatic vegetation can reduce the water storage capacity of the pond by occupying valuable space. Deweeding is a process of removing the weeds from a piece of ground or waterbody. It is often part of a broader strategy for sustainable pond management in India. This may include community-based initiatives where local communities are involved in regular maintenance activities such as weeding, thereby fostering a sense of ownership, and ensuring the long-term sustainability of pond rejuvenation efforts. Figure 5.4 indicates the weeding in the pond.

Figure 5.4 Weeding in the Pond

5.6.3 DISCHARGES OR WASTE DISPOSAL OR WASHING ACTIVITY

Discharges from industrial, agricultural, and domestic sources can introduce pollutants such as chemicals, heavy metals, nutrients, and organic matter into ponds. These pollutants can lead to eutrophication, where excessive nutrient levels stimulate the growth of algae and aquatic plants, resulting in decreased oxygen levels and degraded water quality. Waste disposal and improper land use practices can lead to soil erosion and sediment runoff into ponds. Sedimentation can fill up the pond over time, reducing water storage capacity, and covering aquatic habitats. This process can also contribute to the accumulation of pollutants and nutrients, exacerbating water quality issues. This contributes significantly to the degradation of ponds, necessitating urgent rejuvenation efforts. Figure 5.5 represents the waste disposal in the pond.

Figure 5.5 Waste Disposal into the Pond

5.6.4 EUTROPHICATION

Eutrophication is the process in which the waterbody becomes overly enriched with nutrients, leading to an increase in the production of algae and macrophytes. Figure 5.6 depicts the eutrophication into the pond. The condition of eutrophication of lakes or ponds is caused due to inadequate measures such as indiscriminate discharge of industrial effluents, runoff from agricultural fields, refuse and discharge of sewage, and domestic wastes like food remnants, soaps, and detergents. Eutrophication causes depleted levels of dissolved oxygen in the water which leads to a situation where other aquatic life forms cannot survive. Rejuvenation measures are essential to mitigate nutrient inputs, control algal growth, restore native vegetation, and improve water circulation, thereby addressing the root causes of eutrophication and ensuring the long-term sustainability of pond resources.

Figure 5.6 Eutrophication in the Pond

5.6.5 ENCROACHMENTS AND BLOCKAGES

Encroachments, such as illegal construction, agricultural expansion, urbanization, etc. can reduce the surface area of the pond and its water storage capacity (Figure 5.7). This loss of capacity can lead to water shortages, especially in regions where ponds are critical for irrigation, livestock watering, or domestic use. Encroachments and blockages can lead to changes in water flow patterns, causing stagnation and reducing water circulation within the pond. Stagnant water is more susceptible to pollution. Rejuvenation efforts may involve reclaiming encroached areas to restore the original water storage capacity of the pond.

Figure 5.7 Encroachments and Blockages into the Pond

5.6.6 UNCONTROLLED INFLOW/OUTFLOW AND FREQUENT FLOODING

Uncontrolled inflow and frequent flooding pose pressing challenges that necessitate pond rejuvenation. Unregulated flow into ponds can result from poor land use practices like deforestation and urbanization, which increase surface runoff carrying sediments and pollutants. Additionally, inadequate infrastructure, such as poorly constructed drainage systems, can contribute to uncontrolled inflow. Frequent flooding events can inundate pond habitats, erode banks or bunds, and disturb aquatic life, diminishing the pond's capacity to support biodiversity and provide essential ecosystem services. Poorly maintained outlets or lack of spillways, encroachments, and land use changes alter natural drainage patterns, leading to uncontrolled outflow. Uncontrolled inflow/outflow from ponds poses a significant need for rejuvenation due to its adverse impacts on water levels, water loss, habitat stability, and surrounding ecosystems. The breaching of a pond wall or embankment can indeed lead to significant issues, particularly flooding. When a breach occurs, water can rapidly escape from the pond, causing a sudden increase in water levels downstream. This can result in flooding of surrounding areas, including nearby homes, farmland, or infrastructure and it also poses risks to human safety and disrupt ecosystems. Breaches in embankments can occur due to various factors. Improper compaction and settlement issues can weaken the structure over time, while transverse cracks from uneven settlement create vulnerabilities. Inadequate drainage and the buildup of pore pressure can compromise embankment stability, and erosion caused by river currents and waves, along with bank caving, can weaken embankments, leading to breaches. Overtopping during high floods can overwhelm embankments, causing breaches, while foundation failure due to infiltrations can also weaken them. Additionally, piping resulting from insufficient cross-section or soil shrinkage can lead to leaks and breaches, as can an increase in soil moisture content. These various causes of breaches can ultimately lead to the need for pond rejuvenation [22].

Figure 5.8 shows flooding in the pond.

Figure 5.8 Flooding in the Pond

5.6.7 EMERGING CONTAMINANTS AND HEAVY METALS

Emerging contaminants, including pharmaceuticals, personal care products, and industrial chemicals, can accumulate in pond ecosystems, potentially harming aquatic organisms and disrupting ecological processes. Additionally, irrigation with contaminated water can introduce pollutants to crops, affecting food safety and agricultural yields. Similarly, heavy metals such as lead, mercury, and cadmium, often originating from industrial runoff and agricultural practices, can accumulate in sediments. Figure 5.9 depicts the contamination of the pond due to heavy metals.

Figure 5.9 Contaminated Pond by Heavy Metals

6.0 Restoration Phase

CPCB has provided guidelines for lake or pond restoration techniques. It includes direct (Preventive measures) and indirect measures. Pond restoration techniques of the Preventive measures and indirect measures within the lake or pond are explained phase Chapter 7.0 (Protection phase). However, the basic data required, and the data processing techniques required for the pond restoration are explained in this chapter. Figure 6.1 illustrates the process for restoration and rejuvenation of waterbodies as per CPCB guidelines.

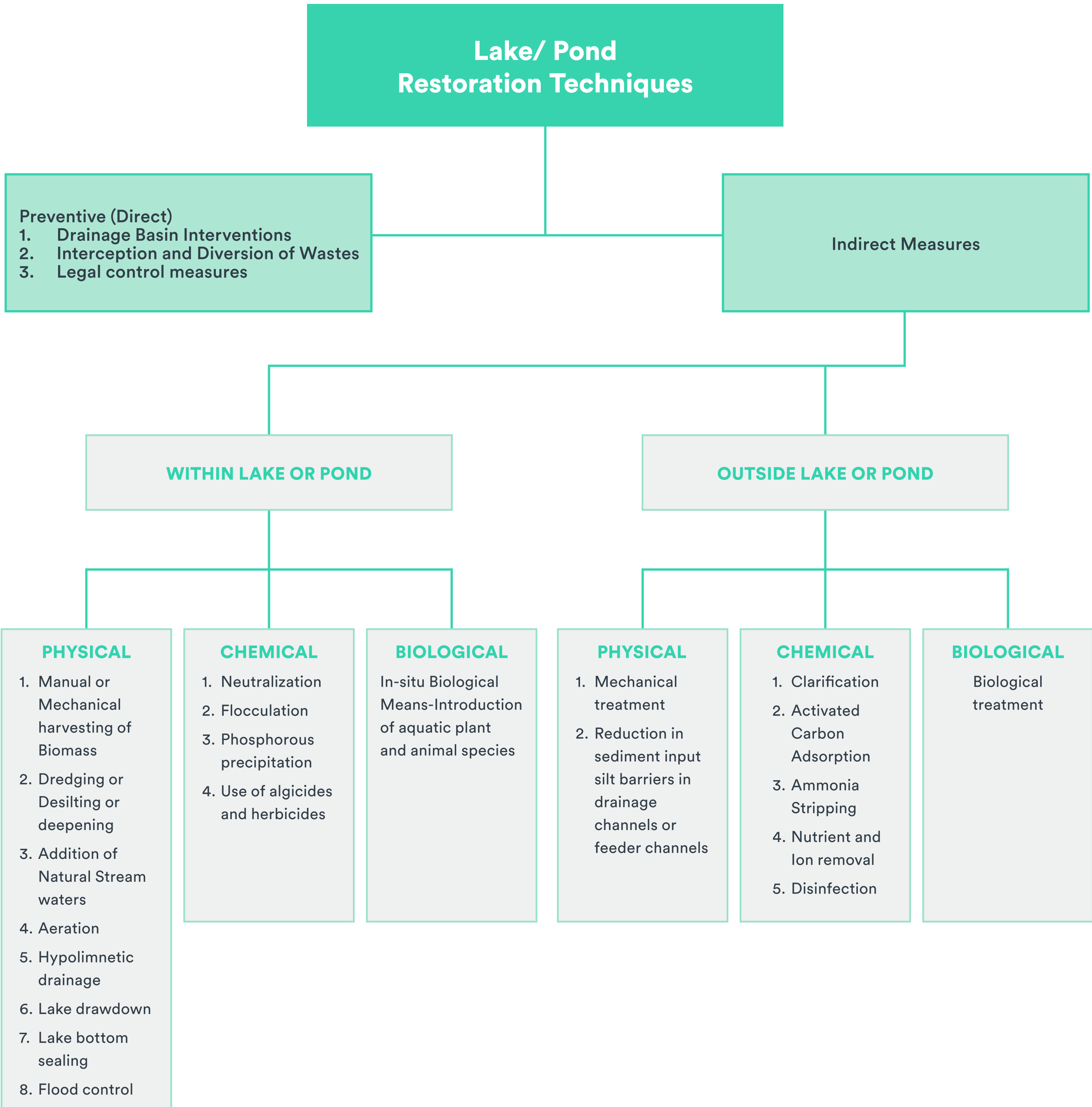

Figure 6.1 Process for Restoration and Rejuvenation of Waterbody as per CPCB Guidelines [3]

6.1 Design Procedure

This section provides a suggested procedure for designing a new pond. The steps and reference section for each action are provided in Table 6.1. Designing a pond should begin with selecting an appropriate location and outlining a general layout, considering factors such as land availability and intended use. Concurrently, a thorough investigation should be conducted to identify potential geotechnical and structural issues, and an erosion control plan is devised to manage soil erosion effectively. Following this initial assessment, a hydrological analysis is required to be performed to determine the inflow from the catchment area and inform decisions regarding the size, shape, and cross-sections of the pond. Parameters like maximum water elevation and design water levels should be established to ensure safe containment and efficient drainage, with careful consideration given to tailwater conditions in the outfall structure [23]. Subsequently, the design should proceed with the development of inflow and outflow structures tailored to regulate water flow into and out of the pond. Emergency spillways should be incorporated to mitigate risks during extreme weather events or outfall blockages. Finally, easement limits are to be defined to delineate the pond area, ensuring appropriate access for maintenance activities and accommodating multi-use purposes. By systematically progressing through these steps, a comprehensive pond design can be achieved, balancing functional requirements with environmental sustainability and safety considerations.

Table 6.1 Procedure for Designing a New Pond [23]

Step	Action	Refer Section No.
1	Select a location and prepare a general layout for the pond	Section 5.5, 6.3.1
2	Determine the inflow to the pond based on the catchment and hydrologic analysis	Section 6.3.4, 6.3.5
3	Determine the size and shape of the pond, Typical Cross Sections	Section 6.1.2
4	Establish the maximum recommended water elevation and design water elevation in the pond and determine tailwater condition in the outfall structure.	Section 6.1.1
5	Determine the inflow and outflow structure	Section 6.1.3, 6.1.4
6	Provide an emergency spillway or overflow structure for an extreme rainfall event or in the event of a blocked outfall pipe.	Section 6.1.4
7	Investigate potential geotechnical and structural problems and establish an erosion control plan	Section 6.1.1
8	Establish the easement limits, including access for maintenance and space for multi-use.	Section 6.1.2

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6.1.1 GENERAL DESIGN CRITERIA

A pond's location, size, and layout are influenced by the physical characteristics of the site, the type of pond proposed, the various uses of the pond, etc. This section covers general criteria and subsequent sections cover criteria for specific features [23].

Pond Location Considerations

Factors to consider in locating the site for the construction of the pond are explained in Section 5.5.

Design Frequencies

A typical pond in urban or rural areas is recommended to be designed for the frequency of one in 25-year return period rainfall events.

Outflow Rates

To prevent adverse effects, the pond's maximum recommended outflow rates must be restricted to a minimum of 25% to a maximum of 1% exceedance probability for 24-hour events. If the downstream channel is flowing bank full or at risk of flooding, ensure that the pond doesn't initiate overflow occurrences beyond bank capacity more frequently [23].

Critical Water Surface Elevations and Freeboard

Critical water surface elevations are:

- Maximum Recommended Water Elevation:
  When determining the maximum recommended water surface elevation, take into account factors such as ground elevation, finish floors of buildings, variable flow depths in the receiving channel, elevations of sewer manholes, water accumulation on roadways, emergency spillway design, and local subdivision and roadway criteria and regulations. Ensure that this elevation is not exceeded for emergency overflow design [23].

- Design Water Elevation:
  Ensure that the water elevation does not exceed 1% exceedance probability (100-year), 24-hour storm event [23].

- Freeboard:
  The difference between the low natural or finished ground elevation and design water elevation with the minimum should be at least 300 mm [23].

- Design Tailwater Elevation:
  In the case of pumped outfalls, ponds with limited outflow rates, or submerged storm sewer outfalls, it is recommended to aim for a water surface elevation corresponding to a 10% exceedance probability in the ponds. This helps reduce the duration and depth of street flooding [23].

Hydraulic Features

Hydraulic features typically constructed within a pond are listed below with the respective design criteria.

- Inflow Structures: Section 6.1.3
- Outflow Structures: Section 6.1.4
- Emergency Overflow: Section 6.1.4
- Layout: Section 6.1.2

Geotechnical Investigations

A geotechnical investigation is necessary for all the projects in existing ponds (that includes deepening or expanding the existing ponds) and proposed new ponds. The Geotechnical Engineer should typically assess and update the following aspects as necessary [23]:

- Stability of the pond side slopes under both short-term and long-term conditions. (If the pond depth is ≤ 1.5 m, a slope stability analysis may not be necessary, but a geotechnical report should still address other concerns.)

- Evaluation of bottom instability due to excess hydrostatic pressure: This helps to prevent issues such as bottom erosion, subsidence, or failure, ensuring the pond can safely contain and manage water without compromising its functionality or safety.
- Control of groundwater: Effective groundwater control helps prevent pond failure, reduces seepage losses, and ensures the proper functioning of drainage systems. Additionally, it aids in maintaining desired water levels within the pond and mitigates potential environmental impacts.
- Potential erosion problems at the inflow and outflow structures: Knowing the soil type (including dispersive soils) is critically important in understanding the erosion potential and designing appropriate erosion protection. Erosion can lead to reduced channel conveyance, stormwater storage due to sedimentation, and interference with maintenance, along with bank failures.
- Constructability issues: The geotechnical engineering consultant must address potential construction issues related to unstable soils, limited headroom, pond stability, slope stability, groundwater control, compaction, and appropriate construction techniques and equipment for the proposed design.

Water Quality Features

Water quality features required to be maintained in a waterbody are covered in Section 7.1, Water Quality Features. Evaluate the impact of water quality features that affect the hydraulic design of the pond [23].

Trees and Shrubs Planting

- Planting trees and shrubs [23]–
  - Maintain continuous minimum maintenance access route of typically 6 m wide along both sides of a grass-lined or partially grass-lined channel and around an entire pond.
  - Minimum spacing should be 2 m for habitat planting, 4 to 5 m for non-habitat planting, and 6 m for the maintenance access corridor.
  - Do not plant trees and shrubs within 6 m of outfall pipes, manholes, or interceptor structures to allow for maintenance access.
  - Trees and shrubs may be planted individually or in clusters along the top of the bank only if spaced 6 meters apart to allow equipment access to the entire side slope.
  - Provide additional easement (3 m minimum) to satisfy maintenance access criteria, if necessary.
  - Preservation of existing natural habitat areas such as native trees, and shrubs is encouraged where possible.
  - Planting new trees and shrubs is costly and can take many years to achieve size, habitat value, aesthetic value, and diversity. Leaving existing trees along roads and adjacent to subdivisions also has aesthetic and environmental benefits [23].

- Vegetated Shelf –

A shallow, vegetated shelf situated at the pond's edge with a flat or mild slope (10:1) is permissible. The purpose of the vegetated shelf is to [23]:
  - Provide substrate for habitat and wetland creation.
  - Facilitate onshore movements for animals and people.
  - Improve water quality.

6.1.2 LAYOUT

This section focuses on the geometric design factors that impact the pond size, depth, side slopes, and bottom design. The layout of a pond is influenced by many factors, such as [23]:

- Topography: The natural contours and elevation of the land shape affect the overall layout of the pond. Topography affects where the pond can be situated, its shape, and how water will flow into and out of it.
- Volume needed: The desired volume of water the pond should hold will dictate its size and depth, influencing its layout in terms of dimensions and capacity.

- Grading and depth requirements: The grading of the land and depth requirements for the pond influence how the basin is excavated or built to accommodate these specifications, impacting its overall shape and dimensions.
- Geometric design criteria: This includes considerations such as the shape and alignment of the pond, which can affect its functionality, aesthetics, and efficiency in managing water.
- Existing and future roads, pipelines, and utilities: The presence of infrastructure like roads, pipelines, and utilities can constrain or dictate the location and layout of the pond to ensure compatibility and avoid interference with these structures.
- Location of inflow, outflow control, and emergency overflow structures: These features determine where water enters and exits the pond, as well as provisions for managing excess water during heavy rainfall or flooding events, which significantly influence the layout.
- Maintenance access requirements: Designing access points for regular maintenance activities such as dredging, vegetation control, and inspection influences the layout to ensure ease of access without compromising the structural integrity of the pond.
- Environmental features: The presence of sensitive habitats, protected species, or other environmental considerations may influence the location and design of the pond to minimize ecological impact and enhance biodiversity.
- Soil and groundwater conditions: Understanding the soil composition and groundwater dynamics helps determine the feasibility of pond construction in certain areas and influences factors such as liner selection, seepage control measures, and overall stability.
- Owner-designated features: Specific preferences or requirements set by the owner, such as aesthetic features, recreational amenities, or water quality enhancements, can influence the layout and design elements of the pond to meet these objectives.

Thus, the following sub-sections provide the typical design criteria for the construction of new ponds.

Depth

The depth of a pond is typically determined by the depth of the outfall channel, roadside ditch, or storm sewer. However, in certain cases, the depth may be determined by the depth of the inflow channel or storm sewer, groundwater level, or soil conditions. For dry bottom ponds, the recommended depth is 0.30 m. For permanent pools and vegetated shelves depth of a minimum of 1 m and, a maximum of 2.5 m, depending on soils, geometry, and habitat goals is recommended [23].

Side Slopes

For pond side slopes [23]:

- For grass-lined slopes, the steepest side slope recommended is 3(horizontal):1(vertical) for long term stability and maintenance.
- For concrete-lined slopes,
    - Side slopes no steeper than 2(H):1(V)
    - Upper limit of lining 1/3 upside slope minimum
    - Concrete thickness on slope and bottom 0.12 m minimum
    - Minimum toe wall depth - Side slope – 0.60 m
    - In most cases, structural slope protection (concrete, riprap, etc.) is needed only 1/3 up the side slope.

Wet Bottom Ponds

The wet bottom ponds can have a permanent water pool and/or vegetated shelf. The purpose of a vegetated shelf (also called a shallow pool) is to support aquatic plants and habitats, improve water quality, and make it easier for people and animals to get back onshore. Water depth in a vegetated shelf usually fluctuates. A vegetated shelf can be incorporated around the edge of a permanent pool. The purpose of a permanent pool (also called a deep pool) is to [23]:

- Provide open water for aesthetics.
- Reduce vegetation management costs in larger ponds.
- Support fish habitats that help sustain a healthy pond.
- Improve water quality.
- Provide fishing opportunities.

The purpose of the bottom shelf is to reduce the risk of people (children) running or rolling down a slope into the water and to improve the aesthetics around a permanent pool. A bottom shelf is required around both vegetated shelves and permanent pools. The minimum water surface area for a permanent pool and vegetated shelf should be typically one acre. The following are the criteria for various components of the wet bottom pond [23]:

- Outfall Pipe Outlet Invert: 300 mm above channel flowline or 300 mm above the normal water surface, whichever is higher.
- Outfall Pipe Inlet Invert: A minimum of 150 mm above outlet invert and a minimum of 1 m per second velocity. It should also be visible for inspection and maintenance from at least one end of the pipe.
- Bottom Shelf: Height (600 mm above the static water surface), Cross-Slope (minimum 2%), Width (minimum 3 m).
- Permanent Pool: Depth (minimum 900 mm), Side Slope (no steeper than 3:1), Bottom slope (flat).
- Vegetated Shelf: Depth (0-500 mm), Bottom Slope (flat or mild slope).

Easement Limits

The minimum easement limits for maintaining a typical pond include [23]:

- The area within the top of the bank plus,
- Six meters for maintenance access plus,
- Three meters for the backslope swale system, where used plus,
- Three meters minimum if trails, trees, or other multi-use features are planned or anticipated in the future within the maintenance berm area at the top of the bank.
- Use the field survey data and pond profile to determine the limits of the pond top of the bank.

Minimum Berm Widths

Minimum berm widths around a pond for typical sections are outlined in Table 6.2. Additionally, allocate an extra minimum of three meters if trails, trees, or other multi-use features are planned. Irrespective of whether the pond plan shape is rectangular or curvilinear, corners must have a minimum radius of curvature of 7.5 meters to ease maintenance [23].

Table 6.2 Minimum Berm Width Around a Pond [23]

Pond Features	The Minimum Berm Width
Grass-lines with a depth > 2 m	9 m
Grass-lines with a depth ≤ 2 m	6 m
Grass-lines where side slopes are 8 (horizontal): 1 (vertical) or flatter	4.5 m
Lined with riprap or partially concrete-lined	Same as grass-lined channel
Fully concrete-lined	6 m

6.1.3 INFLOW STRUCTURES

Stormwater run-off enters off-stream ponds through storm sewer pipes, backslope swale pipes, ditches, and/or overland. Normal hydrologic analysis (Section 6.3.4) is performed for calculating the inflow rate. For a typical extreme event overland inflow at a concentrated location, the concrete overland flow swales and emergency overflow weirs should be constructed. The criteria are explained below [23]:

- Size the swale or weir appropriately to handle overflow. Typically, design flows should accommodate discharges ranging from 1% exceedance probability (100-year) up to 0.2% probability (500-year).
- Set the high bank elevation in the swale or weir below the lowest slab elevation to minimize the risk of flooding during extreme overland flow events.
- Design the berm beyond the weir to manage additional flow.
- Ensure that the geometry of the swale or weir allows inspection and maintenance vehicles on the maintenance berm across the swale during dry periods.
- General criteria are minimum bottom width (1.5 to 2 m), maximum depth (1 to 1.5 m), and side slopes (5H:1V or flatter).
- Line the swale or weir with concrete lining (minimum thickness of lining should be 100 mm) on the channel or pond maintenance berm, extending to the side slope and at the bottom.
- Do not locate inflow structures in the corner of the pond [23].

Side Weir

When aiming to delay the filling of the pond until the water in the channel reaches a specific level, an inflow structure known as a side weir can be utilized [23]. This method:

- Prevents the pond from becoming inundated by smaller, more frequent storms that do not cause flooding, facilitated by a backflow preventer on the pipe outfall.
- Preserves the pond volume for use during severe storm events when the volume is more effective at reducing peak flows.
- May necessitate less stormwater volume and land compared to a conventional flow-through facility.

Note: Whether a side weir or flow-through system is used depends on the pond's location within the watershed and the location of the area where flood level reduction is desired. When the area of flood level reduction is hydraulically close to the pond, a side-weir typically offers greater efficiency [23].

Erosion Control

Inflow pipes can experience high velocities and turbulence, necessitating erosion protection at all storm sewer pipe outfalls. Riprap is the default option, similar to outfalls into channels. In certain cases, custom erosion protection designs may be necessary for outfall pipes or boxes, pond geometry, and soil type variations. This could involve utilizing concrete lining and/or riprap. The concrete lining is preferred for protecting weir structures, ensuring proper coverage, thickness, reinforcement, and the inclusion of the toe walls (a low retaining wall) for each structure. Riprap can be employed to transition to a grass-lined channel or pond [23].

Turf grass establishment is also one of the options for erosion control. An established permanent turf grass cover serves as a cost-effective and efficient means to stabilize pond banks and mitigate erosion induced by overflow and rapid water currents. Achieving a good turf grass cover can necessitate soil testing and preparation, fertilization, appropriate seed selection, proper seeding techniques, securing the seed in place, and consistent watering practices [23].

Stone pitching for pond inlets is a very common approach to erosion control that involves the strategic placement of durable stones like granite or basalt to prevent soil erosion and stabilize slopes. The process begins with proper subgrade preparation, followed by the selection of stones typically ranging from 100mm to 300mm in diameter. Stones are placed in patterns such as random, coursed, or graded pitching, with backfilling and compaction of the area behind them to ensure stability. Edge protection is crucial, as is controlling vegetation growth and implementing regular maintenance for long-term effectiveness. Environmental considerations, including habitat preservation and water quality, should also be taken into account during the implementation of stone pitching projects.

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Pipe Outfalls on a Bottom Shelf

For storm sewer or offsite ditch interceptor pipes that discharge onto a grass-lined bottom shelf within a wet bottom pond, incorporate a swale extending from the pipe to the permanent pool or vegetated shelf [23]. For the outfall pipe, the design criteria are:
The swale criteria are [23]:

- Minimum 150 mm deep.
- Flowline gradient should be the same as the bottom shelf cross slope (typically 2%).
- Minimum top width should be 2x pipe diameter or box width.
- Center on the pipe.
- Line with 70-130 mm granular material, concrete lining, or other acceptable material for the flow condition anticipated.
- Cover granular material lining with a minimum of 150 mm topsoil and vegetate.
- Extend lining a minimum of 1.5 m beyond the edge of the bottom shelf into the permanent pool or the vegetated shelf [23].

Pipe outfalls are a commonly used method for conveying flow into channels and ponds [23].

- Use corrugated metal pipe (galvanized steel or aluminum) or HDPE pipe with a minimum diameter of 0.6 m for outfall pipes.
- Angle pipes and boxes downstream at a minimum of 30 degrees, starting at the last manhole and measured from a line perpendicular to the channel.
- Locate storm sewer outfalls on the downstream side of bridges and culverts.
- Avoid placing outfalls beneath concrete slope paving, spillways, retaining walls, and other structures to prevent hindrances to maintenance and repairs. If unavoidable, utilize concrete pipes or box culverts with headwall/wing walls [23].

6.1.4 OUTFALL STRUCTURES

Common structures used to regulate outflow from a pond are pipes, box culverts, risers, and weirs. These structures can be adjusted in terms of numbers, sizes, and elevations to control outflows for different storm frequencies. References to pipe outflows include box culvert outflows, as well. Numerous equations and computer programs are accessible for calculating flows and head losses through pipes, boxes, and weirs [23].

Minimum Pipe Size or Opening

To minimize the risk of clogging, the minimum size of the outfall pipe should be 0.5 m. If a smaller restrictor is necessary, install a short section of a smaller pipe or a plate at the upstream end of the outfall pipe within the pond to aid in inspection and debris removal. The minimum size for the restrictor is a 150 mm diameter pipe or a rectangular opening measuring 130 mm wide x 150 mm high. Rectangular openings are preferred due to their lower likelihood of clogging [23].

Orifice Equation

To restrict the outflow with a short segment of pipe or reduced opening size, use the orifice Equation 6.1 [24]:

$$Q_0 = C_0 A\sqrt{2gh} \qquad \text{– – – (6.1)}$$

where,

- Q_0 = discharge (m^3/s)
- C_0 = coefficient of discharge = $\dfrac{\text{Actual Discharge}}{\text{Theoretical Discharge}}$
- A = cross-sectional area of the orifice (m^2)
- g = acceleration due to gravity (m/s^2)
- h = the hydraulic head difference between entrance and exit in (m) when the orifice is fully submerged, or the difference between the water surface elevation at the entrance and the centroid of the orifice in m when the orifice is partially submerged.

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Outflow Structures

- For pipe outflow structures in the maintained channels [23]:
- Use only one outfall pipe or box into the channel where hydraulically and physically feasible.
- For corrugated metal pipes, incorporate riprap erosion protection in grass-lined channels and ponds for any size outfall pipe.
- For reinforced concrete pipes or box culverts, use a headwall/wingwalls with an apron in the pond and headwall/wingwalls with an apron recessed into the channel that does not disrupt the flow in the channel.
- Avoid situating outfall pipes and boxes under concrete slope paving, spillways, retaining walls, and other structures to prevent interference with maintenance and repairs. If unavoidable, use concrete pipes or box culverts with headwall/wingwalls and aprons [23].

Backflow Preventers

- Two common types are flap gates and duckbill check valves. During the following situations, the backflow preventers should be used if they [23]:
- Are above the normal water surface.
- Do not project into the channel flow.
- Are recessed into the channel side slope with a headwall and wingwalls.
- Can be easily accessed and designed appropriately to remove debris
- Include an all-weather access road to the backflow preventer to remove debris and make repairs.

Seepage

Seepage around the pipe or box outflow structures can pose a significant problem due to the potential high head differential between the channel and pond. It is crucial to construct carefully with cement stabilized sand around the entire pipes or boxes and ensure proper backfill compaction around the pipes or boxes or as recommended by the geotechnical engineer [23].

Weirs

Weirs can be used to control the design outflow or the emergency overflow from a pond. Weirs are sometimes used as an inflow structure, also. The rectangular weir equation is Equation 6.2 [24]:

$$Q_w = C_w L_w [(h+v^2)/2g)^a - (v^2/2g)^a] \quad --- (6.2)$$

where,

- Q_w = weir discharge (m^3/s)
- C_w = coefficient of discharge = $\frac{\text{Actual Discharge}}{\text{Theoretical Discharge}}$
- L_w = length of weir (transverse to overflow) (m)
- h = driving head on the weir (m)
- V = approach velocity (m/s^2)
- a = weir exponent, 3/2 for transverse weirs and 5/3 for side flow weirs

Erosion Control for Weirs

Concrete lining or riprap should be utilized around pipe inlets in areas where erosive velocities and turbulence are anticipated to prevent high head differentials and erosive velocities for extended periods. Additionally, flow from the outflow structure can lead to erosion in the outfall channel due to high velocities and turbulence. Use concrete lining for weirs. Design coverage, thickness, reinforcement, and toe walls for each structure. Use riprap to transition to a grass-lined channel or pond [23].

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Design Frequency
Design the outflow structures depending on the volume of water pond needs to store (pond capacity), the remaining water should be allowed to overflow through weirs. Besides, the outflow structures are recommended to design for the outflow rates of a rainfall events with a return period of one in 5 years.

Tailwater
The water surface elevation in the outfall channel at the outflow structure is referred to as the tailwater. Two assumptions regarding tailwater conditions are utilized to facilitate analysis and design: Fixed and Variable [23].

Backwater
In areas near channel confluences and coastal zones, backwater can arise, exceeding the tailwater from the flow in the channel. When designing the emergency overflow and establishing design water levels in the pond, it is essential to account for this backwater effect [23].

Emergency Overflow
The purpose of emergency overflows from the ponds is to keep water levels from exceeding an elevation that would [23]:

- Flood the surroundings, the ponds meant to protect.
- Overtop the pond and erode the downstream channel bank.

Water elevations above design elevations are possible when [23]:

- Rainfall amounts, duration, pattern, etc. result in inflows that exceed outflows and the available pond storage.
- The outflow structure is physically blocked resulting in reduced outflow.
- High backwater conditions in the outfall channel.

Following considerations should be made for emergency overflow designs [23]:

- Avoid placing the emergency overflow on fill and banks or bottoms which are easily eroded. If erodible banks or bottoms cannot be avoided, modify, or extend erosion control structure design to minimize erosion.
- Do not place the emergency overflow weir over the outflow pipe structure to minimize disturbance of the overflow weir when the outflow pipe is replaced or repaired. The outflow pipes can be adjacent to the emergency overflow weir [23].

Pond design criteria generally exhibit consistency, yet variations arise in certain aspects based on their location in coastal, arid, or wet regions. Designing for coastal regions requires considering tidal influences and the risk of saltwater intrusion. Freeboard requirements may vary based on factors such as precipitation levels, and flood risk. Coastal regions and wet regions may require a higher freeboard heights to accommodate tidal fluctuations, storm surges, and heavy rainfall. To withstand coastal erosion and wave action, weir/overflow structure design can be done by considering a 100-year return period with proper maintenance. In arid regions, design strategies may prioritize water conservation and minimize evaporation losses. It can be beneficial to utilize impermeable liners to minimize seepage losses and drought-tolerant vegetation for landscaping and bank stabilization. Structural integrity is paramount to ensure the safety and longevity of the pond, regardless of the region.

6.2 Data Collection

The data required for the above design procedure is elaborated in this section. Various data sources such as meteorological data, hydrogeological surveys, and topographical data are included. Through the integration of various data sources, stakeholders can gain invaluable insights into the current state of ponds, enabling informed decision-making and targeted interventions to revitalize these ecosystems effectively. Data sources are given in Table 6.3.

Table 6.3 Data Sources [23]

Heading	Data type	Source
Meteorological Data	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 the closest gauge station with a long meteorological data record.
Hydrogeology	Hydrogeological	CGWB (Aquifer Atlas | cgwb)
		Aquifer Atlas and Maps – Aquifer Systems of India
		State-wise Aquifer Atlas and Maps (as of Sep 23) – Chhattisgarh, Karnataka, Kerala, Himachal Pradesh, Meghalaya, Goa, Andhra Pradesh, Madhya Pradesh, Tamil Nadu
	Soil Map	Soil & Land Use Survey of India
Catchment and topography	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 patterns can also be derived through ArcGIS software using the Digital Elevation Model (DEM). The gridded tiles for DEM downloaded from Bhuvan (Indian Space Research Organisation (ISRO) website) (Bhuvan | NRSC Open EO Data Archive | NOEDA | Ortho | DEM | Elevation | AwiFS | LISSIII | HySI | TCHP | OHC | Free GIS Data | Download) have a vertical accuracy of 8m at 90% confidence.
		Higher resolution DEM can be purchased from (Home | Natural Resources Conservation Service (usda.gov)) Natural Resources Conservation Service (NRCS).

Heading	Data type	Source
Incoming flow to waterbody	Flow from the catchment	Runoff Estimation, Manual on Storm Water Drainage System, Volume -I (Part A: Engineering Design), 2019. Published by Central Public Health and Environment Engineering Organization (MOHUA : Ministry of Urban Development)
		Using tools such as Arc Hydro (Arc Hydro GIS for Water Resources | Tools for Watershed Management (esri.com)), Soil & Water Assessment Tool (SWAT) (SWAT | Soil & Water Assessment Tool (tamu.edu)), Better Assessment Science Integrating point and Nonpoint Sources (BASINS) (BASINS Download and Installation | United States Environmental Protection Agency (US EPA)), Personnel Computer Storm Water Management Model (PCSWMM) (SWMM5 modeling with PCSWMM).
	Other sources of flow	Incoming flow from upstream Used water treatment plants discharging into the waterbody. Collect the outflow discharges from the utility/organization operating the plant.
		Untreated used water from areas not connected to the network is discharged into the drains leading to the waterbody. Install flow meters at the inlet of the waterbody.
Land use and land cover	Land use and land cover	Municipal corporation, regional development authority
		BHUVAN Portal (Indian Geo Platform of ISRO (nrsc.gov.in))
		Procured satellite images from NRSC
Bathymetry with waterbody inlet and outlet survey	Waterbody bathymetry	Primary data collection. It is recommended to collect the data at a 10 m × 10 m grid. It will include surveying the waterbody inlet and outlet.

6.3 Data Processing

The data collected in Section 6.2, should be processed to further use in the pond design. This section also discusses the technical calculations required for pond design.

6.3.1 TOPOGRAPHY

A detailed topographic map for pond design or construction can be created using GIS software. The following steps and analysis can be implemented to process the topographic data:

- It can be initialized by importing elevation data, whether in points, contours, or a DEM. Generate a surface model, such as a Triangular Irregular Network (TIN) or raster surface, and produce contour lines representing elevation changes.
- Analyze slopes to understand terrain variations, identify drainage patterns, and delineate pond boundaries based on the elevation data.
- Utilize GIS tools to calculate volume, ensuring pond capacity aligns with project requirements.
- Overlay additional data, like land use and soil types, for comprehensive site analysis.
- Symbolize features, label key elements, and finally, export the map for use in the design or construction process. Accuracy in data collection is crucial, and consulting with GIS professionals can enhance the precision of the topographic map.
- The site should be such that the largest storage volume is available with the least amount of earthfill. A narrow section of the valley with steep side slopes is preferable. Large areas of shallow water should be avoided as these will cause excessive evaporation losses and, also cause water weeds to grow. Conduct a drainage area analysis to determine the area draining to the pond.

A DEM is a representation of the Earth's surface in digital form, capturing elevation data for each point on the terrain. These models are crucial for topographical analysis. DEMs are sourced from various methods including satellite imagery, Light Detection and Ranging (LiDAR) technology, and aerial photography, providing resolutions ranging from coarse global datasets to high-resolution local surveys. The availability of DEMs with diverse resolutions allows for tailored analyses, from large-scale regional studies to detailed local terrain modeling. Table 6.4 shows some of the open-access sources of DEM with different resolutions. Various DEM sources for India are given in Table 6.4.

Table 6.4 Various DEM Sources for India

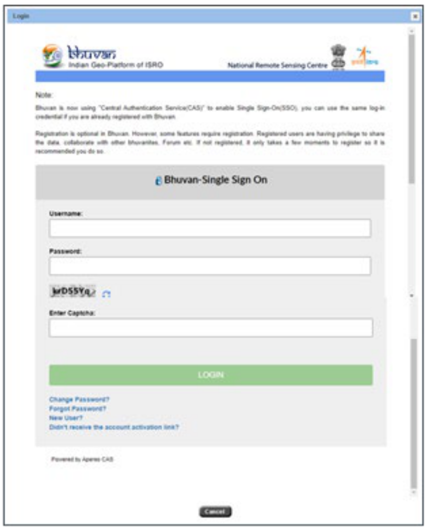
Various DEM and Their Sources	
Bhuvan DEM- CARTOSAT (30m×30m) (Year 2005)	Bhuvan | NRSC Open EO Data Archive | NOEDA | Ortho | DEM | Elevation | AwiFS | LISSIII | HySI | TCHP | OHC | Free GIS Data | Download
SRTM (30m×30m) (Year 2000)	EarthExplorer (usgs.gov)
ALOS PALSAR (12.5m×12.5m) (Year 2007)	ASF Data Search (alaska.edu)
ASTER (30m×30m) (Year 2013)	Earthdata Search | Earthdata Search (nasa.gov)

The procedure for downloading DEM data varies depending on the chosen source. For this purpose, we will focus on acquiring DEM data from Bhuvan, a platform maintained by the ISRO.

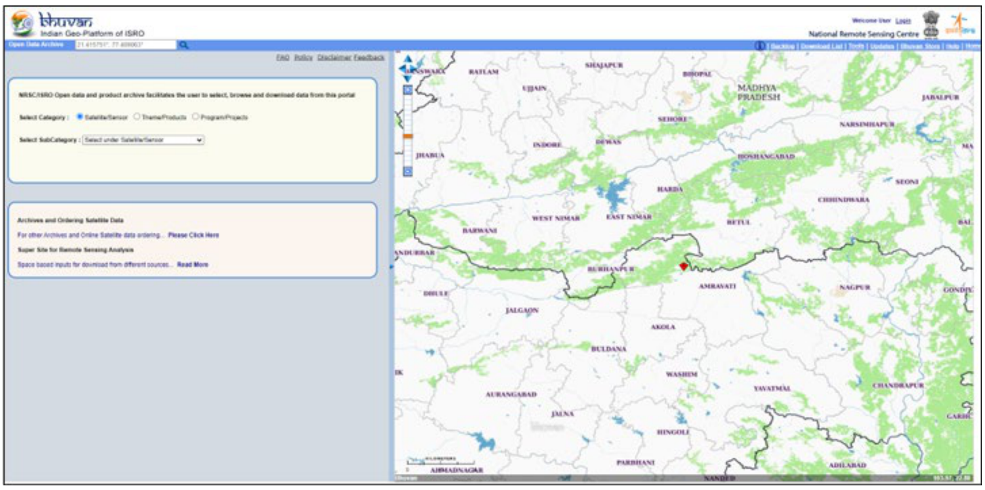
Below is the formal procedure for downloading DEM data from Bhuvan:

Step 1:
Access the Bhuvan website [Bhuvan | NRSC Open EO Data Archive | NOEDA | Ortho | DEM | Elevation | AwiFS | LISSIII | HySI | TCHP | OHC | Free GIS Data | Download]

Step 2:
Login on the Bhuvan website. If you do not have an account, please click on "NEW USER" to create an account. Alternatively, if you already have an account, please log in using your Username and Password. This step is necessary to access the download functionality and ensure a seamless experience on the Bhuvan platform.



Step 3:
Select the desired region or area of interest by giving coordinates (Latitude, Longitude).



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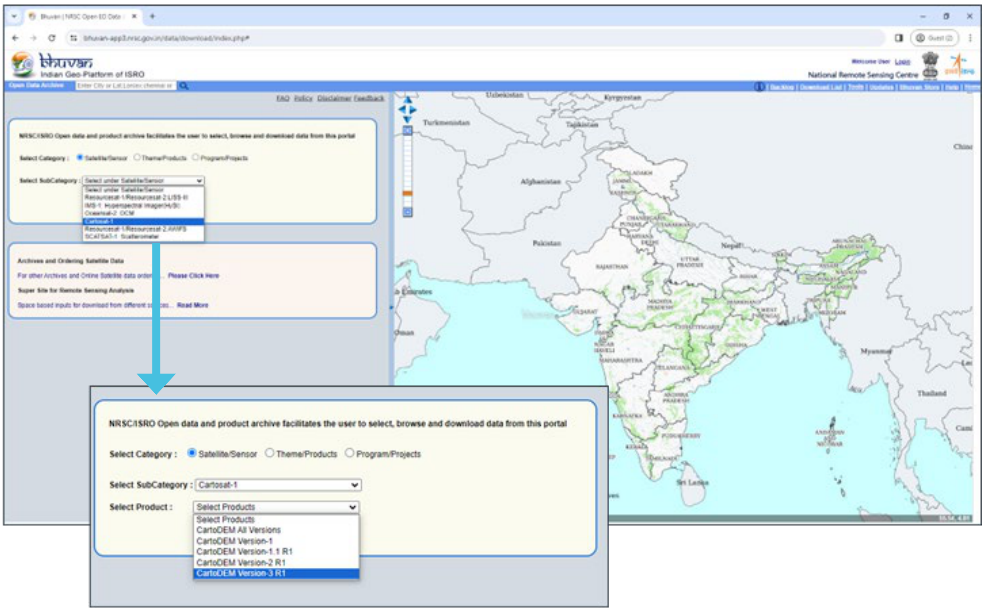
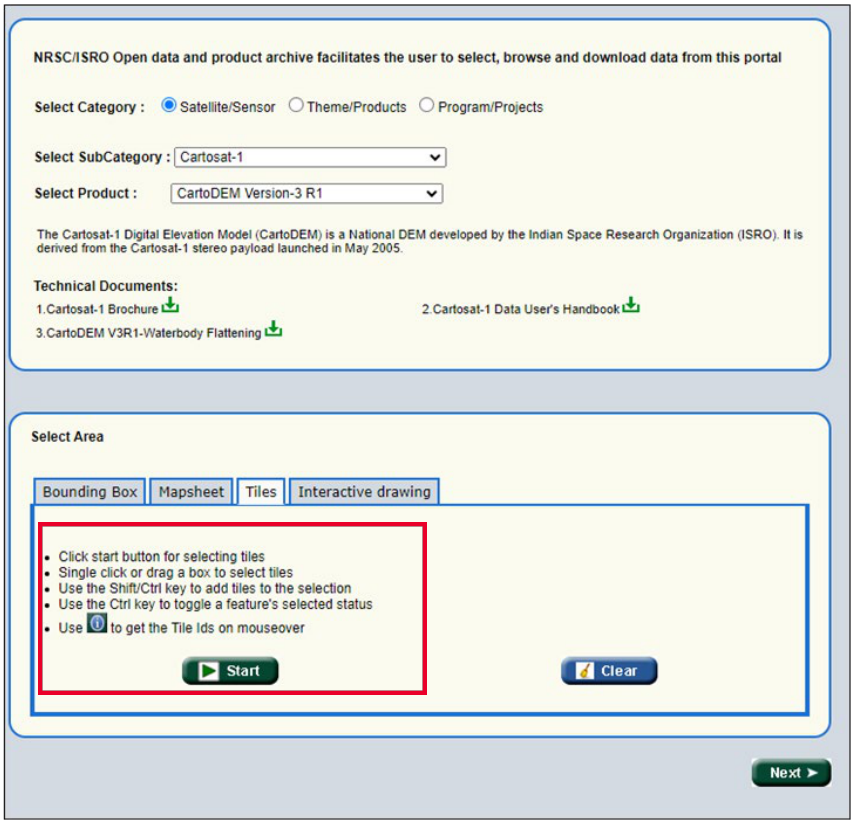
Step 4

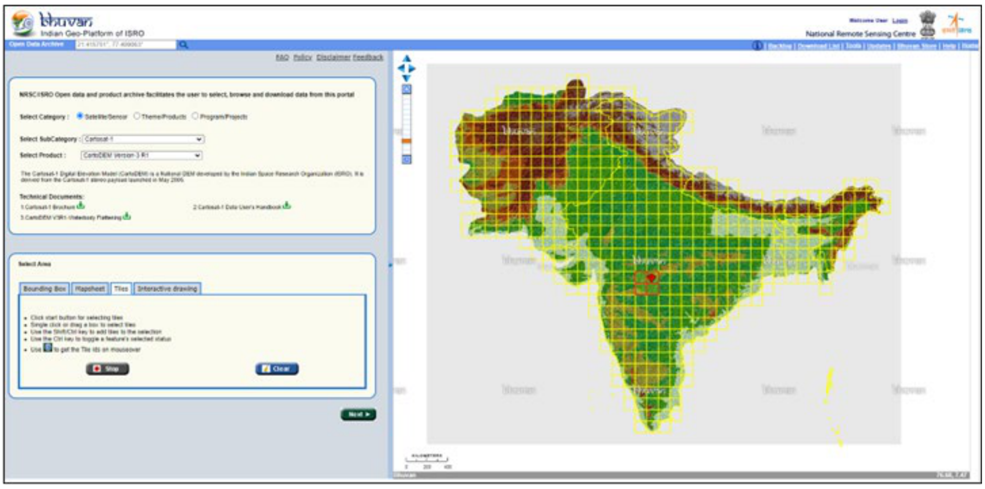
Choose the appropriate DEM dataset based on your requirements, considering factors such as spatial resolution and coverage area. The DEM developed by the ISRO from Cartosat-1 version-3 (latest available) from Bhuvan with 30m x 30m grid resolution will be used for catchment analysis. Select Cartosat-1 and CartoDEM Version-3 R1.



Step 5

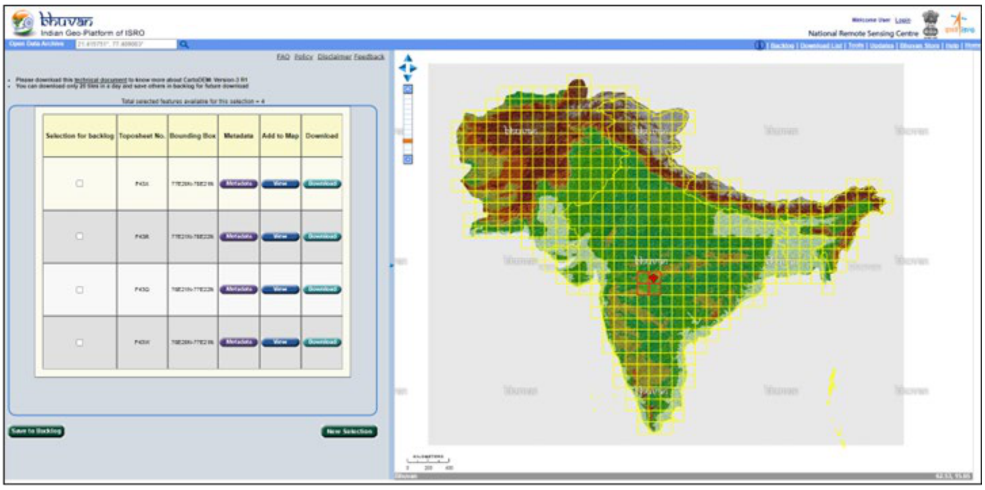
Select the study region tiles by following the steps given in the dialog box.





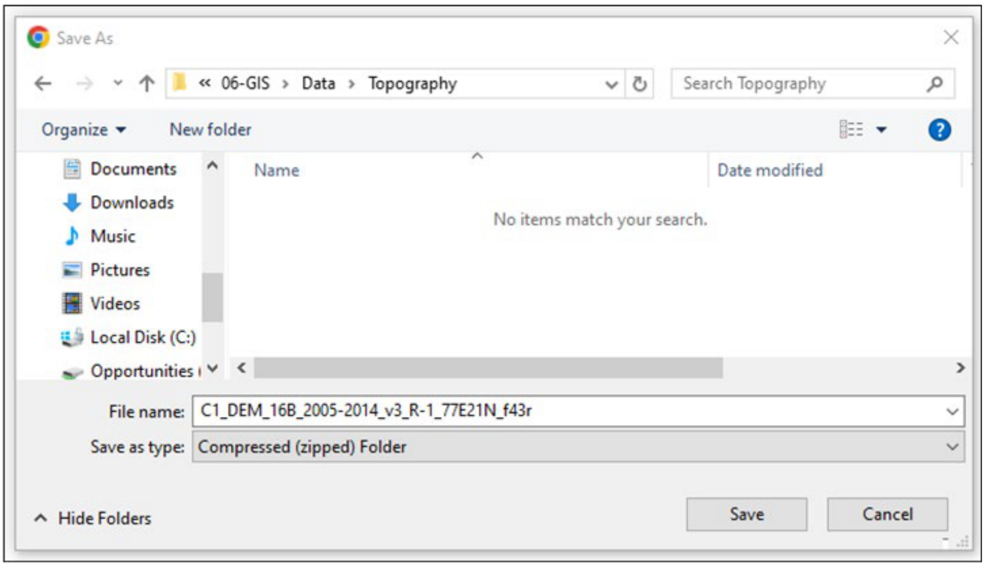
Step 6:

After selecting tiles click stop and next. Specify the desired data format and download options, ensuring compatibility with your software or analysis tools. Then download each tile DEM Zip file by clicking DOWNLOAD.



Step 7

Review and confirm the selected parameters before initiating the download process and saving files. Once the download is complete, verify the integrity of the DEM data and ensure it meets the specifications for your intended analysis or application.



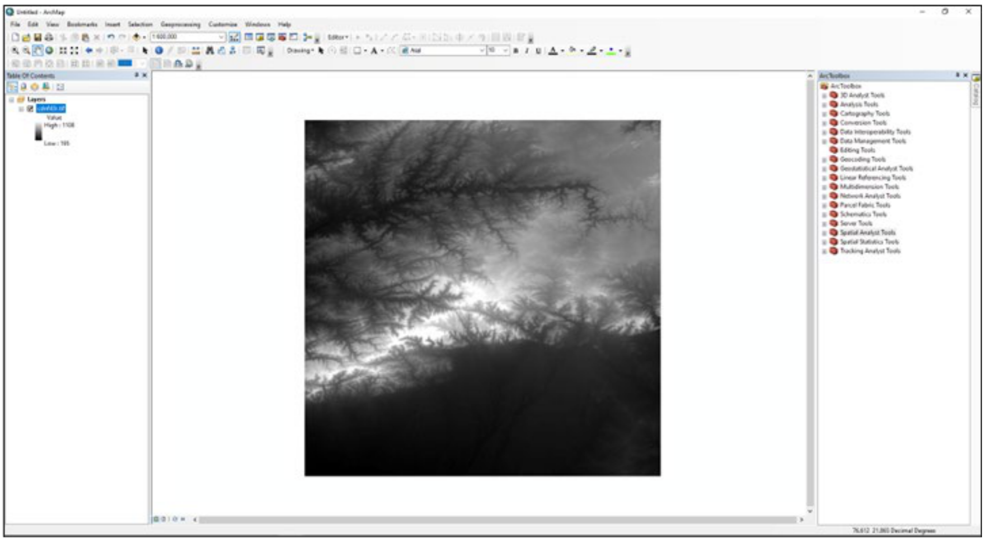
By following these steps, users can effectively download DEM data from Bhuvan for further processing and analysis.

DEM Processing

The ArcMap software of ArcGIS can be used for catchment delineation for the pond. Below are the steps explained for the catchment delineation of Jamlivan Pond, Amaravati as an example.

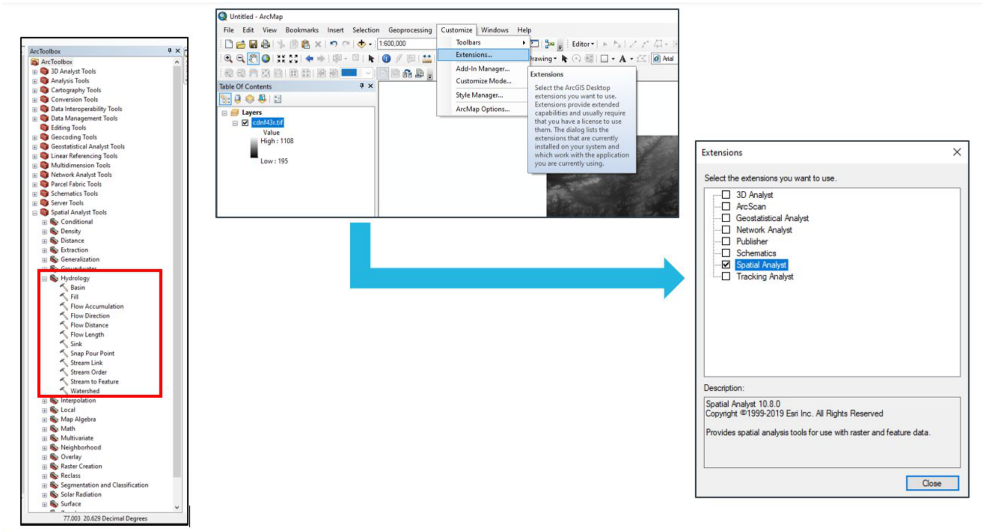
Step 1:

Open ArcMap and import the DEM file which is downloaded from Bhuvan. DEM files can be imported by dragging the TIF file to the Layers panel.



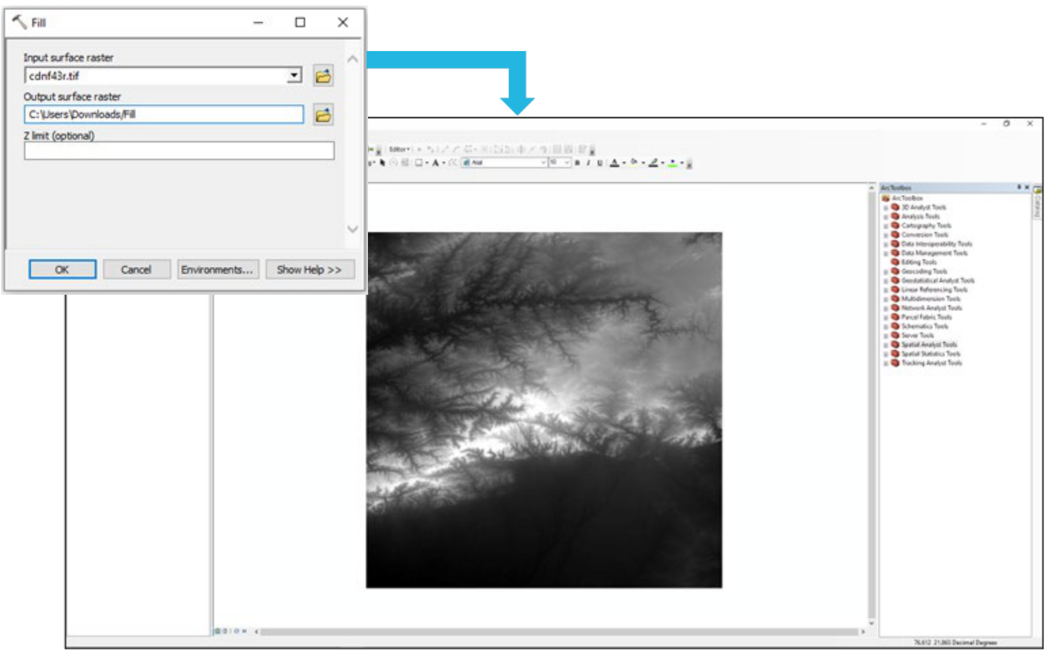
Step 2

Fill: Go to the “ArcToolbox” panel. Navigate to “Spatial Analyst Tools” > “Hydrology”. For the watershed delineation process also check the Spatial Analyst Extension.



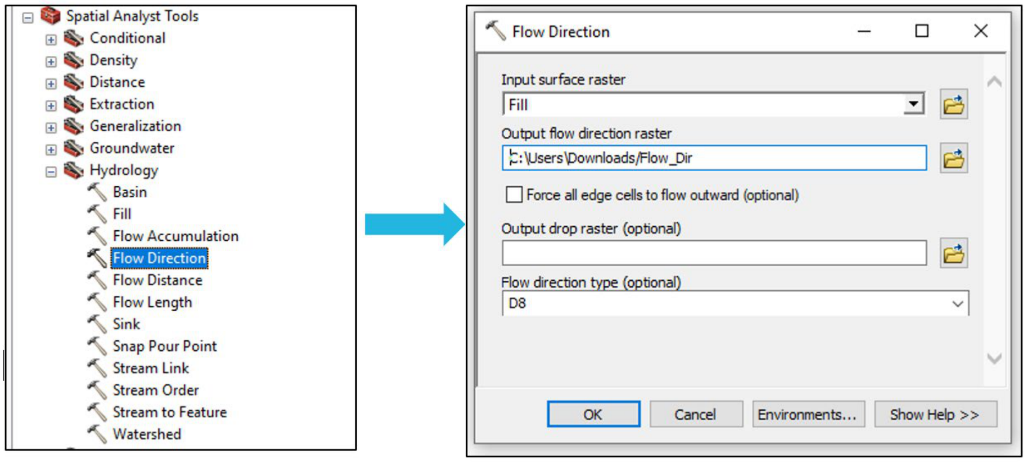
Step 3:

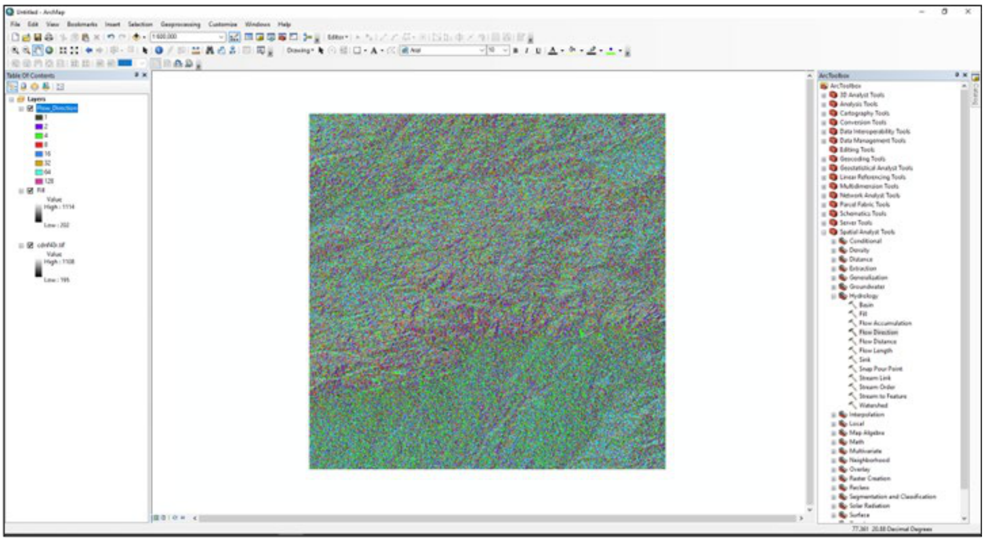
Choose the “Fill” tool. Input the DEM raster dataset and specify an output location and filename for the filled DEM. Run the tool to fill sinks in the DEM.



Step 4:

Flow Direction: In the "ArcToolbox" panel under "Spatial Analyst Tools" > "Hydrology". Select the "Flow Direction" tool. Input the filled DEM raster dataset and specify an output location and filename for the flow direction raster. Run the tool to calculate flow direction based on the filled DEM.





Step 5:

Flow Accumulation: Within the "ArcToolbox" panel under "Spatial Analyst Tools" > "Hydrology". Choose the "Flow Accumulation" tool. Input the flow direction raster obtained in the previous step and specify an output location and filename for the flow accumulation raster. Run the tool to calculate flow accumulation based on the flow direction raster.

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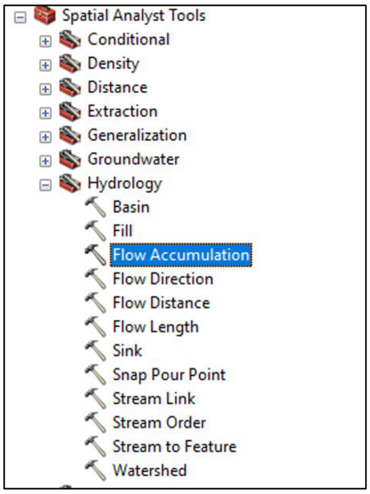
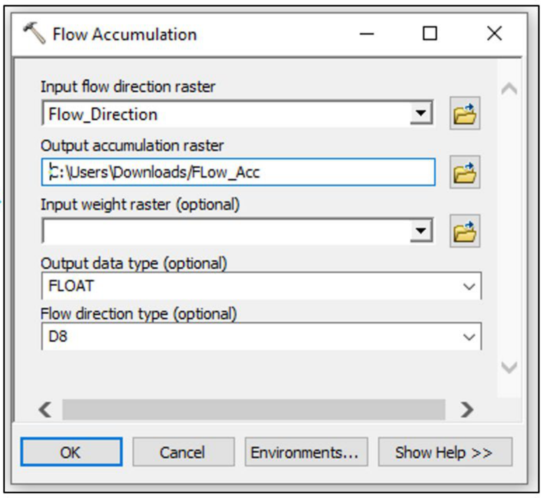
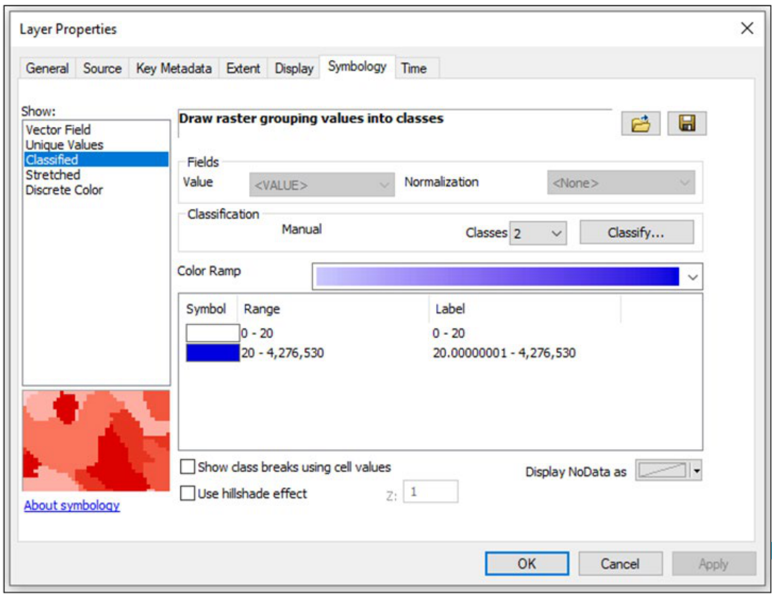
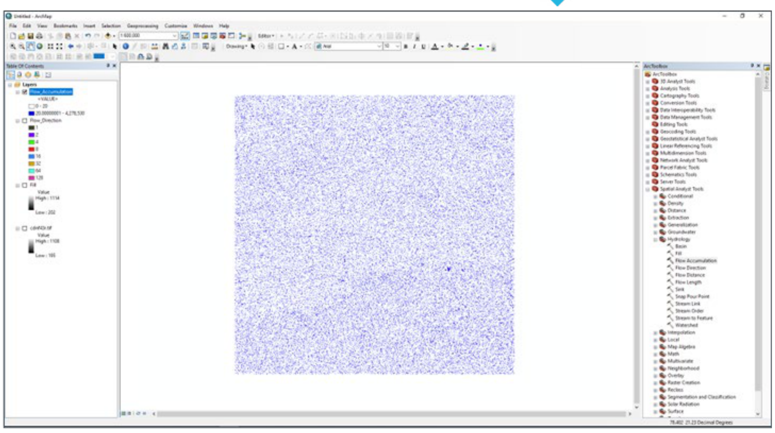




Step 6:

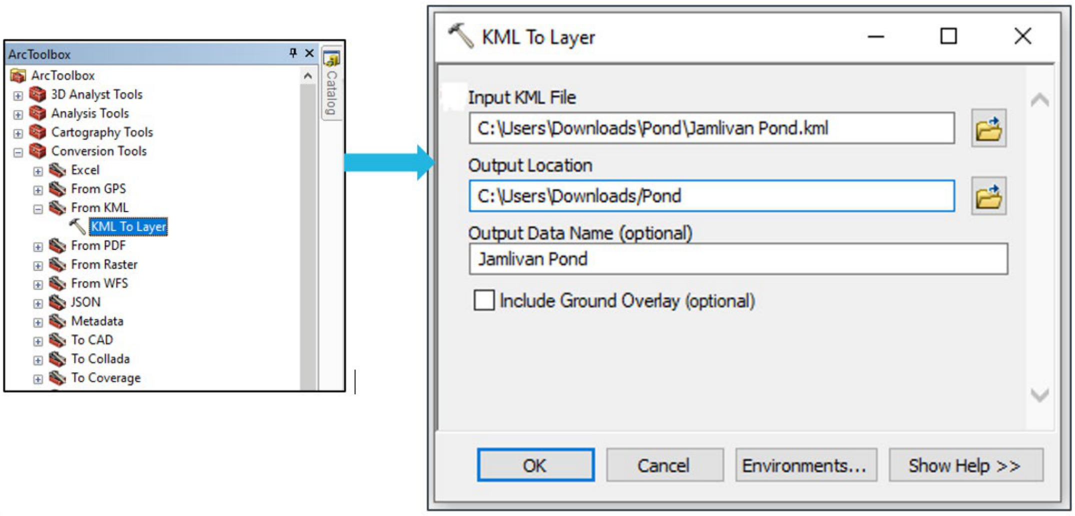
In the Layers panel right click on the Flow Accumulation layer. Go to “Properties” > “Symbology” > Show: Classified – Classes: 2 – Classify: Change Range – Change Colour.





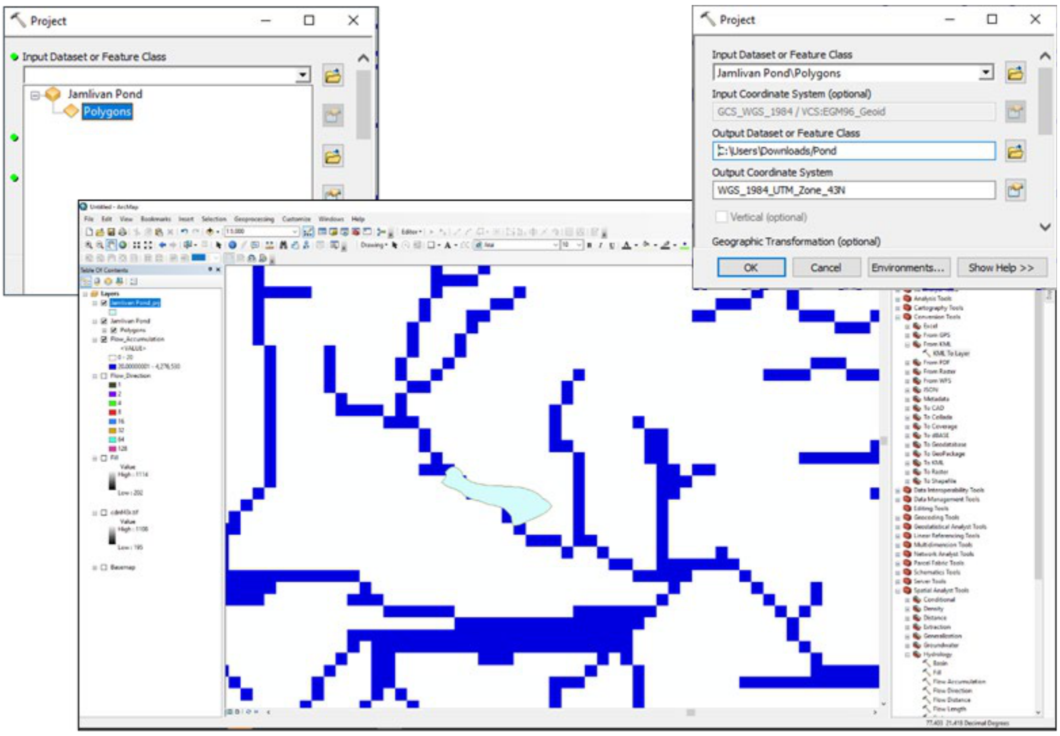
Step 7:

Convert located pond KML file to shape file by Conversion Tool in ArcTool Box. Input the pond KML file and specify the output location.



Step 8:

To project the pond location shape file to the appropriate UTM zone go to Project (Data Management) Tool and project the shape file.



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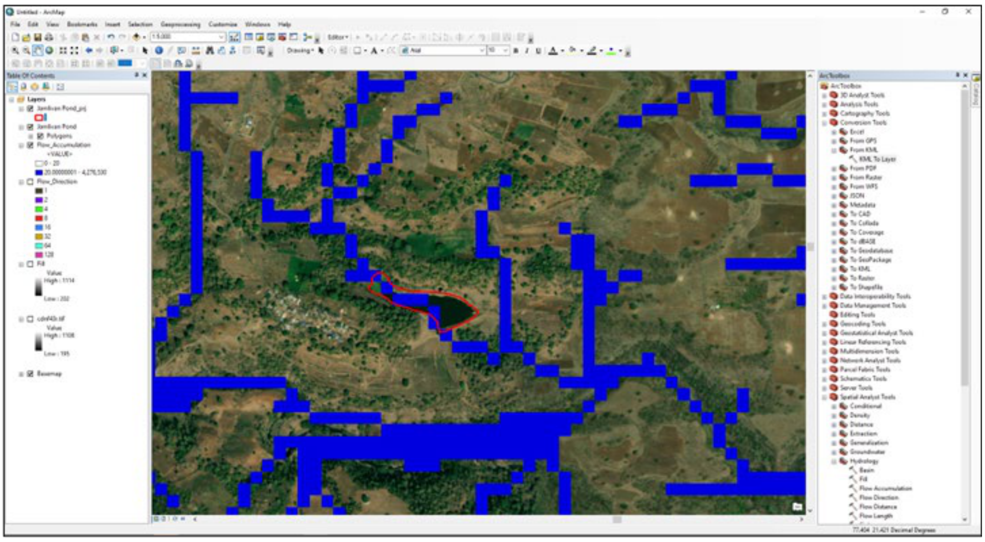
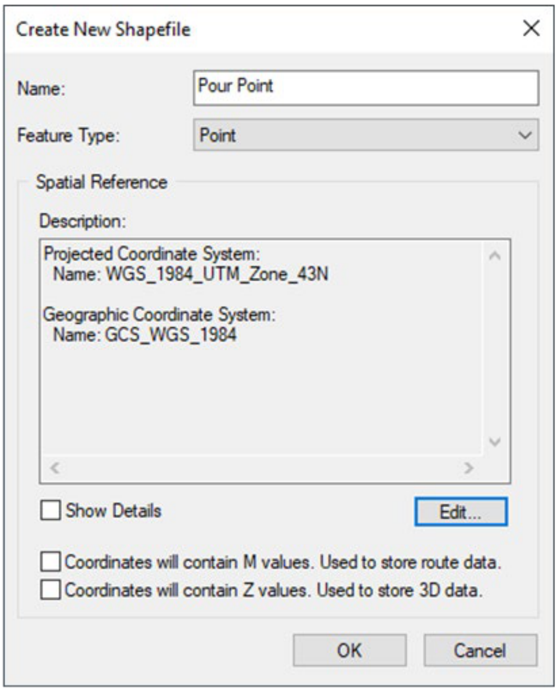
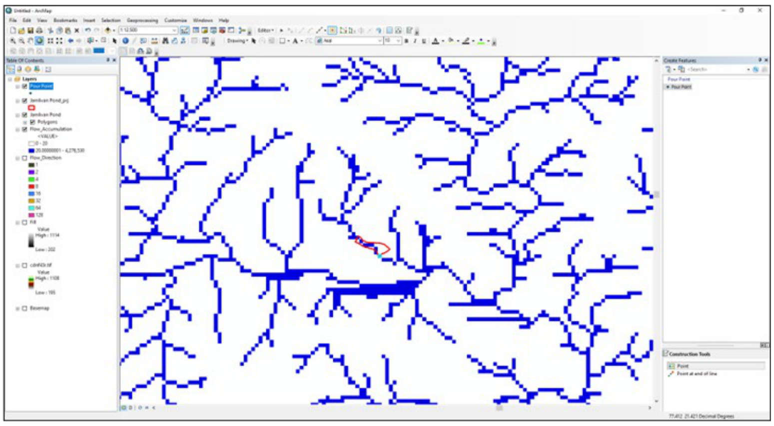


Step 9:

Catchment Delineation: From the catalog – create a new shape file of pour point. From the EDITOR Tool- start editing the pour point. Then go to EDITOR > Editing Windows > Point. Then save edits.





Step 10:

Identify the location of the pour point. Go to the “ArcToolbox” panel under “Spatial Analyst Tools” > “Hydrology”. Select the “Watershed” tool. Input the flow direction raster obtained earlier, the pour point feature representing the outlet, and optionally the flow accumulation raster. Specify an output location and filename for the watershed raster. Run the tool to delineate the watershed based on the specified pour point.

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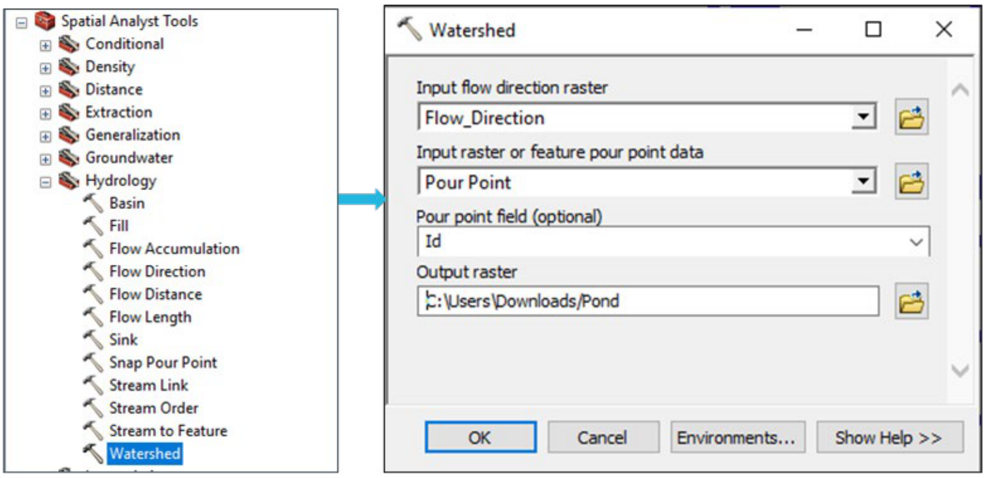
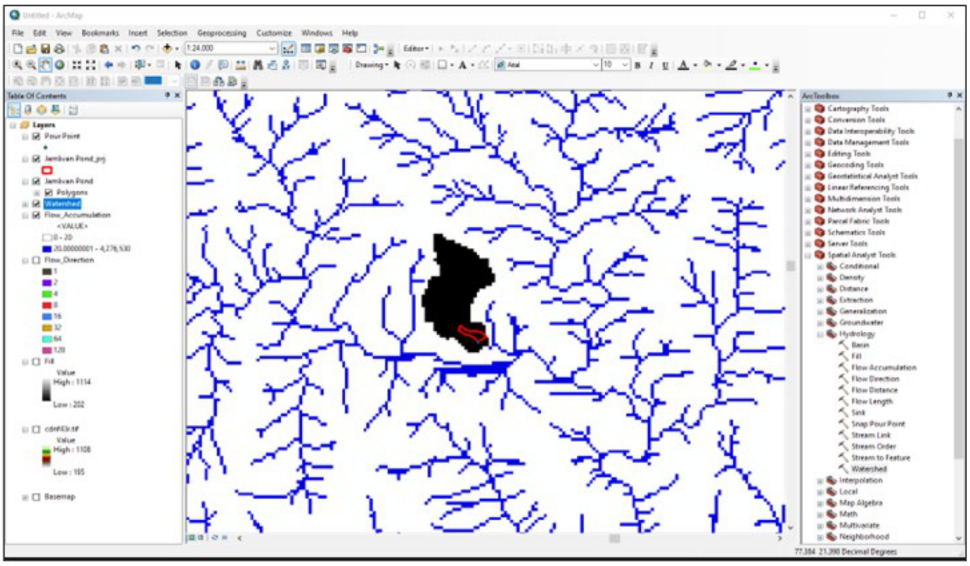
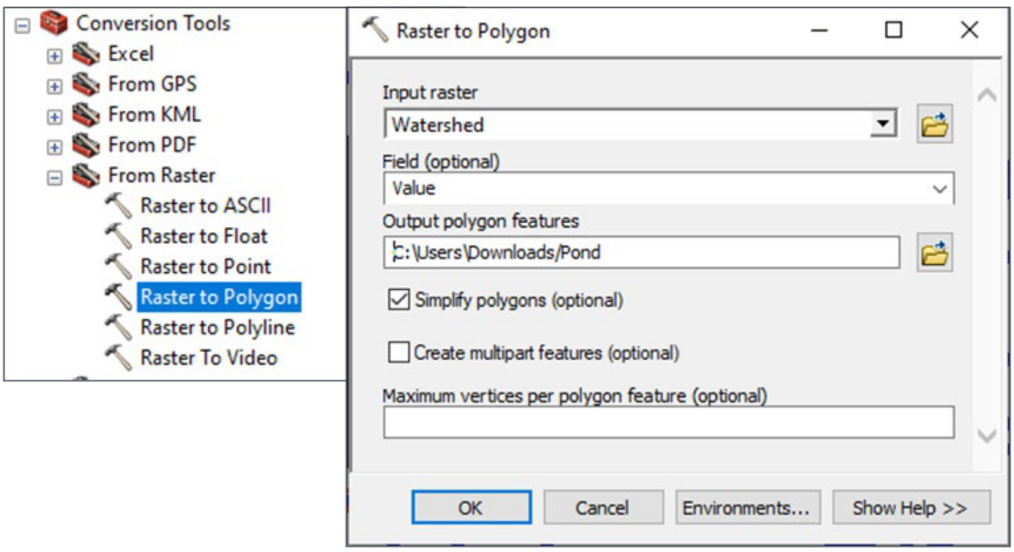
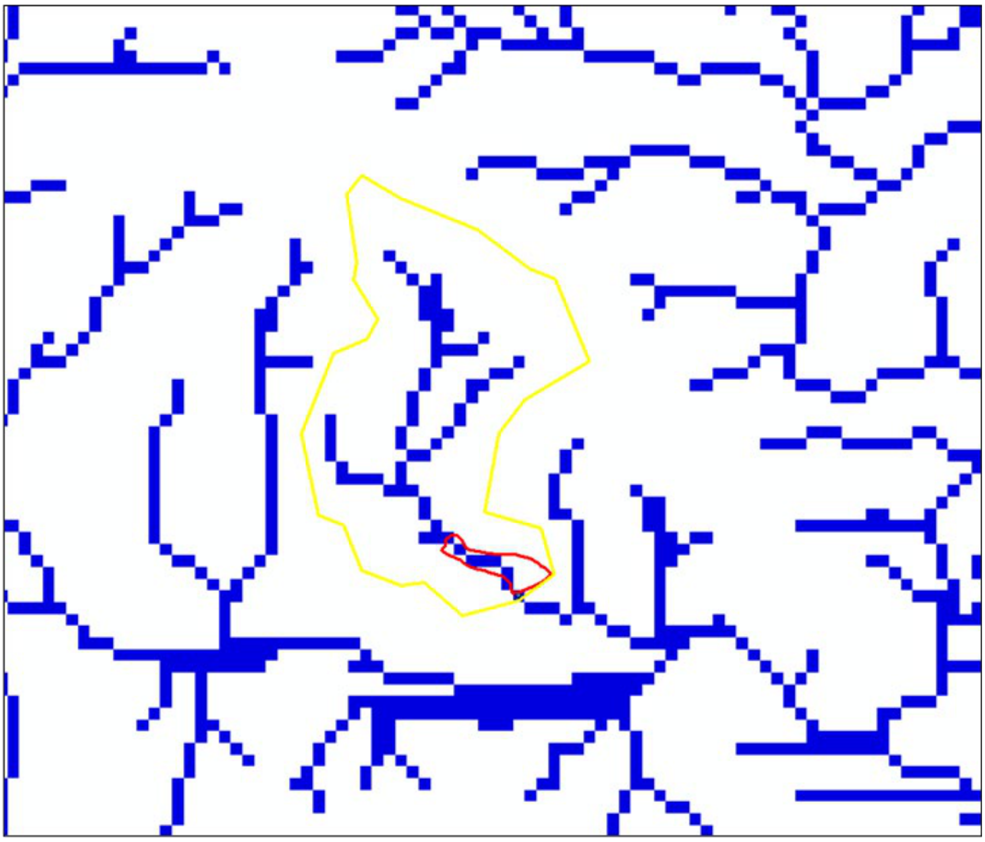




Step 11:
Convert the catchment area raster file to a polygon file by using the Conversion Tool and calculate the area of the catchment.





Table

Drainage Area

OBJECTID *	Shape *	Id	gridcode	Shape_Length	Shape_Area	Area_Acre	Area_ha
1	Polygon	1	0	3291.095621	477611.189024	118.0203	47.76112

0 (0 out of 1 Selected)

Drainage Area

6.3.2 SOIL ANALYSIS

Soil analysis is required to understand the composition, texture, permeability, and nutrient content of the soil. The analysis can be done by collecting soil samples from different depths and locations across the proposed pond area. Process these samples through geotechnical laboratory testing to analyze the following properties of the soil:

- Particle size distribution
- Nutrient content
- Soil classification
- Soil composition (to ensure it can support pond construction)
- Soil texture
- Soil permeability (to understand seepage potential and to ensure there are no excessive seepage losses in the pond)
- Moisture content (to understand water-holding capacity and to maintain a consistent water level in the pond)
- Conduct compaction tests (to ensure stable construction)
- Evaluate shear strength (for embankment stability)
- Perform chemical analysis (to determine soil fertility and acidity)

Analyze the laboratory reports for the above tests, considering factors like soil composition, stability, and nutrient levels. Incorporate these findings into the pond design to ensure a robust and well-suited construction process that addresses specific soil characteristics and supports the intended purpose of the pond.

Soil Composition

For the pond construction, it is advisable to use soil free of stones, with a low potential of Hydrogen (pH), and low Electric Conductivity (EC). Peat soils pose special challenges due to their typically high acidity and may necessitate adequate liming. Soils with a high limestone content present create special problems related to the precipitation of phosphate and iron [8].

Depth of Soil

Soils with greater depth have the ability to retain harvested water for longer periods. Therefore, for the pond construction, soils with a depth of more than 1 meter is most suitable. Deeper soils allow for greater pond depths, thereby helping to minimize evaporation losses [8].

Soil Texture

The texture of pond soil is highly related to the processes of erosion, sedimentation, dyke stability, seepage through pond sides, and the suitability of the pond bottom habitat. It also affects soil workability, water and air retention, and water movement rates within the soil. To determine soil texture, start by separating the fine earth, all particles smaller than 2 mm from larger particles such as gravel and stones. Fine earth consists of a mixture of sand, silt, and clay. It's advantageous to have soil with a high proportion of silt and/or clay, as these hold water well. Soil textures suitable for pond culture include clay, clay loam, silty clay loam, silty loam, loam, and sandy clay loam. A general and convenient field test to assess soil quality involves taking a handful of moist soil from test holes at the proposed site and compressing it into a firm ball. If the ball retains its shape without crumbling after some handling, it indicates sufficient clay content for pond construction purposes [17]. Accurate determination of the composition of the soil and its water-holding character is possible by hydrometer method. Test procedure can be adopted from (IS: 2720 (Part 4) – 1985).

Pond soil should have a high capacity to retain water. Soils with a low infiltration rate are most suitable for ponds. Loamy soils can also be used, but they require thorough compacting and may initially experience slight leakage, though they tend to self-seal over time. Sandy and gravelly soils should be avoided; however, if they are the only option available, they must be rendered impermeable with a thick layer of clay or polythene sheeting. Soil impermeability can also be achieved through compaction at the pond bottom and dyke using a mixture of soil with 1–5% cement or soil with 10–20% cow dung. Table 6.5 shows the infiltration rate of different types of soils. The best soil for our purpose is thus the impermeable clay which can be easily compacted and made leakproof.

Table 6.5 Infiltration Rates of Different Types of Soil [17]

Soil Type	Infiltration Rate (mm/ha)
Clay	1-5
Clay loam	5–10
Silty loam	10–20
Sandy loam	20–30

Seepage losses in ponds can be checked through several methods. One common approach involves installing seepage monitoring devices like piezometers or observation wells around the pond perimeter to measure groundwater levels. Regular monitoring of these levels enables the identification of significant fluctuations, indicating potential seepage issues. Additionally, geophysical techniques (refer IRC 123) such as electrical resistivity imaging or ground-penetrating radar can be utilized to assess subsurface conditions and identify potential seepage pathways. These methods are effective for monitoring and addressing seepage losses, thereby enhancing the overall efficiency of the pond system. Table 6.6 provides suitable slope recommendations for different soil types.

Table 6.6 Suitable Slopes for Different Soils [17]

Soil Type	Side Slope (Horizontal: Vertical)
Clay	1:1 to 2:1
Clay loam	1.5:1 to 2:1
Sandy loam	2:1 to 2.5:1
Sandy	3:1

6.3.3 RAINFALL

Design rainfall refers to the total amount of rainfall during the crop season, at or above which the catchment area can provide sufficient runoff to meet crop water requirements. If actual rainfall falls below the design rainfall, crops may experience moisture stress. Conversely, if actual rainfall exceeds the design rainfall, surplus runoff may occur, potentially causing damage to structures. Design rainfall is determined through probability analysis (Reddy et al., n.d., 2012), where it is assigned a probability level of occurrence or exceedance. For instance, if a rainfall event is assigned a probability of 67%, it means that the seasonal rainfall may occur or exceed two years out of three, thereby meeting crop water requirements in two out of three crop seasons. Higher probability of rainfall indicates greater reliability of assured runoff into the ponds [8].

In probability analysis for pond design, a simple graphical method can be employed to determine the frequency of annual or seasonal rainfall. Various analytical methods exist for selecting a suitable probability distribution function, with the Weibull distribution being commonly used due to its simplicity and adaptability to field situations. The first step involves obtaining seasonal rainfall data (typically from June to September) for the crop season from the area of concern. It's crucial to gather long-term data spanning at least 20 years to ensure accurate probability analysis. Short-term data covering 5 to 10 years may not adequately represent the realistic rainfall pattern in the region. Once seasonal rainfall data is collected, each value is assigned ranks based on their amounts arranged in descending order. The occurrence probability for each ranked observation can then be calculated using Equation 6.3 provided by Critchley and Siegert (1991) for the period N=10 to 100 [8].

$$P\% = \frac{m-0.315}{N+0.25} \times 100 \qquad ---(6.3)$$

Where,
P = probability in % of the observation of the rank m
m = rank of the observation
N = total number of observations used.

Steps in probability analysis [8]:

1. Annual or seasonal rainfall for a period of 20-30 years may be collected from nearby weather stations of either govt (or) research station or India Meteorological Department (IMD) for selected areas.
2. All the above data may be entered into an MS Excel sheet.
3. Arrange the annual/ seasonal rainfall data in descending order and rank them, having maximum rainfall as 1 and the minimum value with maximum rank.
4. If two rainfall events are equal consecutively, the same rank must be given to both quantities.
5. Calculate the probability of each rainfall by using Equation 6.3.
6. Plot the probability vs rainfall on a normal probability paper.
7. Determine the rainfall for 50%, 67%, and 75% from the plotting curve.

The return period T (in years) can easily be determined once the exceedance probability P (%) is known. Therefore, the return period can be calculated from Equation 6.4 [8].

$$T = \frac{100}{P} \qquad ---(6.2)$$

To download district-wise daily rainfall data, India's WRIS (Water Resources Information System) website can be used. The following steps provide the detailed information:
Visit the India WRIS Website: Start by accessing the official website of India's Water Resources Information System (WRIS) (https://indiawris.gov.in/wris/#/). You can easily find it by searching for "India WRIS" on your preferred search engine.

Locate Rainfall Data Section:
Click on the Water Data on the toolbar. In that Hydro-meteorological – Rainfall will take you to the rainfall data window. Navigation menus or search bars on the website can help you find this section quickly.

Choose Parameters:
Depending on your needs, select the parameters for the rainfall data you want to download. This may include specifying the time frame (e.g., monthly, yearly), geographic region (e.g., state, district), and any other relevant parameters available on the website.

Select Data Format:
Decide on the format in which you want to download the data. Common formats include Comma-Separated Values (CSV) or Excel spreadsheets.

Download Data:
Once you've set the parameters and chosen the format, look for the download button or link. Click on it to initiate the download process. Depending on the size of the data and your internet connection speed, the download may take some time.

Verify and Analyse:
After downloading the data, verify that it has been downloaded correctly and is accessible. Open the file using spreadsheet software such as Microsoft Excel or Google Sheets. You can then analyze the data to extract insights or conduct further research as needed.

Refer to Documentation: If you encounter any difficulties during the download process or need additional information, refer to the website's documentation or user guides. These resources often provide helpful instructions and troubleshooting tips

Figure 6.2 displays the India WRIS website's interface for reference.

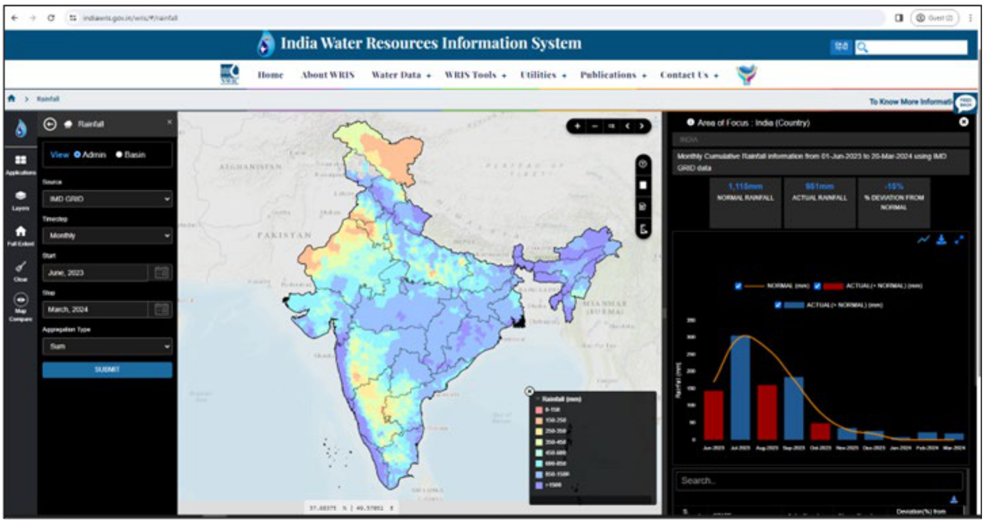


Figure 6.2 India WRIS Website Interface

By following these steps, you can successfully download rainfall data from India's WRIS and use it for various purposes such as research, and analysis.

Gumbel Extreme Value Distribution

The Type 1 Generalized Extreme Value distribution proposed by Gumbel, commonly referred to as the Gumbel distribution, is widely utilized as a probability distribution function for extreme values in hydrological and meteorological studies. It is particularly employed for predicting flood peaks and maximum rainfall events. The Gumbel distribution is extensively utilized in the Indian sub-continent for such analyses. Below is a description of the process involved in conducting this analysis [24]:

The Equation 6.5 is given as

$$X_T = u + \alpha\, y_T \qquad ---(6.5)$$

Where u and α are the mode of distribution and sample moments respectively which is given by the Equation 6.6 and Equation 6.7, respectively.

$$u = \bar{X} - 0.5772a \qquad ---(6.6)$$

$$\alpha = \left(\frac{\sqrt{6}}{\Pi}\right)\sigma \qquad ---(6.7)$$

A reduced variate yT for a return period can be calculated by Equation 6.8

$$y_T = -ln\,[ln\,(\frac{T}{T-1})] \qquad ---(6.8)$$

Where,

X_T: T year return period value

$\bar{X}$: Mean of the N observations

σ: Standard deviation of N observations = $\sqrt{\frac{(X-\bar{X})^2}{N-1}}$

X: Rainfall Event

T: Recurrence interval (Storm Return Period)

N: Sample size

Intensity Duration Frequency Curves:

The Intensity Duration Frequency (IDF) curves can be generated using the Gumbel method from the daily maximum rainfall data obtained for the past 30 years from IMD. The IDF curve illustrates the relationship between rainfall intensity, duration, and frequency of occurrence. This curve helps assess the probability of different rainfall events, aiding in the understanding of potential flood risks associated with varying storm conditions. The x-axis represents rainfall duration (minutes), the y-axis denotes rainfall intensity (mm/hr), and different curves on the graph signify varying return periods or frequencies of rainfall events. Figure 6.3 shows an example of the IDF curve.
Short-duration rainfall data can be obtained for short durations from the daily rainfall data using an empirical reduction formula (IMD). The IMD 1/3rd rule essentially allows for the transformation of daily rainfall data into shorter-duration rainfall series. By applying Equation 6.9, synthetic rainfall data for shorter durations can be generated, which can be used for generating more accurate Intensity-Duration-Frequency (IDF) curves [25].

$P_t=P_{24}\,(t/24)^{(1/3)}$ – – – (6.9)

Where,
P_t = Rainfall in mm for t hours duration
P_{24} = Daily Rainfall data in mm
t = Shorter duration in hours

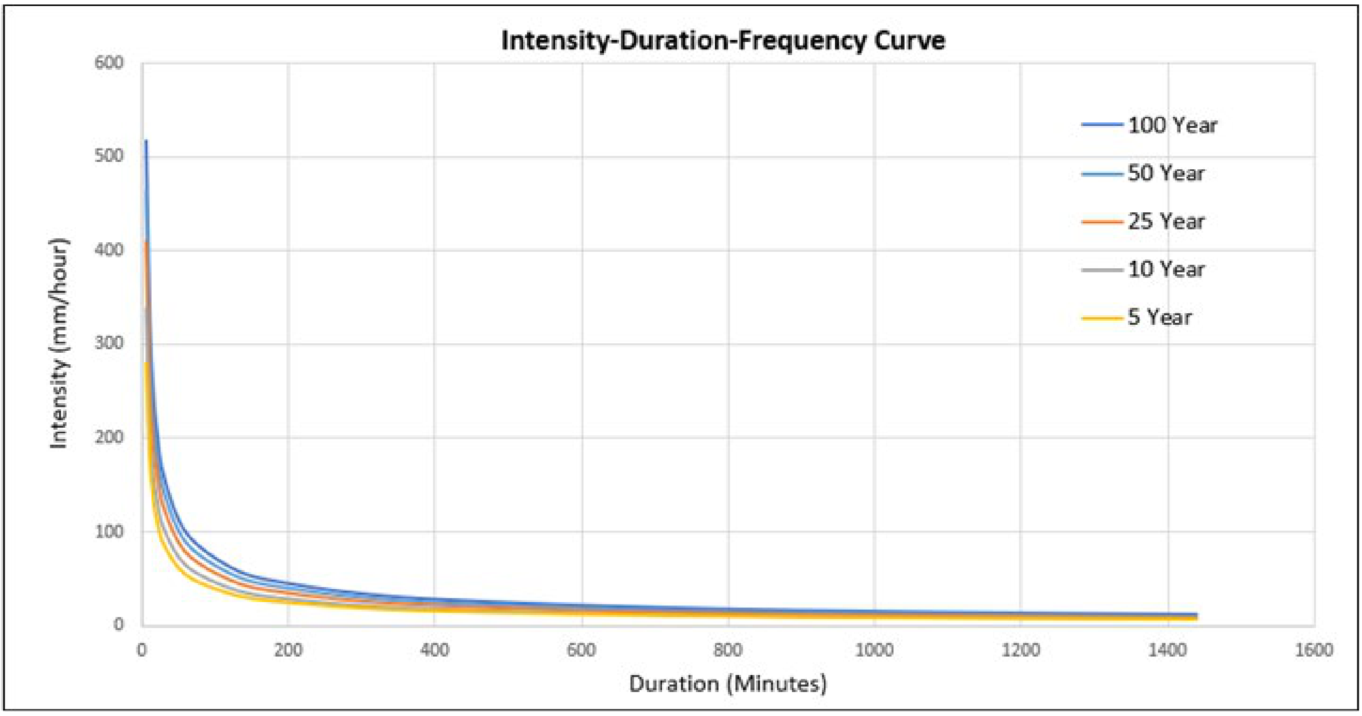


Figure 6.3 IDF Curve

Surface Runoff / Water Yield:
Surface runoff within a catchment area is generated subsequent to fulfilling various processes such as soil infiltration, interception, and local depressions. The magnitude of surface runoff is contingent upon several factors including the physical characteristics of the soil, land use patterns, antecedent soil moisture levels, topography, as well as the shape and size of the catchment. Additionally, the characteristics of rainfall including intensity, frequency, and duration play a crucial role in determining the amount of surface runoff generated [8].

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6.3.4 RATIONAL METHOD

The rational method, developed during the second half of the 19th century, serves as a fundamental approach for estimating design discharge from urban catchments. Despite its various limitations, the majority of urban storm drainage systems worldwide, up to 90% in many cases, are designed based on the Rational Method [24].

The procedure for the estimation of storm runoff by the rational method is mentioned in the following steps [24]. Also, Appendix- A provides a practical example with a detailed calculation for the hydrological analysis.

Step 1: Obtain historical rainfall data of 30 years or more for the given project area

Step 2: As mentioned in Section 6.1.1, select the frequency of one in 25-year return period rainfall events.

Step 3: Prepare the IDF curve for the above return period

Step 4: Demarcate the catchment

Step 5: Determine the Time of Concentration (tc)

Step 6: Determine rainfall intensity against the tc from the IDF curve

Step 7: Determine runoff coefficient (C)

Step 8: Calculate peak flow by Rational formula

Design Flow

Stormwater drains are designed with consideration for the peak flow, which is defined as the flow rate occurring when the entire catchment is contributing to its outlet. This scenario typically transpires when a given intensity of rainfall starts instantaneously and persists until the tc is reached [24].

Procedure for Estimation of Runoff

If properly understood and applied, the 'rational method' can produce satisfactory results for sizing storm drains, street inlets, and small on-site detention catchments [24]. An example spreadsheet and detailed calculations are provided in Appendix- A.

The formula for calculating peak flow is given as Equation 6.10:

$$Q_p = 10\ C\ I\ A \qquad ---(6.10)$$

Q_p: Peak flow at the point of design, m^3/hr

C: Runoff coefficient, dimensionless (Table 6.7)

I: Average rainfall intensity should be taken for the duration of rainfall equal to the tc, mm/hr

A: Catchment area, hectares (Section 6.3.1)

This formula is dimensionally consistent with other measurement systems. Although this method is widely used in stormwater drainage design, the estimation of runoff involves the following assumptions [24]:

1. The maximum size of a catchment should be between 8 to 10 Square Kilometers (sq km)
2. Larger catchments can be sub-divided into smaller sub-catchments
3. The peak flow occurs when the entire catchment is contributing to the flow
4. The rainfall intensity is uniform over the entire catchment
5. The rainfall intensity is uniform over a time duration equal to the tc
6. The frequency of the computed peak flow is the same as that of the rainfall intensity corresponding to the return period of the 'design storm.'
7. The coefficient of runoff is the same for all storms of all recurrence probabilities

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Runoff Coefficient (C)

The C is a function of the surface characteristics of the catchment and is assumed to remain constant for all storms of varying recurrence probabilities. Recommended values of C for different surface types within catchments are provided in Table 6.7. When selecting the values for C, it's important to consider the long-term development plans for the catchment as outlined in the master plan [24].

Table 6.7 Runoff Co-efficient of Various Surfaces [24]

S. No.	Type of Area	Runoff Coefficient
1.	Commercial Area	0.70-0.95
7	Industrial Area	0.60-0.90
3.	Institution Area	0.70-0.95
4.	Residential Area • High Density • Low Density	 0.60-0.75 0.40-0.60
5.	Recreational areas	0.10-0.25
6.	Pavement • Asphaltic Pavement • Concrete Pavement • Brick Pavement	 0.70-0.95 0.80-0.95 0.70-0.85
7	Roof Catchment • Tiles • Corrugated metal sheets • Concrete	 0.80-0.90 0.70-0.90 0.70-0.90

While the runoff coefficient suggests a consistent ratio of rainfall to runoff, in reality, this ratio fluctuates throughout a storm due to changing surface conditions and rainfall patterns. As a simplification, average coefficients are often utilized for different types of areas, with the assumption that these coefficients remain constant throughout the storm duration [24].

The weighted average runoff coefficient of the catchment area containing the different characters of surfaces for a flow concentrating at a point may be estimated as follows [24]:

A weighted average of 'C' values of different types of urban surfaces should be calculated by Equation 6.11

$$C = \frac{C1A1+C2A2+C3A3+\ldots\ldots\ldots}{A1+A2+A3\ldots\ldots\ldots} \quad ---(6.11)$$

Where,

C1, C2, C3 .... are runoff coefficients of urban surfaces

A1, A2, A3................. are areas of respective urban surfaces

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Time of Concentration in Storm Drainage System (t_c)

The rainfall intensity (I) in the rational formula is the average rainfall intensity over a given duration equal to the tc for the drainage area. The rainfall intensity for the design storm can be obtained from the IDF relationship [24].

The tc refers to the duration it takes for water to travel from the hydraulically farthest point within the contributing catchment to the specific point of interest. In the context of drain sizing, the tc represents the time needed for water to reach the design point from the most remote point in the catchment. Generally, the tc comprises two main components given in Equation 6.12 [24]:

1. Time for the surface flow to reach the first inlet, i.e., t_0
2. Time to flow through the storm drainage system to the point of consideration i.e. t_f.

$$t_c = t_0 + t_f \quad --- (6.12)$$

The inlet time is influenced by factors such as the distance from the farthest point in the drainage catchment to the inlet manhole, as well as the shape and characteristic topography of the catchment. In urban areas, inlet time typically ranges from 5 to 30 minutes. In regions with steep slopes, the inlet time may be as low as 3 minutes. However, a widely used formula can provide a reasonably accurate estimation of the inlet time [24].

Time of Surface Flow (t_o)

The formula to compute the to has been developed by the Corps of Engineers, USA from airfield drainage data. The method was originally intended for use on airfield drainage problems but has now been used frequently for surface flow in urban catchments [24]. The formula to calculate the t_0 is given as Equation 6.13:

$$t_o = \frac{0.994(1.1-C)L^{0.5}}{S^{0.333}} \quad --- (6.13)$$

Where,
t_0: Time of surface flow (Minutes)
C: Rational Method runoff coefficient
L: Length of surface flow (m)
S: Surface Slope, in percentage (%)

Note: If slope (S) is expressed as a ratio, then Equation 6.14 is to be applied.

$$t_o = \frac{0.218(1.1-c)L^{0.5}}{S^{0.333}} \quad --- (6.14)$$

Time of Flow (t_f)

The formula to calculate the t_f is given as Equation 6.15 [24]:

$$t_f = \frac{Ldrain}{V} \quad --- (6.15)$$

The velocity of flow in m/s is computed from Manning's equation given as Equation 6.16

$$V = \frac{1}{n}R^{0.67}S^{0.5} \quad --- (6.16)$$

Where,
V: Velocity of Flow, m/sec
t_f: Time of travel, minutes
n: Manning's roughness coefficient
R: Hydraulic radius, m
S: Longitudinal slope

6.4 Capacity of the Pond

The capacity of a pond is determined through a contour survey of the site where the pond will be situated. By analyzing the contour plan of the site, the capacity for various stages of the pond can be calculated using methods such as the trapezoidal rule or Simpson's rule. These mathematical techniques allow for accurate estimation of the pond's capacity based on the site's topographical features [7]. For this purpose, the area enclosed by each contour is measured using a planimeter or with GIS. According to the trapezoidal rule, the volume V between two contours at an interval H and having areas A1 and A2 is given by Equation 6.17 [7],

$$V = \frac{H}{2}(A_1 + A_2) \qquad \text{....(6.17)}$$

Using Simpson's rule the volume between any odd number of contours is given by Equation 6.18 [7],

$$V = \frac{H}{3}\,[\text{Twice the area of odd contours} + 4 \text{ times the area of even contours} + \text{Area of the first and last contours}] \qquad \text{...(6.18)}$$

This formula is also known as the prismodial rule. For using this equation, the number of contours should be odd i.e. the number of intervals considered should be even [7].

6.5 Typical Technical Drawings / Design

This section provides the typical technical drawings required for a typical pond rejuvenation project. The drawings should include- the pond layout (contours), plan view, and cross-section view.

The sizes, specifications, and soil types mentioned in the drawings are purely indicative. Actual estimates and detailed design specifications must be prepared and provided by the local contractor or bidder, adhering to the site's specific size, conditions, and prevailing cost norms as outlined by the Works Department, State Government, or relevant Government schemes [11].

Furthermore, in the case of rural community ponds, the natural contouring can be maintained, while for urban ponds, the chosen size should align with the land holdings of the beneficiaries, such as 10m x 10m x 3m, 15m x 15m x 3m, 20m x 20m x 3m, etc. [11]. Figure 6.4 illustrates a typical cross-section of a pond in urban settings. Further, the design drawings for a typical pond are provided in Exhibit 1.

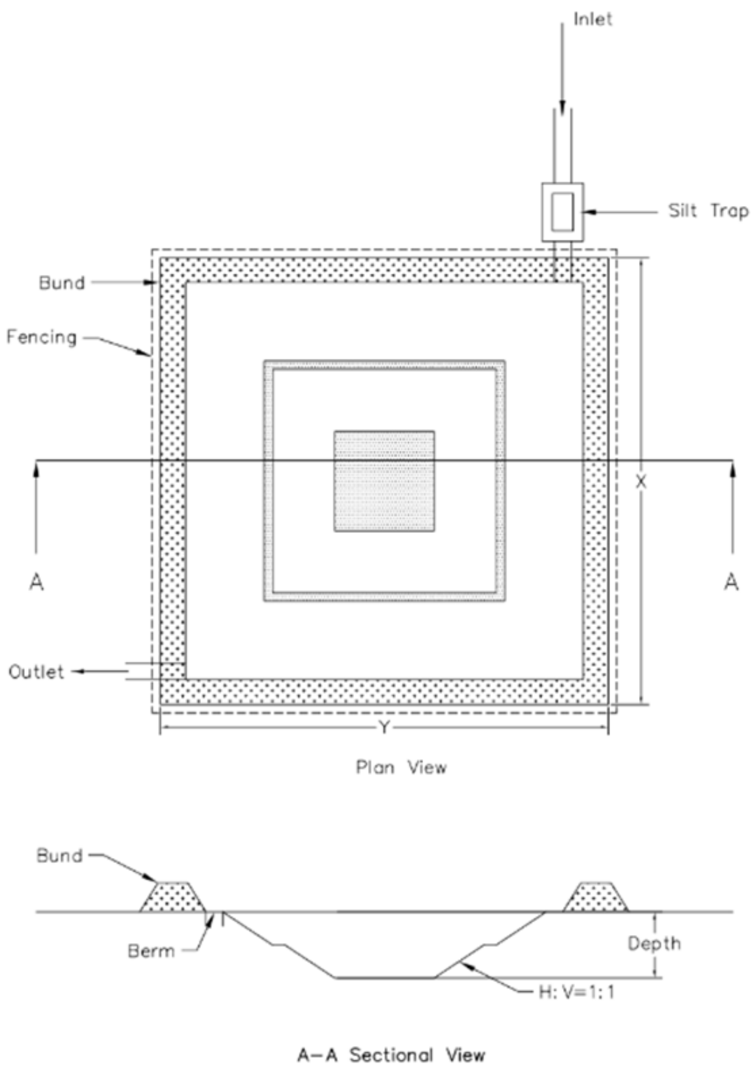
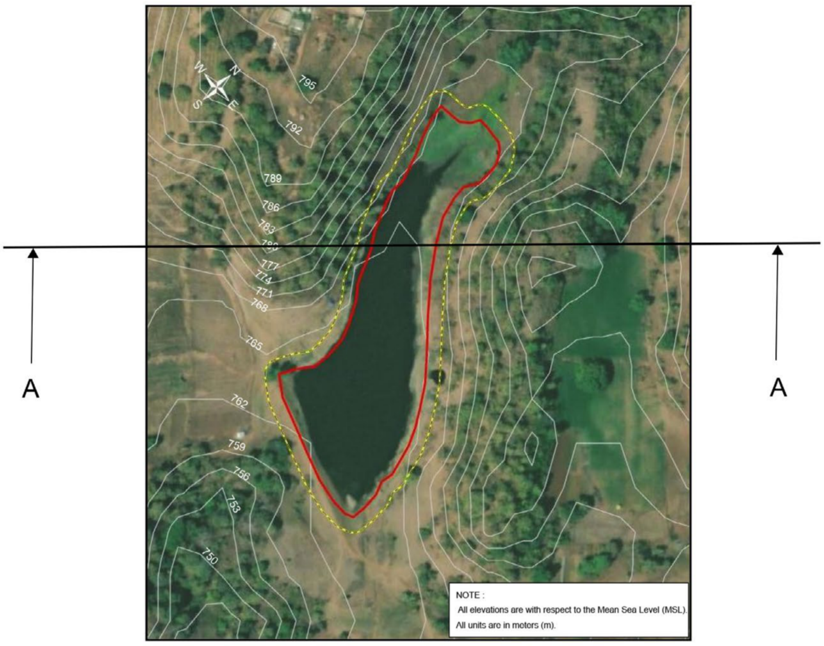
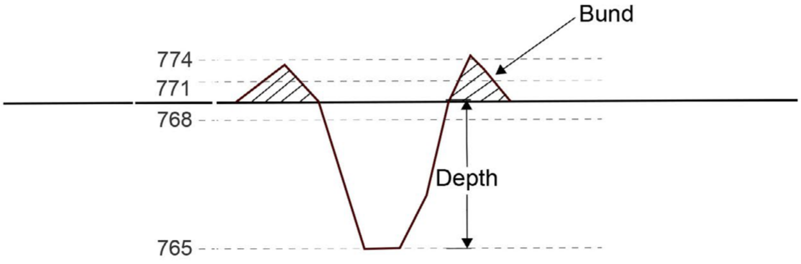


Figure 6.4 Typical Cross-Section of Pond for Urban Area [11]

Figure 6.5 illustrates a typical cross-section of a pond, particularly for rural areas or natural pond settings. This example showcases the cross-section of Jamlivan Pond located in Amaravati, providing a visual representation of its structure and cross-section.



Layout / Plan View



A - A Sectional View

Figure 6.5 Typical Cross Section of Pond for Rural/Natural Pond

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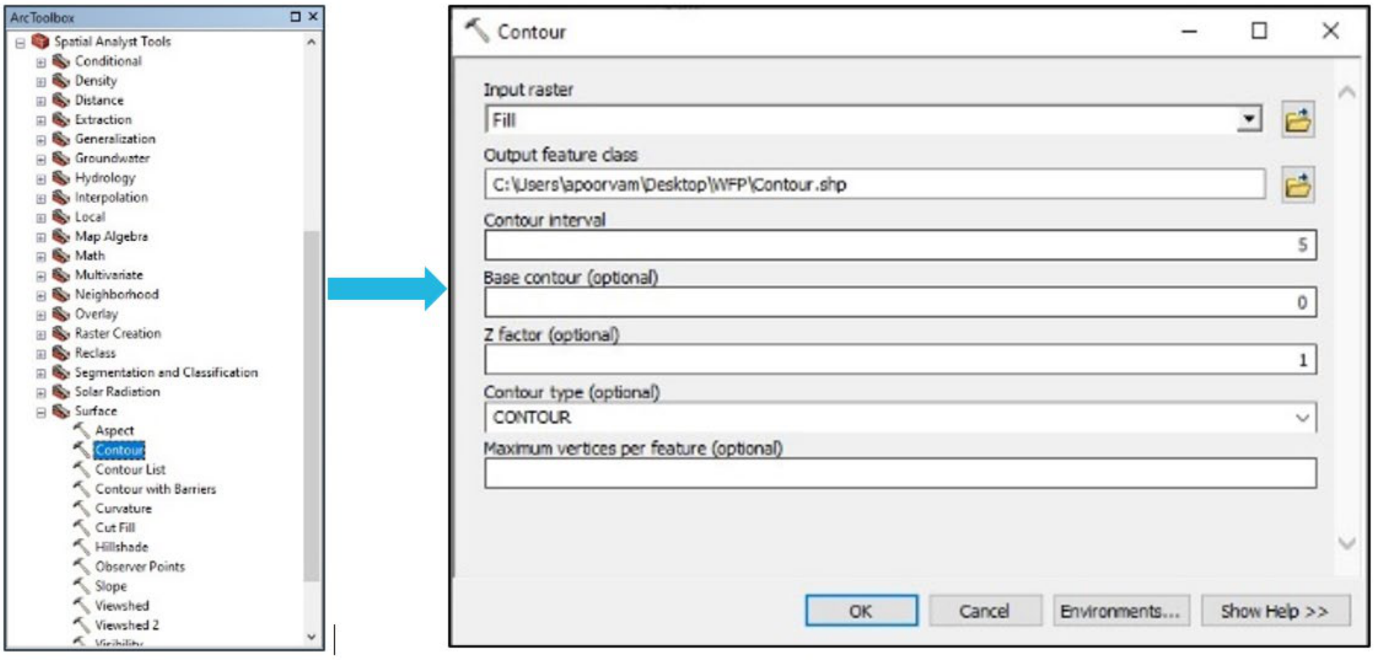
Following are the steps for generating the contours and creating a cross-sectional profile by using ArcMap.

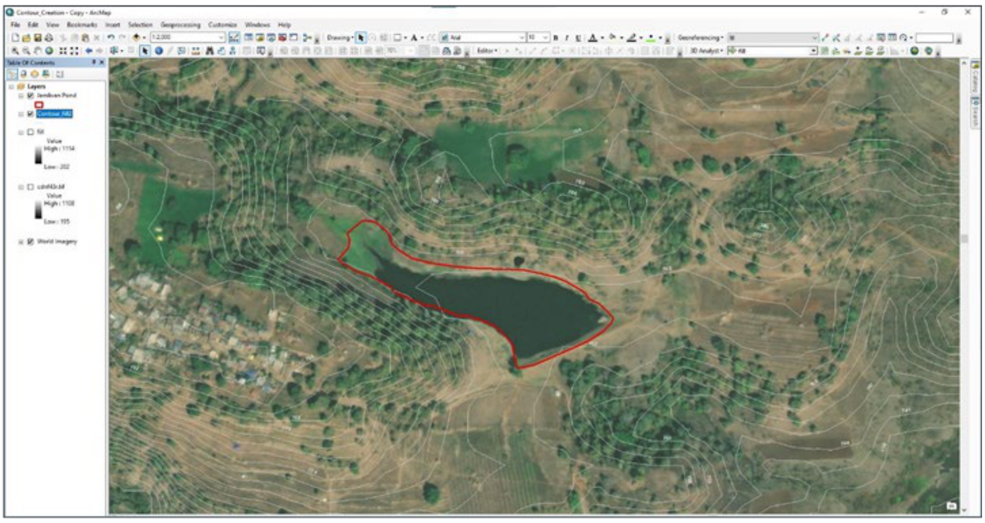
Step 1:

Go to the Customize menu, select Extensions, and check the box next to Spatial Analyst to activate the extension if it's not already activated as described in section 6.2.1. In the ArcTool box window, navigate to Spatial Analyst Tools > Surface and double-click on the Contour tool to open it. In the Contour tool dialog box, select your input raster dataset "Fill" (given in section 6.2.1) and enter the desired contour interval value in the Contour Interval field. This value determines the vertical distance between contour lines. Specify the Output location and name for the output contour feature class.



Step 2

Click OK to run the Contour tool. ArcMap will generate contour lines based on the specified interval from the input raster dataset. Additional settings can be adjusted in the Contour tool dialog box, such as smoothing options or base contour levels, to customize the output according to your preferences.

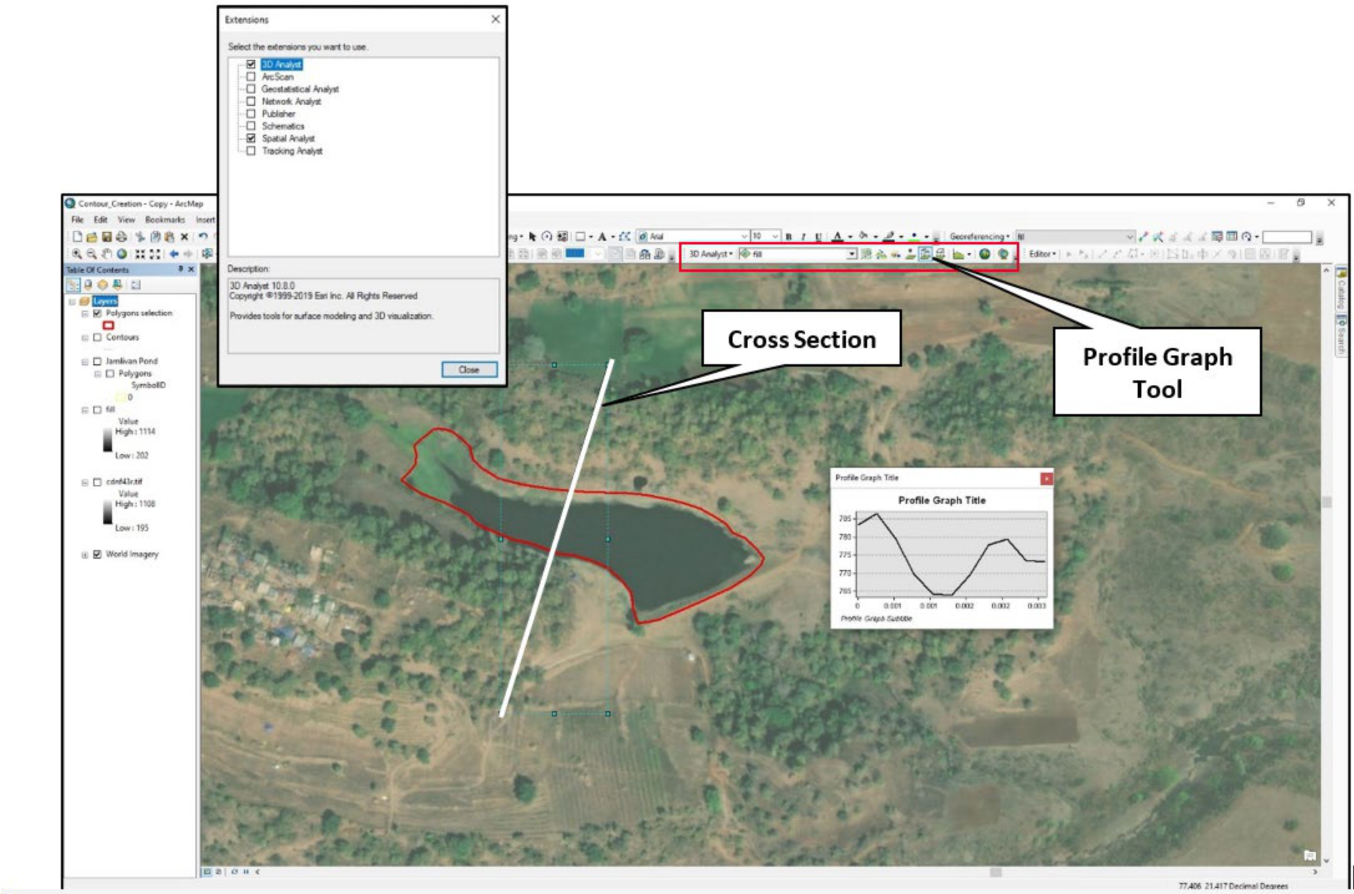


Step 3

Save your map document and, if needed, export the contour lines to a different format for further analysis or sharing.

Step 4

For creating the cross-section profile select the '3D Analyst' extension from the 'Customize' option in the menu bar, by which the 3D Analyst toolbar will be obtained. Select the filled DEM as the base reference layer to create a profile. Draw a line across the desired area on a map representing the pond's cross-section and activate the Create Profile Graph tool to obtain the required profile at that cross-section.



By following these steps, contour lines and cross-section profiles can be generated from elevation data using ArcMap.

6.6 Typical Components of a Pond

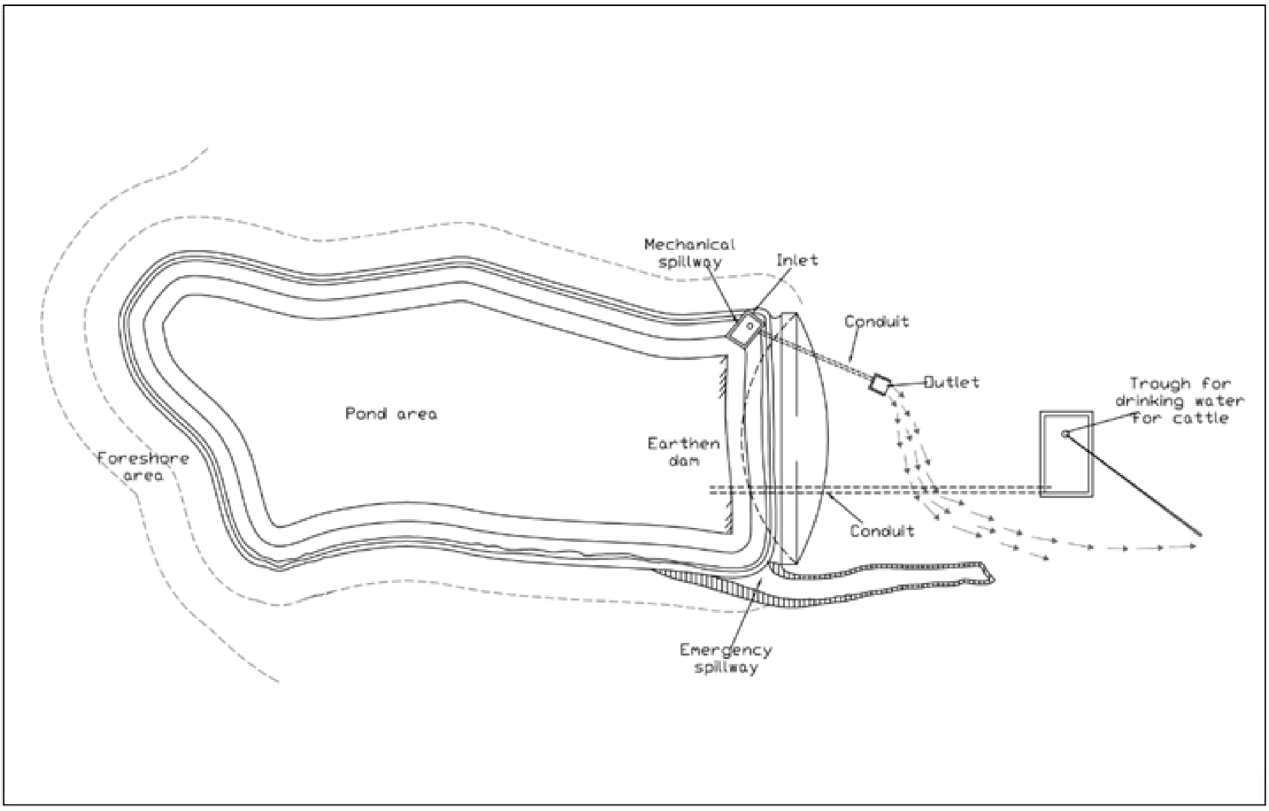


Figure 6.6 Typical Components of a Pond [7]

Figure 6.6 illustrates the typical different components of a pond, particularly designed for farm use. The illustration shows the fundamental elements integral to the functioning of the pond infrastructure. It is important to note that the composition of pond components may vary depending on the intended use of the pond.

Pond Area:
The primary body of water that serves as the reservoir. It is excavated or constructed to retain water, providing a source for irrigation, livestock watering, and aquaculture.

Inlet Structure:
Designed to regulate the inflow of water into the pond, typically through a pipe or channel connected to a water source such as a stream, rainfall runoff, or a diversion structure.

Outlet Structure:
Controls the outflow of water from the pond, ensuring proper drainage and management of water levels. It may include features like a control valve, spillway, or drainage pipe.

Mechanical Spillway:
The mechanical spillway is used for letting out the excess water from the pond and also as an outlet for taking out the water for irrigation. This is Mainly used for agricultural and maintenance purposes [7]

Emergency Spillway:
The emergency spillway is to safeguard the earthen dam from overtopping when there are inflows higher than the designed values [7].

A typical pond layout is shown in Figure 6.7.

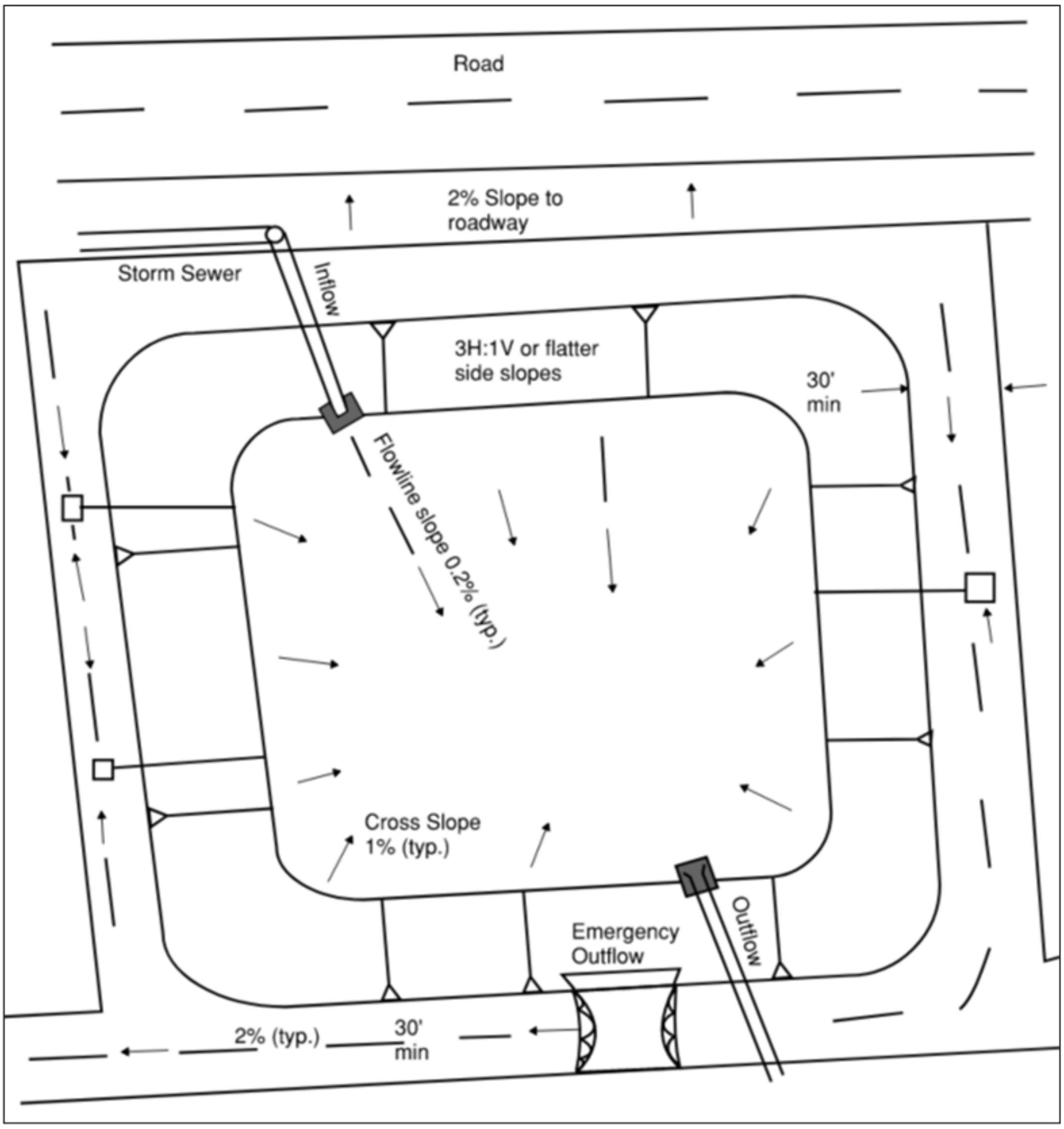


Figure 6.7 Typical Pond Layout [23]

6.7 Water Balance Study

Water balance studies are essential for the construction and rejuvenation of waterbodies like ponds and lakes. They provide insights into the hydrological conditions of an area, including rainfall patterns, surface runoff, groundwater recharge, and evaporation rates. By understanding these factors, engineers and planners can optimize the design of waterbodies to ensure sustainability and resilience to changing conditions. This optimization process involves determining the size, shape, and depth of the waterbody to effectively store water during wet periods and maintain sufficient levels during dry periods. Additionally, water balance studies help in predicting and mitigating flooding and erosion risks, designing habitats for aquatic organisms, and maintaining water quality.

In nature, water is almost constantly moving and can transition between liquid, solid, or vapor states under appropriate conditions. The principle of conservation of mass dictates that within a given area and timeframe, water inflows must balance with outflows, accounting for any changes in storage within that area. Essentially, the amount of water entering an area must either exit or be retained within it. The basic water balance equation can be expressed as Equation 6.19:

$$P = Q + L \pm \Delta S \qquad .....(6.19)$$

Here, P represents precipitation, Q is runoff, L is losses (seepage, evaporation, etc.), and ΔS signifies changes in storage within soil, aquifers, or a waterbody.
In water balance analysis, it's often beneficial to categorize water flows as 'green' and 'blue' water. 'Blue' water refers to surface and groundwater available for various uses such as irrigation, urban, industrial, and environmental needs. On the other hand, 'green' water denotes water stored in the soil, which evaporates into the atmosphere. The origin of 'green' water is rainfall, while 'blue' water may have been utilized for irrigation purposes. A water balance analysis serves several purposes:

- Evaluate the current state and trends in water resource availability within a specific area over a defined period.
- Enhance decision-making in water management by assessing and refining the accuracy of visions, scenarios, and strategies.

Figure 6.8 provides an example representation of the monthly water balance for an average rainfall year.

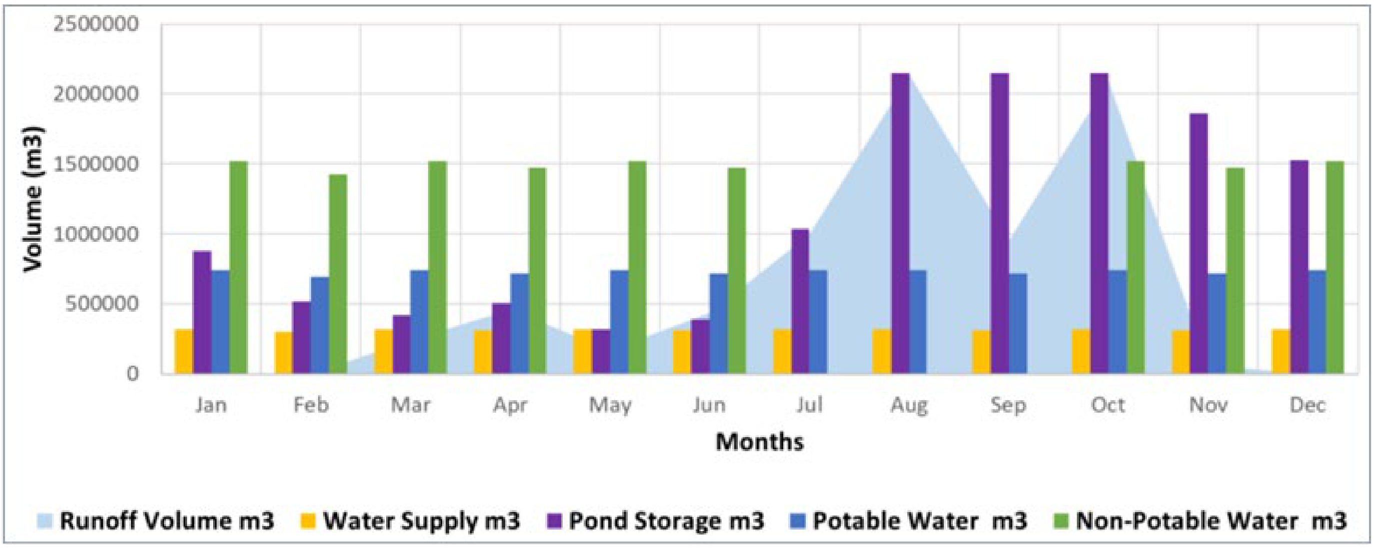


Figure 6.8 Example of Monthly Water Balance for an Average Rainfall Year

6.8 Bill of Quantities

A Bill of Quantities (BOQ) is a detailed document outlining the quantities and costs of various materials, labor, and equipment required for the construction of a pond project. It serves as a comprehensive reference for estimating project costs and procuring resources efficiently. The costing of each element should be done as per the latest District Schedule Rates (DSR) or Schedule of Rates (SOR). Refer Appendix B for a unit cost of various waterbody restoration techniques and interventions. Appendix C also provides a overall costing range for various tasks involved in a waterbody rejuvenation case study.

6.9 Design Deliverables

6.9.1 DESIGN SPECIFICATIONS FOR POND CONSTRUCTION/REJUVENATION FORMAT

1.1. SCOPE OF WORK

1. This section specifies the requirements for the construction/rejuvenation of a pond.
2. The pond shall be of the size, type, and location, and to the lines, grades, and elevations shown on the plans and constructed in accordance with these specifications.
3. The inflow and outfall structure shall be of the size, and type as given in the coordination drawings.

1.2. IS CODES

1. IS 3370 Part 1:1967 Code of practice for concrete structures for the storage of liquids - Part 1: General requirements.
2. IS 13737: 1993 - Code of practice for construction of ponds for fisheries.
3. IS 456:2000 Code of practice for plain and reinforced concrete.
4. IS 15489:2004 Guidelines for the design, construction, and maintenance of bunds for water harvesting.
5. IS 14891:2001 Guidelines for water harvesting and conservation in urban areas.
6. IS 12701:1989 Guidelines for water quality management for fisheries.
7. IS 13574:1992 Guidelines for design and construction of sub-surface dykes for water harvesting.
8. IS 6461 Part 4:1972 Glossary of terms relating to soil engineering - Part 4: Terms relating to soil erosion and conservation.
9. IS 10500:2012 - Drinking Water Specification.

1.3. PROJECT CONDITIONS

1. The Engineer-in-Charge shall ensure that the contractor sets out the work in accordance with the contract drawings and information provided.
2. The site engineer should ensure that the safe bearing capacity of soil is verified at the site.

1.4. SUBMITTALS

1. Coordination drawings for pond and outfall along with BOQ.
2. Design calculations for pond and epoxy dowel (if any).
3. Material data sheets for all materials used in pond construction/rejuvenation, including liners, concrete, reinforcement bars, and epoxy dowels.
4. Test reports for materials and structural elements, such as concrete compressive strength tests, liner permeability tests, and epoxy dowel bond strength tests.

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1.5. QUALITY CONTROL

1. The design should comply with the corresponding codes and standards.
2. Aggregates used in concrete construction should meet the required standards for durability and structural performance as per IS 383: 2016.
3. Concrete grade specified on drawings should be per approved pre-mix and preferably RMC having w/c ratio not exceeding 0.4 concrete grade for various structural elements of the pond, such as retaining walls, floors, or liners. For example, use M25 grade concrete for retaining walls and M30 grade concrete for pond floors. Concrete should conform to requirements laid out under all relevant sections of Clause 6, 7, and 8 of IS456:2000. Base properties should be in line with that stated below:
   - Modulus of elasticity, Ec = 5000 √fck N/mm2
   - Dynamic Modulus of elasticity, Ec, dyn = 1.35 x Ec
   - Shrinkage Strain (Approx.) = 300×10^{-6}
   - Poisson's Ratio = 0.2
   - Coefficient of Thermal Expansion = 9.5×10^{-6}/ 0C (Conservatively assumes granite/basalt type aggregate).
   - Creep coefficient:

Age at Loading	Creep Coefficient
28 days	2.2
7 days	1.6
1 year	1.1

4. Reinforcing bar used should be High strength deformed steel bars conforming to IS 1786:2008 minimum design characteristic strength of 500 N/mm2. It should have been produced by Thermo-mechanical treatment & have at least 14.5% elongation. Owner identifies vendors, who can provide continuous supply rebar within the code-specified acceptability criteria and per project-related demands. Base property definitions should be:
   - Modulus of elasticity, Es = 2×10^{5} N/mm2
   - Poisson's Ratio = 0.30
   - Coefficient of Thermal Expansion = 12×10^{-6}/ 0C
5. Soil testing for the geotechnical properties of the pond site should be assessed, including soil composition, compaction, and permeability, ensuring that the soil is suitable for pond construction and can withstand the hydraulic pressures exerted by water. IS 2720 (Part 1-16): 1983 - Methods of test for soils.
6. Liners should be as per the specified type, thickness, and quality of material to be used in pond construction. Design liner thickness based on permeability requirements and anticipated hydraulic conditions, typically ranging from 0.3 mm to 2.0 mm for geomembranes and 300 mm to 600 mm for compacted clay liners. It should be ensured that the liners meet the required standards for durability, puncture resistance, and chemical compatibility.
7. Water quality test for the suitability of water sources for filling the pond should be assessed. Parameters such as pH, turbidity, dissolved oxygen, and nutrient levels should be tested to ensure compliance with regulatory standards and suitability for aquatic life.
8. Existing retaining wall surface to be intentionally roughed prior to casting proposed weir (outfall).

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1.6. TECHNICAL SPECIFICATIONS

1. Excavation depth and volume, slope stability requirements, and compaction specifications should ensure the structural integrity and stability of the pond's embankments and basin.
2. The material type, thickness, and installation method for the pond's liner should prevent seepage and ensure watertightness.
3. Design requirements for dams, spillways, or other structural elements, along with material specifications and construction methods should ensure their durability and functionality.
4. Specifications for inlet and outlet structures, including pipe sizes, materials, and gate or valve specifications, should regulate water flow into and out of the pond effectively.
5. Specifications for planting vegetation around the pond and implementing erosion control measures should stabilize embankments and enhance habitat diversity.
6. Specifications for measures to maintain water quality, such as aeration systems if applicable, should ensure the health and suitability of the pond's water for its intended use.
7. Specifications for safety barriers/fencing and warning signs should protect workers and the public and prevent accidents or unauthorized access to the construction site.

1.7. APPROVAL AND SIGNATURES

1. Sign-off section for approval by the project consultant/engineer and the project owner/client.

6.9.2 REPORT FORMAT

This report format provides a structured framework designed to document the pond construction/rejuvenation project.

Title Page:

1. Title of the Project
2. Date
3. Name of the Organization or Institution
4. Project Location
5. Name(s) of Author(s)

Table of Contents:

1. List of all sections and subsections with page numbers.

Executive Summary:

1. A concise overview of the pond construction/rejuvenation project, its objectives, methods including materials and techniques, and expected outcomes.
2. This section encapsulates the main points of the report in a concise manner, highlighting key findings such as specific results obtained during the project, such as improvements in water quality, habitat enhancement, etc., and recommendations for the future use of the pond.

Introduction:

1. Detailed explanation of the need for pond construction/rejuvenation, including ecological, agricultural, or community purposes. Statement of the problem or purpose of the project.
2. Specific goals and aims of the project, such as improving water retention, enhancing biodiversity, or providing recreational opportunities. Description of the project's scope, including the size of the pond, surrounding land use, and intended functions.

Objectives of the project:

1. The introduction sets the stage for the project by providing background information on the need for pond construction or rejuvenation. It outlines the problem statement, therefore from that background, this section identifies the objectives of the project and explains its significance.

Site Description:

1. This section describes the physical characteristics of the pond project site, such as geographic location (coordinates), topographical features, and accessibility of the project site. Also, measurements of the pond's area, depth, and volume.
2. Hydrological feature's detailed analysis of water sources, drainage patterns, and soil characteristics.
3. Description of environmental factors affecting the site, such as surrounding vegetation, habitats, and potential impacts on natural resources.
4. Description of the current state of the pond site and understanding the challenges for a specific pond site project.

Project Design and Methodology:

1. Detailed explanation of the proposed design or rejuvenation plan based on site conditions, hydraulic calculations, environmental sustainability, and regulatory requirements.
2. Presentation of detailed engineering technical drawings, including plans, cross-sections, and elevations of the pond.
3. Methods and techniques used for construction/rejuvenation and detailed work phases, by which completed tasks of construction/ rejuvenation.

Technical Specifications:

1. This section provides specific technical details regarding construction materials (including types of soil, liners, aggregates, and reinforcement), equipment specifications, and any engineering calculations or designs that are relevant to the project. It ensures that all aspects of the project are well-defined and can be implemented effectively.

Environmental Impact Assessment:

1. This section assesses the potential environmental impacts of the project and proposes measures to mitigate any adverse effects. It ensures that the project complies with environmental regulations and permits, minimizing harm to the ecosystem.
2. Community Engagement and Stakeholder Involvement:
3. Description of outreach efforts, public meetings, and stakeholder engagement activities conducted throughout the project. Feedback received and how it has influenced the project design.
4. Identification of social, economic, and environmental benefits generated by the project, including improved water resources, enhanced recreational opportunities, and increased property values.

Risk Assessment and Management:

1. Here, potential risks and challenges associated with the project are identified and strategies for mitigating these risks are outlined. It ensures that the project is well-prepared to address any unforeseen issues that may arise.

Monitoring and Evaluation Plan:

1. This section outlines a plan for monitoring progress during construction or rejuvenation and evaluating the success of the project. It establishes criteria and indicators for measuring impact and ensures accountability throughout the project lifecycle.
2. Outline of post-construction monitoring activities to evaluate the effectiveness of mitigation measures and ensure long-term environmental sustainability of the pond.

Conclusion:

1. Overview of key findings, achievements, and outcomes of the pond construction/rejuvenation project.
2. Reflections on lessons learned and offers insights for future projects.

Appendices:

1. Appendices contain additional supporting documents such as maps, drawings, permits, contracts, photos of the pond site, or any other supplementary information that enhances the understanding of the project.

References:

1. Citations for any sources referenced in the report, ensuring that credit is given where it is due and allowing readers to explore further if desired.

Thus, the restoration phase covers the site selection, problem identification, finding the best solutions to the problem, and implementation of the solution on the ground with the help of the design guidelines and technical calculations. Once the restoration of the waterbody has taken place, it is important to protect the waterbody for its long-term use. The details of the protection phase are covered in the upcoming chapter.

7.0 Protection Phase

The protection phase takes care of the general health of the waterbody and ensures normal functioning. A long-term, preventive approach focused on the causes of waterbody degradation is essential. Based on the historical information collected, desk review, and reconnaissance survey conducted, a detailed gap analysis should be conducted to ensure additional measures required for restoration and protection of the waterbody (varies from case to case), covering both direct and indirect measures with timely targets [3]. The following sections provide various measures to protect the waterbodies as a part of rejuvenation. Figure 7.1 presents the flow chart for the components of the Protection Phase.

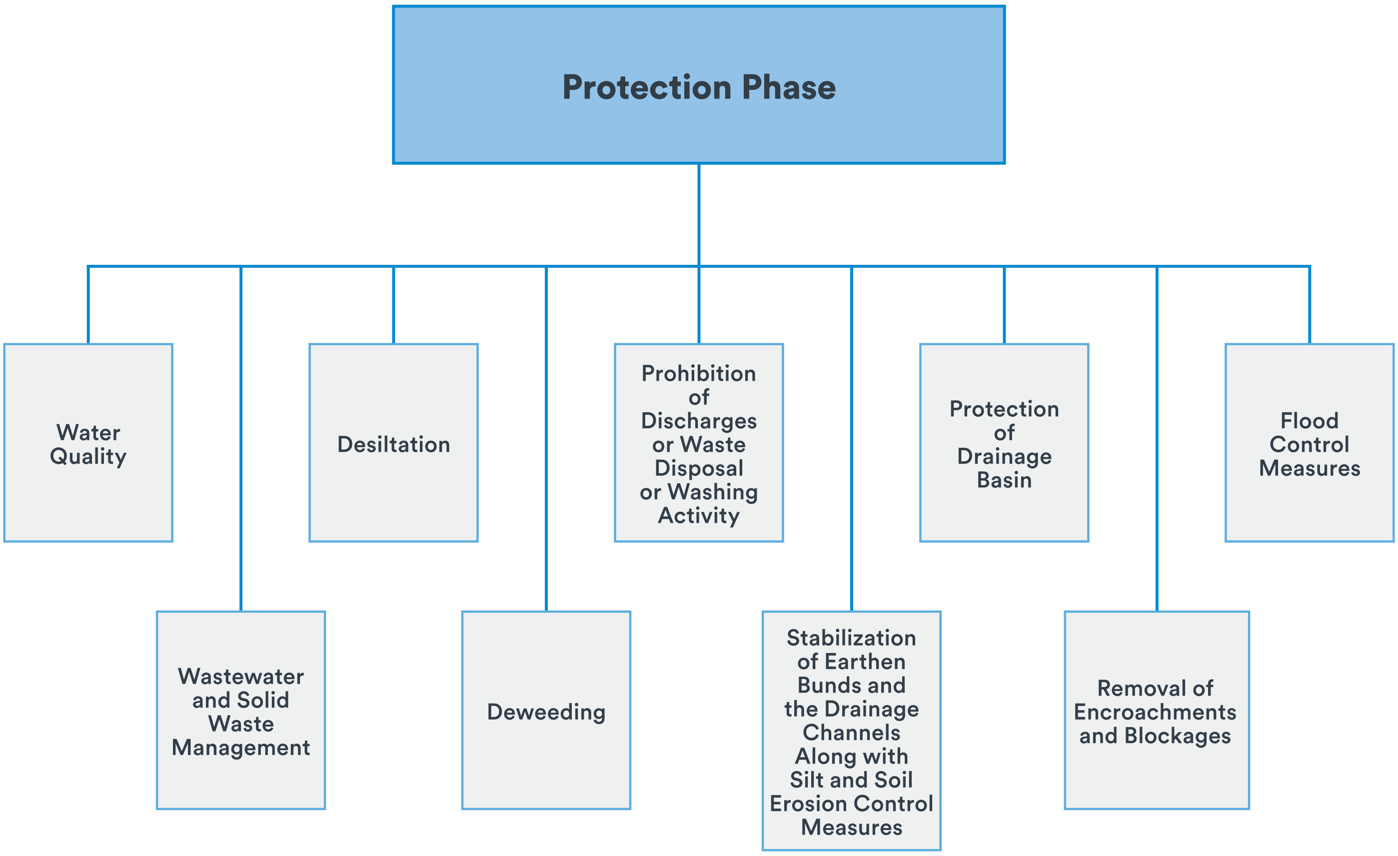

Figure 7.1 Components of the Protection Phase

7.1 Water Quality

It is necessary to monitor and assess the water quality of the waterbodies that undergo restoration and rejuvenation in order to protect them for their long-term usability. In the absence of specific water quality criteria developed with respect to waterbodies, CPCB's guidelines for designated best-use criteria for surface waters should be considered for improving the water quality of waterbodies [13]. Table 7.1 illustrates the primary water quality criteria for designated best use. For water quality testing procedures, IS 10500 should be referred.

Table 7.1 Designated Best Use Classification of Surface Water [13]

Designated Best Use	Primary Water Quality Criteria
Drinking Water Source without conventional treatment but after disinfection	1. Total Coliform Organism MPN/100 ml shall be 50 or less. 2. pH between 6.5 to 8.5 3. Dissolved Oxygen @6ml/l or more. 4. Biochemical Oxygen Demand: 5 days @20° C should be 3mg/l or less.
Outdoor Bathing (Organized)	1. Faecal Coliform Organism MPN/100ml shall be 2500 (max permissible) or 1000 (desirable). 2. pH between 6.5 to 8.5 3. Dissolved Oxygen @ 5mg/l or more. 4. Biochemical Oxygen Demand: 5 days @20°C should be 3mg/l or less.
Drinking water source after conventional treatment and disinfection	1. Total Coliform Organisms MPN/100ml shall be 5000 or less. 2. pH between 6 to 9 3. Dissolved Oxygen 4mg/l or more 4. Biochemical Oxygen Demand: 5 days @20°C 3mg/l or less.
Propagation of Wildlife and Fisheries	1. pH between 6.5 to 8.5 2. Dissolved Oxygen @4mg/l or more 3. Free Ammonia @1.2 mg/l or less.
Irrigation, Industrial Cooling, Controlled Waste Disposal	1. pH between 6.0 to 8.6 2. Electrical Conductivity at 25°C micromhos/cm Max.2250 3. Sodium absorption Ratio Max. 26 mg/l 4. Boron Max. 2mg/l.

Table 7.2 outlines the sampling points for water quality monitoring of ponds and provides an overview of strategically selected locations for water collection. These sampling points are chosen to represent various ecological zones within the pond, allowing for a thorough assessment of water quality parameters such as pH, dissolved oxygen, nutrient levels, and pollutant concentrations. By systematically monitoring these key areas, stakeholders gain valuable insights into the overall health of the pond ecosystem and can identify potential sources of contamination or environmental stressors, facilitating targeted management and conservation efforts. The frequency of samples can be once for the pre-project phase, bi-monthly during the project implementation phase, and quarterly for the post-project construction.

Table 7.2 Sampling Points for Water Quality Monitoring and its Significance [9]

Types of Sample	Sampling Points	Sample Collection Zone	Significance
Lake water	Shallow zone	Surface Layer	Water quality at these locations will represent water quality variation between shallow and deeper zones.
	Deeper zone	Bottom Layer	
Lake sediment	Shallow zone	Sediment Surface	Sediment quality at these locations indicates the health of the waterbody.
	Deeper zone		
Inlet water	Inlet to the lake	Inlet	Water quality at this location will represent the quality of water entering the waterbody
	Inlet to the lake wetland (if proposed)		Water quality at this location will represent the quality of water entering the floating wetland (if proposed)
	Inlet to the lake wetland (if proposed)		Water quality at this location will represent the quality of water after floating wetlands. This data will help to assess floating wetland treatment efficiency.
Outlet water	Outlet of the lake	Outlet	Quality of water exiting the waterbody
Outlet water	Outlet of marshy (if proposed)	Surface	Water quality at this location will represent the quality of water after natural treatment. This data will help assess the treatment efficiency of floating, marsh wetlands and natural treatment as a unit.

7.2 Wastewater and Solid Waste Management

It's important to tailor the management approach based on the specific characteristics of the pond, the surrounding environment, and the type of wastewater and solid waste being generated. Regular maintenance and monitoring are key to ensuring the long-term health and sustainability of ponds while minimizing their environmental impact. The following sections provide the management approaches.

7.2.1 SEWAGE MANAGEMENT

Regular testing of water quality parameters such as pH, dissolved oxygen, ammonia, and nitrate levels plays a crucial role in the early detection of any issues resulting from sewage intrusion into waterbodies. To manage sewage inflow, if present, (which often leads to eutrophication of lakes or ponds), infrastructure for sewage treatment should be provided. This includes ensuring an adequate capacity of Sewage Treatment Plants (STPs) or employing a combination of other low-cost treatment technologies to meet discharge norms specified under the Environment (Protection) Act, 1986. Compliance with these norms should be ensured both by individual generators of sewage and the relevant local or urban bodies. Following are the simple yet effective sewage management practices, which can be adopted the protect the waterbodies [3].

Aeration

Aeration is essential for maintaining water quality in ponds. It increases the oxygen levels in the water, which helps in breaking down organic matter and reducing odors.

Natural Filtration

Incorporating plants like water lilies and submerged vegetation can help naturally filter the water by absorbing nutrients and pollutants.

Mechanical Filtration

Depending on the scale and purpose of the pond, mechanical filtration systems such as settling tanks, sand filters, or biofilters can be installed to remove solid particles and pollutants.

Biological Treatment

Beneficial bacteria and microorganisms can be introduced to ponds to aid in the breakdown of organic matter and pollutants.

7.2.2 INDUSTRIAL EFFLUENT MANAGEMENT

Effective industrial effluent management for ponds requires collaboration between industry, regulators, and other stakeholders to achieve environmental protection and sustainable development goals. To manage industrial effluent inflow, it is essential to provide adequate infrastructure for treating industrial effluents. This includes establishing CETPs by the industries contributing to waterbody pollution. The responsibility for ensuring the establishment and operation of CETPs lies with the respective State Industrial Development Corporations or SPCB or Pollution Control Committee (PCC). Additionally, adopting state-of-the-art technologies in production processes can facilitate the treatment of generated industrial effluents, with the feasibility of adopting zero liquid discharge measures being explored [3].

7.2.3 SOLID WASTE MANAGEMENT

Sufficient infrastructure must be established to manage various types of waste, including municipal solid waste, industrial hazardous waste, construction and demolition waste, plastic waste, and e-waste, in accordance with the provisions outlined in the Environment Protection Act, of 1986. It is the responsibility of all relevant parties to ensure compliance with these regulations. Regular physical removal of improperly disposed waste, such as municipal solid waste, construction and demolition waste, plastic waste, industrial hazardous waste, and human or animal night soils, should be conducted by the respective local or urban authorities. Following are the simple yet effective solid waste management practices, which can be adopted to protect the waterbodies [3].

Sedimentation
Allowing solid waste to settle at the bottom of the pond and periodically removing accumulated sediment can help maintain water clarity and quality.

Mechanical Removal
Using equipment such as skimmers, screens, or nets to physically remove floating solid waste from the surface of the pond.

Vegetative Buffer Strips
Planting vegetative buffer strips around the pond can help reduce the influx of solid waste, nutrients, and pollutants from surrounding areas.

Waste Segregation
Implementing waste segregation practices to separate biodegradable and non-biodegradable waste can make it easier to manage solid waste in ponds.

Proper Disposal
Disposing of solid waste in an environmentally responsible manner, such as recycling or landfill disposal, can prevent contamination of the pond and surrounding ecosystem.

Provision of Litter Traps
Creating a litter trap for ponds involves designing a structure to capture floating debris while allowing water to flow through. Typically, this involves constructing a frame with netting or mesh attached, where debris tends to accumulate, buoyed by floats or other buoyant materials to keep it afloat on the water's surface. Regular maintenance, including debris removal and proper disposal, is necessary to keep the trap functional.

7.3 Desiltation

Desilting is the removal of fine silt and sediment that have collected in a waterbody, to restore its natural capacity, without widening or deepening of the waterbody. Regular removal of nutrient-enriched accumulated sludge in ponds is essential for various reasons, including groundwater recharge potential, removal of contaminated sediments, and increasing the storage capacity of ponds. Sediments extracted from ponds should be stored in a designated area until all moisture is completely drained out. It's crucial to store these dried sediments at a suitable distance away from ponds and promptly remove them to prevent them from reintroducing into the waterbodies, especially during rainfall. Depending on their characteristics, these sediments, after draining, may be repurposed as manure, provided they comply with the quality standards specified under the Solid Waste Management Rules, 2016, and relevant provisions outlined in the Environment Protection Act, 1986 [3]. There are various methods available for desilting ponds. The flowchart below are some of the methods for desilting. Figure 7.2 depicts a flow chart for types of desiltation.

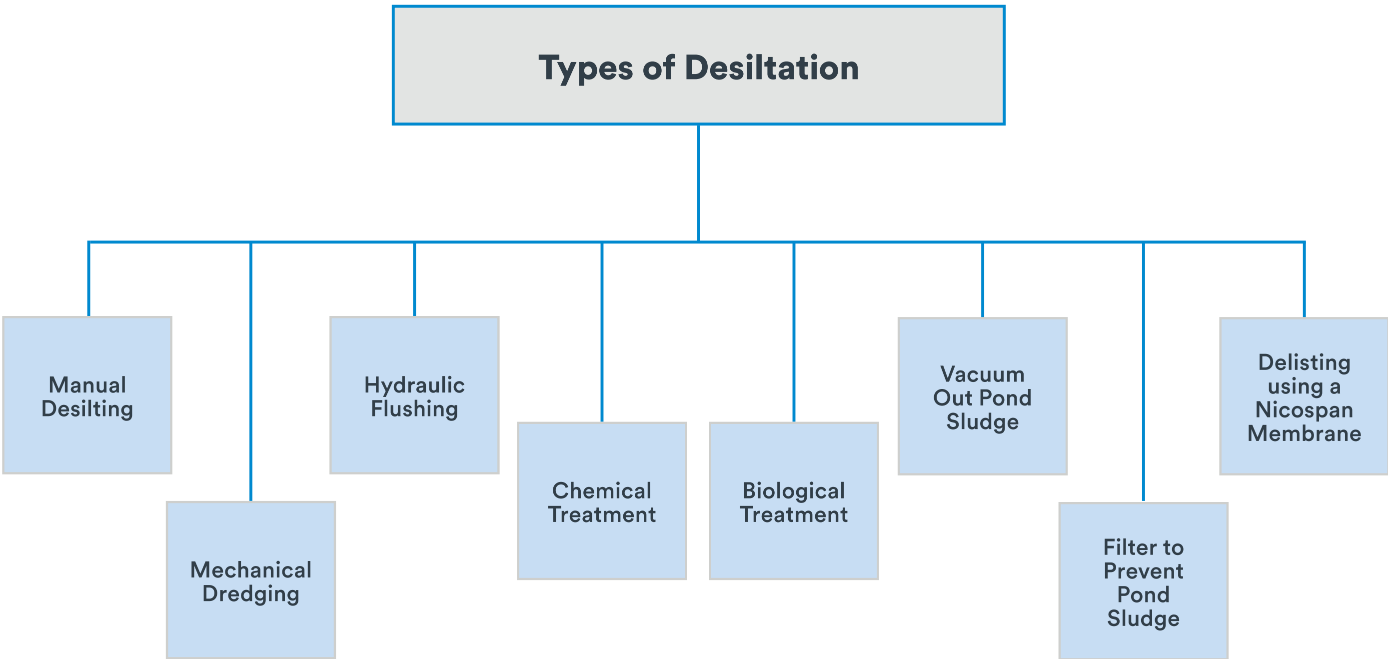

Figure 7.2 Types of Desiltation

7.3.1 MANUAL DESILTING

Manual desilting entails the hands-on removal of sediment and debris from waterbodies by laborers using tools such as shovels, spades, pond nets, or excavators. This process involves workers physically accessing the water, scooping out the accumulated silt, and transferring it to designated disposal areas or containers for reuse. This method often requires meticulous attention to detail, and it is labor-intensive but effective for smaller ponds or areas inaccessible to machinery.

Removal of Sludge with a Pond Net

If the pond bed consists mainly of leaves and organic material, a coarse net with a sturdy handle can be considered to remove the material. Dragging the net across the pond floor until it's clear of debris can help. For any remaining particles in the water, a finer net can be used to skim through the midwater, capturing as much as possible. Additionally, pond sludge can be manually removed to ensure the safety of aquatic life without causing harm.

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7.3.2 MECHANICAL DREDGING

The use of machinery such as dredgers or excavators equipped with buckets or suction pumps to remove silt mechanically. This method is faster and suitable for larger ponds but may require access to heavy equipment.

Silt Pumping using De-Watering / Silt Bags

To ensure stability, de-watering bags should be positioned on level ground to prevent any movement of the bags. The silt is pumped into the bags. Once filled with pumped silt, the bags are left to de-water, resulting in a fabric container filled with pure silt. These bags can be unsealed, allowing the silt to be reused onsite for landscaping purposes. Given its decaying organic matter composition, the silt is an excellent plant compost.

7.3.3 HYDRAULIC FLUSHING

This involves diverting water from another source into the pond to create a flow that carries away silt. This method can be effective for shallow ponds with a nearby water source.

7.3.4 CHEMICAL TREATMENT

Adding chemicals to the water to coagulate suspended solids, makes it easier to remove silt through settling or filtration. However, this method may have environmental implications and requires careful consideration.

7.3.5 BIOLOGICAL TREATMENT

Beneficial aerobic bacteria can help to reduce and liquefy sludge, clearing the water, and making it easier for your filter to remove.

7.3.6 VACUUM OUT POND SLUDGE

To effectively remove silt, mud, dead algae, fish food, and fish waste from the pond bottom, the ideal tool to use is a pond vacuum cleaner. Specifically designed for pond cleaning, this device operates similarly to vacuuming carpets, but instead, it is slowly maneuvered across the pond floor. As the vacuum operates, it collects pond sludge and dirty water. Water then discharged through a drain hose located at the back. Pond vacuums offer a hassle-free method for thoroughly cleaning the pond bottom. Concerned about inadvertently suctioning up small living organisms, users can attach a sludge bag or detritus collector to the waste hose. Regularly vacuuming the pond promotes healthier water conditions.

7.3.7 FILTER TO PREVENT POND SLUDGE

After the pond is netted and vacuumed, a solids handling pump connected to a pond filter is utilized for long-term detritus control. Ponds should be designed to ensure that all waste accumulates at the deepest point, where the pump is positioned. Solids handling pumps are capable of managing large solid waste without requiring frequent maintenance, as they lack foam inside the cage. Their primary function is to collect waste and transport it to the filter located at the pond's edge for disposal. If the pond lacks a single deep spot, the pump can be relocated around the pond over several days or weeks to effectively remove detritus. Some pumps offer the option of attaching an additional inlet, allowing suction and solids removal from two different locations.

Pressure Filters

In ponds with high levels of dirt, pressure filters can be blocked frequently, which can diminish their effectiveness. If a pressure filter has to be used for other practical considerations, select one equipped with a cleaning mechanism and flushing capacity for easier maintenance. Alternatively, if prefer a low-maintenance option, consider installing the largest black box filter available. These filters feature a vast sponge surface area and a bypass system, minimizing blockages and maintaining consistent water flow. For ponds housing numerous large fish and undergoing heavy feeding, koi filters are recommended. These filters are specifically designed to manage substantial amounts of solid and biological waste, offering convenient cleaning and drainage features for waste disposal. Additionally, for those seeking a truly hands-off approach to filtration, automatic self-cleaning filters are available.

7.3.8 DESILTING USING A NICOSPAN MEMBRANE

One method for depositing silt where there is little space around the watercourse can be installing a permeable membrane along the water's edge to form a new bank. Using a Truxor with a clamshell bucket, the silt can be dredged behind the membrane, allowing water to separate through it while retaining the silt. Once the area is filled and begins to dry, planting the area with marginal plants creates an aesthetically pleasing new border along the water's edge. Planting vegetation along the pond's edge or in designated areas will also help trap sediment and prevent erosion, thus reducing silt accumulation. The membrane can be adjusted to the desired depth, size, and shape to match the planting and bank edge requirements.

Besides the above-mentioned proactive measures to minimize the build-up of silt and sediment in the waterbody, the following are some additional effective strategies:

- Implementing soil conservation practices such as contour plowing, terracing, and cover cropping on surrounding land to minimize soil erosion and sediment runoff into the pond.
- Implementing measures to control stormwater runoff, such as installing detention ponds or rain gardens to reduce the influx of sediment into the pond during heavy rainfall events.
- Installing sediment traps or settling basins along the water's flow path to capture sediment before it reaches the pond, reducing siltation.
- Conducting routine inspections and maintenance activities such as dredging, shoreline stabilization, and vegetation management to help prevent excessive siltation.

7.3.9 FREQUENCY OF DESILTING

The frequency of desilting depends on the rate of silt accumulation, which can be influenced by factors like watershed runoff, erosion, and vegetation cover. Typically, smaller ponds may require desilting every 5-10 years, while larger ponds may need it less frequently, perhaps every 10-20 years. Regular monitoring of sediment buildup will help determine the appropriate frequency.

The best season for pond desilting often depends on climate and local conditions. In general, it's best to conduct desilting during dry seasons or periods of low water flow to minimize disruptions to aquatic life and surrounding ecosystems. However, it's important to consider any regulatory restrictions or permits required for desilting activities, as well as potential impacts on wildlife breeding seasons.

7.4 Deweeding

The Deweeding method involves the physical removal of the plant material from the waterbody either mechanically (harvesters) or manually (Gulati et al., 2013; Habib and Yousuf, 2016). Consequently, Cooke et al., 1986 stated that the procedure can achieve numerous objectives including the elimination of harmful/toxic pollutants, taking out dense weeds, capturing phosphorus, and easing navigation. Regular dredging, typically conducted once every three months, is crucial for managing dense and thickly covered aquatic plants, including floating species like algae, duckweed, watermeal, and water hyacinth, as well as submerged plants such as milfoil, hydrilla, water lettuce, curly-leaf pondweed, clasping-leaf pondweed, coontail, sago pondweed, water lily, and water shield. This dredging process also targets the removal of bottom sediment and associated nutrients to maintain the health and balance of the waterbody [3]. The following sections explain the common deweeding measures. However, To prevent excessive growth of vegetation in waterbodies, it is essential to implement preventive measures such as ensuring proper design and construction of ponds including leveling and smoothing the banks [3].

7.4.1 MANUAL OR PHYSICAL CONTROL MEASURES

Manual or physical control measures such as non-chemical and non-motorized measures should be implemented for the removal of weeds, employing methods such as hand pulling, the use of rakes, cutters, benthic barriers, drawdown, aeration, shading, and weed rollers. These approaches are generally cost-effective but labor-intensive, making them more suitable for addressing small or less established weed populations. However, it's important to note that hand pulling and raking can lead to turbidity in the water and may result in the creation of plant fragments that could spread to new areas [3].

7.4.2 MECHANICAL CONTROL MEASURES

Motor-driven underwater weed cutters, floating weed rotovators, and draglines for underwater dredging, or dry-land excavation machinery like bulldozers for drained ponds, are effective methods for large-scale weed and sediment management. Additionally, reducing sunlight exposure to aquatic plants by employing techniques such as floating black plastic sheeting on the water surface or using dark-colored, non-toxic water dyes like nigrosine, aniline, and aqua-shade can also be utilized [3].

7.4.3 BIOLOGICAL CONTROL MEASURES

Aquatic animals and plants that consume or compete with waterweeds can be introduced to manage weed growth. Herbivorous organisms such as insects, snails, crayfish, tadpoles, turtles, fish (sterile, triploid grass carp), ducks, geese, and swans can be introduced into ponds to feed on aquatic plants and help control their expansion [3].

7.4.4 FREQUENCY OF DEWEEDING

The frequency of deweeding depends on the growth rate of weeds and the desired condition of the pond. Generally, smaller ponds may require deweeding more frequently, perhaps annually or biannually, while larger ponds may need it less often, every 2-3 years. Regular monitoring will help determine the optimal frequency of deweeding. The best season for deweeding depends on the types of weeds present and local climate conditions. In temperate regions, early spring or late fall is often ideal as it allows for effective weed control before the peak growing season while minimizing disruption to aquatic life. However, for some types of weeds, such as aquatic invasive species, targeted treatments may be necessary during specific growth stages regardless of the season.

7.5 Prohibition of Discharges or Waste Disposal or Washing Activity

The discharge of industrial effluent sewage or waste (such as municipal solid waste / industrial hazardous waste / plastic waste/ construction and demolition waste or sludges from septic tanks/ STPs/CETPs) into lakes or ponds or drainage channels connected with ponds is often against the government guidelines and should be closely monitored. Similarly, open defecation in the vicinity as well as washing of clothes or wading of cattle is highly discouraged because it impacts the quality of water and the ecosystem of the pond. Strict enforcement actions should be taken by the SPCB or Pollution Control Committee (PCC) against industries found violating environmental regulations outlined in the Water (Prevention and Control of Pollution) Act, 1974, and Environment (Protection) Act, 1986. Penalties, including fines or environmental compensation, should be imposed on violators who improperly dispose of sewage, industrial effluent, or waste into ponds [3].

7.6 Stabilization of Earthen Bunds and the Drainage Channels Along with Silt and Soil Erosion Control Measures

The stabilization of earthen embankments and protection of shorelines using vegetative cover or rock riprap is essential to prevent soil erosion. Inflow drainage channels should be reinforced with stone revetments or pitching to mitigate rapid seepage or leakage. Additionally, silt barriers, sediment traps, or sediment detention basins should be installed at appropriate intervals along the drainage channels to control silt, particularly during the monsoon season. Moreover, suitable strainers or traps should be placed at all outfalls of drainage channels to manage the inflow of floating materials, with periodic removal of such materials to be ensured [3]. Geofilters can also be the solution to prevent soil erosion and manage land sustainably. These are typically made of special materials like geotextiles, which are permeable materials designed to stabilize soil, control sediment, and improve water drainage. Placed strategically in erosion-prone spots like slopes or riverbanks, geofilters reduce water flow impact, prevent soil loss, and maintain ecological balance.

7.7 Protection of Drainage Basin

The drainage basin of a pond serves as the fundamental basis for planning and managing sustainable use. It requires a long-term, preventive strategy aimed at addressing underlying causes of degradation. This involves restoring drainage channels with diminished efficiencies, diversions, or blockages. Actions may include halting the influx of untreated municipal sewage or industrial effluent. If necessary, diverting such untreated waste through a properly designed dedicated sewerage network to ensure conveyance and treatment via STPs/CETPs. Additionally, exploring the feasibility of in-situ treatment of sewage and industrial effluent within drainage channels before inflow into waterbodies is recommended. Identifying major channels from larger watersheds based on historical data and preserving and protecting them with suitable buffer land devoid of impervious cover is also crucial [3].

7.8 Removal of Encroachments and Blockages

The state government or local administration should maintain records of the boundaries of each pond or lake within their jurisdiction. They should take necessary measures to remove any encroachments within the waterbody spread area or boundary as needed. Periodic removal of encroachments is essential to facilitate natural aeration within the waterbody. Additionally, installing a fence along the pond boundary, either permanent or temporary, is necessary to prevent unauthorized entry [3].

7.9 Flood Control Measures

Efficiently designed 'spillways' with controlled gates should be provided to manage excess floods from drainage basins, ensuring a smooth flow of runoff during the monsoon season. Encroachments, including those on lakebeds and stormwater drains, must be removed to prevent flood-related disasters and to promote interconnectivity between waterbodies. Additionally, all blockages at inlets or outlets should be cleared to prevent stagnation or obstruction of stormwater flow [3].

To prevent flooding resulting from breaches in embankments, several preventive measures can be adopted. These include implementing toe drainage to manage water buildup at the base of the embankment and placing sandbags along the toe with covered drains to enhance shear resistance and prevent slipping. Additionally, reducing seepage through the construction of ring wells with sandbags near the toe can help lower the seepage head. Plugging piping holes using divers and tarpaulins soaked with bitumen from the riverside face can further mitigate breaches. In cases of overtopping, raising the embankment height with wooden planks can be considered, ensuring stability against slipping while effectively containing floodwaters. Breaches should be closed on a war footing in order to minimize the flooding of the countryside [22].

Thus, the protection phase covers various measures to take care of the general health of the waterbody and to ensure its long-term normal functioning. The next chapter provides insights into the improvement phase of the waterbody rejuvenation framework.

8.0 Improvement Phase

This phase provides various strategies for overall improvement in the waterbody and its uses including the resolution of conflicts among competing users of waterbody resources, considering the needs of present and future generations, and the environment. Figure 8.1 indicates the components of the improvement phase.

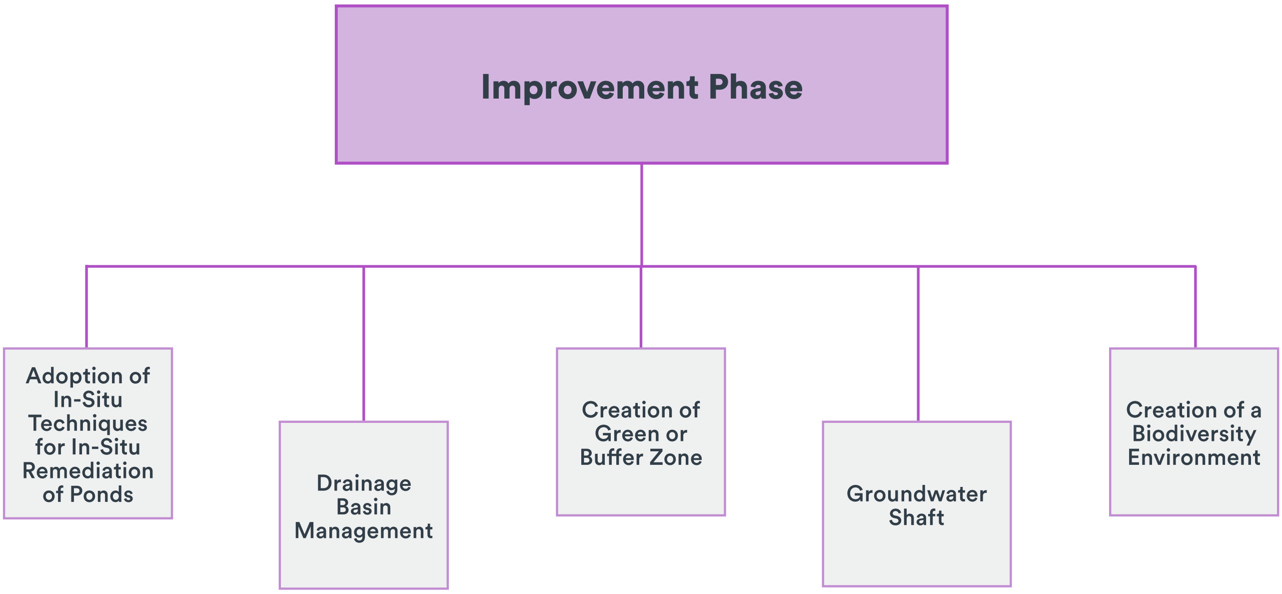

Figure 8.1 Components of Improvement Phase

8.1 Adoption of In-Situ Techniques for In-Situ Remediation of Ponds

8.1.1 PHYSICAL TREATMENT

In this method, mechanical or solar-powered aeration is implemented using surface aerators, submerged aerators, or a combination of both to enhance the dissolved oxygen levels in the waterbody. This dissolved oxygen is essential for microorganisms to decompose pollutants. Aeration also facilitates the mixing of different thermal layers within the waterbody, promoting destratification and allowing the lower layers to come into contact with atmospheric air. The requirement and extent of aeration are determined based on various factors such as water quality parameters, depth of the waterbody, ambient temperatures, wind conditions, etc. Additionally, practices like wastewater diversion, periodic deweeding, sediment dredging, and proper maintenance of drainage or feeder channels also contribute to increasing dissolved oxygen levels [3].

8.1.2 CHEMICAL TREATMENT

This method involves flocculation using chemicals such as alum and neutralizing agents, particularly when addressing acidification (a rise in pH levels) in stagnant waterbodies. The application rate and frequency of these chemicals can be adjusted according to the specific water quality parameters that need to be addressed [3].

8.1.3 BIOLOGICAL TREATMENT

In-situ techniques can also involve the use of aquatic plants such as water hyacinth (Eichhornia crassipes), water lettuce (Pistia stratiotes), whorlleaf watermilfoil (Myriophyllum verticillatum), pondweed (Potamogeton spp.), common reed (Phragmites communis), cattail (Typha latifolia), duckweed (Lemna gibba), and canna (Canna indica). Additionally, aquatic animals like clams, snails, and other filter-feeding shellfish can be introduced into the waterbody ecosystem as part of the in-situ remediation strategy [3].

Biological techniques involve decomposing, transforming, and absorbing water pollutants. The concentration and frequency of dosing of microbial cultures are determined based on the volume of the waterbody, water quality parameters, ambient temperatures, and extent of algal growth. Here are some in-situ biological techniques [3]:

- Phycoplus enzyme and nutrient mixture sprayed into the pond.
- Hydroponics-based treatment method that absorbs nutrients dissolved in the water, supporting living species inside the lake.
- Floating treatment wetlands (FTW) using artificial islands made of inert materials and gravel, with floating plants like wetland plants, water hyacinth, mosquito repellents, and ornamental plants such as cattails, bulrush, citronella, canna, hibiscus, fountain grass, flowering herbs, tulsi, and ashwagandha, facilitating cleaning through a hydroponics system.
- Introduction of the nutrient mixture to grow algae formed by diatoms (the most basic, single-cell life form found in waterbodies), which release oxygen into the water. Aerobic bacteria then break down organic matter, converting pollutants to base constituents and reducing odors. Zooplankton consumes diatoms, which are then eaten by fish.

8.2 Drainage Basin Management

Managing drainage basins effectively is crucial for preventing pond pollution. Here's a comprehensive approach to achieve this goal:

8.2.1 WATERSHED MANAGEMENT

Implement watershed management practices to control runoff and minimize the introduction of pollutants into the drainage basin. This can include erosion control measures such as planting vegetation along streambanks, installing check dams, and creating buffer zones to filter runoff before it enters the pond.

8.2.2 STORMWATER MANAGEMENT

Develop stormwater management plans to capture and treat runoff before it enters the pond. This may involve the construction of retention ponds, green infrastructure like rain gardens and permeable pavement, and the use of sediment traps and filters to remove pollutants.

8.2.3 VEGETATIVE BUFFERS

Establish vegetative buffers around the pond to filter pollutants and prevent sedimentation. Buffer zones can consist of native plants and grasses that help absorb nutrients and trap sediment, reducing the influx of pollutants into the pond.

8.2.4 SEDIMENTATION CONTROL

Implement measures to control sedimentation within the drainage basin, such as erosion control practices, sediment traps, and sediment ponds. Regular maintenance of these structures is essential to ensure their effectiveness in preventing sediment from entering the pond.

8.2.5 NUTRIENT MANAGEMENT

Manage nutrient inputs from sources such as fertilizers, animal waste, and sewage to prevent excessive nutrient loading in the pond. This can be achieved through proper land use practices, agricultural best management practices, and the implementation of nutrient management plans.

8.2.6 POLLUTION PREVENTION

Educate stakeholders within the watershed about the importance of pollution prevention and responsible land use practices. Encourage the adoption of practices such as proper waste disposal, reducing the use of pesticides and herbicides, and minimizing impervious surfaces to mitigate pollution in the drainage basin.

8.2.7 MONITORING AND MAINTENANCE

Regularly monitor water quality parameters in the pond and the surrounding watershed to detect any signs of pollution. Establish a maintenance schedule to inspect and maintain drainage infrastructure, sediment traps, and other pollution control measures to ensure their continued effectiveness.

8.2.8 REGULATORY COMPLIANCE

Ensure compliance with local, state, and federal regulations related to water quality and pollution control. Stay informed about any changes in regulations and adjust management practices accordingly to meet compliance requirements.

By implementing the above measures, drainage basin management can effectively mitigate pollution and maintain the water quality of ponds, ensuring their ecological health and the well-being of surrounding communities.

8.3 Creation of Green or Buffer Zone

Creating green or buffer zones around waterbodies is crucial for safeguarding their ecological well-being and preventing pollution. These buffer zones, extending at least 50 to 100 meters from the periphery of lakes or ponds, should be designated as green belt zones or no-activity zones. No activities should be permitted within these buffer zones by the relevant state departments. If any activities currently exist within the buffer zone (50 to 100 meters), such as residential, commercial, or industrial operations, measures must be taken to prevent the discharge of any waste into the waterbody. Within the buffer zone, impervious cover should be prohibited, and instead, dense plantations comprising deeply rooted plants, trees, shrubs, and grasses should be established. These plants serve to absorb nutrients, which are often derived from anthropogenic activities, and promote aquatic plant growth while positively influencing water quality [3]. Following are the ways to establish such green/ buffer zones effectively:

8.3.1 VEGETATION SELECTION AND WIDTH OF THE BUFFER ZONE

Choose native plants, grasses, and trees for the buffer zone. Native species are well-adapted to the local environment and require less maintenance. They also provide better habitat and food sources for native wildlife. Determine the appropriate width for the buffer zone based on factors such as the size of the waterbody, the slope of the land, and potential sources of pollution. A wider buffer zone can provide better protection by filtering out pollutants and reducing runoff velocity.

8.3.2 EROSION CONTROL, FILTRATION, AND NUTRIENT UPTAKE

Use vegetation and natural features like swales and berms to control erosion along the shoreline. Vegetation with deep root systems helps stabilize soil, preventing sediment from entering the waterbody. Plant vegetation that can absorb nutrients and filter pollutants from runoff. Wetland plants, for example, are highly effective at removing excess nutrients like nitrogen and phosphorus from water.

8.3.3 MAINTENANCE PRACTICES

Establish a maintenance plan to ensure the health and effectiveness of the buffer zone. This may include regular mowing, removing invasive species, and replanting areas that have been disturbed. Regularly monitor the health of the buffer zone and the waterbody it surrounds. Assess water quality, wildlife habitat, and vegetation cover to identify any issues that may require attention.

8.3.4 REGULATORY SUPPORT AND PUBLIC EDUCATION

Work with local government agencies to implement regulations or incentives that promote the creation and maintenance of buffer zones around waterbodies. This could include zoning ordinances, conservation easements, or financial assistance programs for landowners. Educate the community about the importance of buffer zones and how they help protect water quality and wildlife habitat. Encourage residents to avoid activities like mowing or dumping yard waste in the buffer zone. Also, collaborate with local conservation organizations, watershed groups, and landowners to establish and maintain buffer zones. Pooling resources and expertise can help ensure the long-term success of these efforts.

By implementing these strategies, you can create green or buffer zones around waterbodies that effectively protect water quality, enhance habitat, and contribute to the overall health of the ecosystem.

8.4 Groundwater Shaft

Groundwater shafts are artificial structures designed for recharging shallow phreatic aquifers, which are not in direct hydraulic connection with surface water due to impermeable layers. It is a vertical excavation or borehole made into the ground to access underground water sources. These shafts are typically constructed to extract groundwater for various purposes such as irrigation, drinking water supply, or industrial use. Although they primarily target shallow aquifers, they can also potentially recharge deeper aquifers if sufficient water supply is available. In areas with high suspended solid loads in recharge water, subsurface application techniques like deep pits, groundwater shafts, and wells are susceptible to failure. Recharge shafts are similar to recharge pits but are constructed to enhance recharge into phreatic aquifers where water levels are lower. They are typically smaller in cross-section compared to recharge pits [26].

Groundwater shafts can be dug manually in non-caving strata, may reach up to approximately 2 meters in diameter at the bottom, or drilled using direct rotary or reverse circulation methods for deeper constructions. In the case of drilled shafts, the diameter may not exceed 1m. The shafts should penetrate low-permeability layers to reach permeable strata, but they do not necessarily need to intersect the water table. By tapping into aquifers or underground reservoirs, groundwater shafts provide a reliable and sustainable source of water [26].

8.5 Creation of a Biodiversity Environment

If the waterbody happens to be a site for the visit by migratory birds, it's essential to monitor the number and type of trees along the waterbody and water channels. This monitoring ensures there's sufficient shelter and a suitable environment for egg-laying and the propagation of bird species [3].

Once the restoration and improvement phase is completed, the next phase is the sustenance phase. This phase deals with maintaining the efficiency of the pond operation in terms of capacity of the pond, quality of the water, outflow from the pond, and general usability of the pond. It also provides some insights on the technological enhancements that should be accounted for the ease and quality of the work to be done.

9.0 Sustenance Phase

The sustenance phase focuses on maintaining the efficiency of the pond's functionality, capacity, and water quality. Effective governance, characterized by fairness, transparency, and empowerment of all stakeholders, is crucial for ensuring the pond's sustainability. Additionally, establishing a clear responsibility matrix for each pond is vital, as most of them face indefinite sustenance due to fragmented administrative control or lack of specific oversight by a singular authority. The in-charge authority should view the pond as a natural resource and leverage its potential to enhance civic health, provide recreational opportunities, boost tourism, and potentially address local water needs, etc. Such benefits can only be realized through an ecosystem-based approach to pond management. When rejuvenating the pond, it's essential to develop a self-sustainable rejuvenation model capable of maintaining the pond's health over the long term [10]. Figure 9.1 shows the components of the sustenance phase.

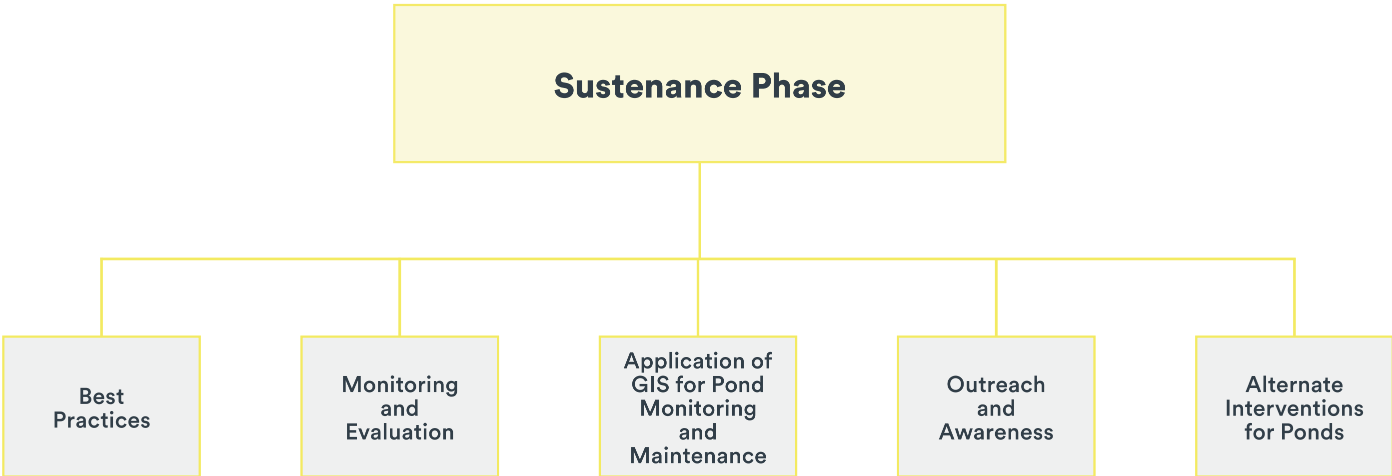

Figure 9.1 Components of Sustenance Phase

9.1 Best Practices

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The sustainable use of the pond and long-term efficiency of the pond can be ensured with an effective operation and maintenance plan. Below is the list of the best practices which can help with the smooth operation of the pond [10].

- Enhancing public awareness about the significance of maintaining pond cleanliness, which stands as a pivotal aspect of pond conservation and sustainable management.
- Installing informative signages highlighting the services offered by pond ecosystems and their inherent worth.
- Regularly removing fallen leaf litter from the pond or moat water.
- Employing low-phosphate fertilizers and manures for tree plantations in the lakefront area to prevent nutrient imbalance in the pond.
- Erecting protective barriers around the pond and its landscaped surroundings, such as high walls (without obstructing the view from outside) and inclined nets, to deter solid waste disposal.
- Placing an ample number of dustbins around the waterbody to minimize littering in the pond.
- Constructing community toilets to prevent fecal pollution in the drains surrounding the pond area.
- Implementing strict surveillance measures to discourage solid waste dumping in the pond, including the installation of directional signs and warning messages.
- Enforcing waste disposal regulations and fostering community awareness to curb littering in the pond.
- Taking strict actions to prevent and penalize encroachment activities, if any [10].

Table 9.1 DOs and DON'Ts for the Sustenance of Ponds and Waterbodies

Sr. No	DOs	DON'Ts
1	Implement a rainwater harvesting system to replenish the pond during dry spells, promoting water conservation and sustainable water use.	Avoid introducing non-native or invasive species to the pond, as they can disrupt the ecosystem and outcompete native species.
2	Introduce native aquatic plant species to enhance biodiversity and provide habitat for aquatic organisms.	Do not use chemical pesticides or herbicides near the pond, as they can harm aquatic life and disrupt the ecosystem balance.
3	Encourage eco-friendly recreational activities such as birdwatching, nature walks, and non-motorized boating to minimize disturbance to wildlife.	Avoid overfertilizing the surrounding land, as excess nutrients can lead to algal blooms and degrade water quality.
4	Establish a regular monitoring and maintenance schedule to address water quality issues promptly, including testing for pollutants and invasive species.	Do not allow motorized watercraft or other activities that produce noise or pollution that can disturb wildlife and disrupt the tranquil environment.
5	Promote sustainable fishing practices, such as catch-and-release policies and adherence to legal size limits, to maintain fish populations and ecosystem balance.	Avoid draining or dredging the pond without thorough ecological assessments and proper permits, as these actions can harm habitat and disrupt natural processes.
6	Create buffer zones of native vegetation around the pond to filter pollutants, reduce erosion, and provide wildlife habitat.	Do not use the pond as a dumping ground for household or industrial waste, as this can contaminate the water and harm aquatic life.
7	Collaborate with local schools and community groups to organize educational programs and workshops on pond ecology, conservation, and sustainable use.	Avoid excessive shoreline development or modification, as it can disrupt natural hydrology and diminish habitat quality for aquatic organisms.

9.2 Monitoring and Evaluation

Continuous monitoring of pond capacity and water quality is essential to maintain the efficiency and functionality of the pond. Some key benefits of implementing a waterbody monitoring plan include [9]:

- Improved understanding of the correlation between rainfall and runoff, leading to reduced risks of flooding-related damage and disruptions.
- Enhanced real-time management of treatment and storage components by enabling timely adjustments of overflow/outflow structures based on current levels and flow conditions.
- Effective and reliable assessment of influent quality to optimize load management and treatment processes, thereby preventing significant contamination issues [9].

9.2.1 FLOW MONITORING

Flow monitoring is essential for understanding the drainage flow towards the pond and its recharge. Any hindrance affecting the flow to the pond might impede its functionality and ecosystem. Flow meters installed in stormwater drains aid in gauging the runoff volume in the catchment. This is used to design the drain capacity. Data collected from flow monitors stationed at the waterbody's inlet or outlet can anticipate runoff trends entering and exiting the waterbody[9].
Flow monitoring methods available are listed below [9]:

- 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 waterbodies:
These monitoring sites would assist in determining the flow rates into the waterbody. Hence, it is advisable to position these sites near the inlet, although not directly adjacent to it to avoid hydraulic influence [9].

Flow monitoring sites on drains:
Ideally, these monitoring sites should be situated in a section of the drain characterized by free flow, cleanliness, and straightness, without bends, blockages, constrictions, or changes in shape within a 100-meter radius. This setup ensures an accurate depiction of the rainfall-runoff relationship for similar catchments [9].

Flow monitoring sites at Used Water Treatment Plant (UWTP):
This strategy is employed when the waterbody lies downstream of a UWTP (Urban Wastewater Treatment Plant) and receives treated effluent from the facility. It serves to alert site operators of potential flooding and enables them to manage flood risk by diverting excess water away from the waterbody [9].

Flow measurement and corresponding frequency as presented in Table 9.2 below, is recommended to be included as part of the waterbody monitoring plan.

Table 9.2 Flow Monitoring Sampling [9]

Data	Frequency	Method 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.	• Automation-digital, data stored on-site for manual collection: and • Automatic digital, data transmitted by phone network to offsite database. • Manual reading

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9.2.2 WATER QUALITY MONITORING

Water quality monitoring is imperative for evaluating the effectiveness and functionality of any waterbody rejuvenation initiative. In addition to gauging pollution from the watershed, water quality monitoring aids in assessing the level of treatment attained at various depths within the waterbody, especially in scenarios where natural treatment mechanisms like floating wetlands are employed. Table 9.3 outlines the types of samples and sampling sites recommended for assessing water quality across different locations within the waterbody [9].

Table 9.3 Sample Type and Sampling Locations for Water Quality Assessment in a Waterbody [9]

Sample type	Sampling point	Relevance
Lake water	Shallow zone	Representative of the quality of water in the waterbody
	Deeper zone	
Lake sediment	Sediment surface	Representative of the 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.

9.2.3 MONITORING UNITS

- EWLI:EWLI stands for Electronic Water Level Indicator, also known as electronic remote water level indicator. This device is designed to remotely monitor and display the water level in tanks, reservoirs, or other waterbodies. It typically consists of sensors placed inside the waterbody and a display unit located at a remote location, allowing users to monitor the water level without the need for manual inspection. EWLI systems are commonly used in various applications such as agriculture, water management, and industrial processes to ensure efficient water usage and prevent overflow or shortages. EWLI systems provide real-time information on water levels, allowing for prompt action in case of fluctuations or emergencies.
- Piezometer: The sensor is to be placed within the pond and the data logger for it to be placed within the BMS (Building Management System) room. The water level sensor can be used to measure water level, well depth, groundwater level, surface water flow, pipe flow, water pressure, etc.
- The purpose of the Online Tailing Pond Safety Monitoring System is to establish a comprehensive remote automation system with safety monitoring, analysis, evaluation, and forecasting. This includes real-time tailing pond safety monitoring using a dynamic monitor, a communication sub-system between the tailing pond and monitor center in an enterprise building, and both a monitor center computer system and web query reporting system [27].

9.3 Application of GIS for Pond Monitoring and Maintenance

Geographic Information Systems (GIS) have emerged as indispensable tools for addressing complex challenges in water sustainability. The applications of GIS in water resource management, highlight its role in monitoring, analysis, and decision-making processes. The integration of spatial data with hydrological models allows for a better understanding of water dynamics, facilitating informed decision-making for sustainable water use. Figure 9.2 shows a flowchart of how a GIS server interacts with data, stakeholders, and data processing units. It also shows an example of a cell phone GIS tool that can be used by various stakeholders for data management and processing.

Figure 9.2 Example of a GIS Tool for Data Management and Sharing

GIS facilitates the integration of diverse data sources related to water resources, including hydrological data, water quality measurements, groundwater levels, and precipitation data. Water resource managers can use GIS to model water availability, predict water demand, and optimize water allocation strategies. GIS-based decision support systems help stakeholders make informed decisions regarding water allocation, conservation measures, and infrastructure planning.

GIS-based mapping and visualization tools facilitate community engagement and public participation in water resilience initiatives. Interactive maps, dashboards, and web applications help communicate complex water-related information to stakeholders in an accessible and understandable format. GIS supports participatory decision-making processes by enabling stakeholders to visualize the potential impacts of water management decisions on their communities and the environment. By leveraging GIS technology monitoring and maintenance of storage facilities will be efficient. Stakeholders can develop more effective strategies for sustainable water management, mitigate water-related risks, and build resilience to future challenges.

9.4 Outreach and Awareness

The best possible approach towards sustainable maintenance of pond ecosystems is by involving the stakeholders directly affected by the pond rejuvenation project in the task of pond rejuvenation. Community participation is the key to sustainable conservation and enhancing ecological literacy in citizens is extremely crucial [10].

The creation of awareness among diverse groups such as citizen organizations, resident welfare associations, and governmental agencies regarding the importance of preserving waterbodies and the necessity of adhering to water quality standards [28]. During the awareness program, several key topics can be discussed. Firstly, water crisis, the importance of maintaining the rejuvenated pond ecosystem should be emphasized, highlighting its ecological significance, recreational benefits, potential contributions to the local economy, and suggestions [1]. Participants can also learn about the specific challenges facing the pond and the potential consequences of neglecting its maintenance. Best practices for pond maintenance can be shared with attendees. These may include regular litter clean-up sessions, monitoring water quality, controlling invasive species, maintaining vegetation around the pond, and implementing sustainable fishing practices if applicable. Also, training initiatives and initiatives to encourage public participation, enabling individuals to actively contribute to rejuvenation activities through volunteering, workshops, and educational programs can be implemented. Lastly, the establishment of recreational centers around ponds serves not only to promote community engagement but also to enhance the aesthetic appeal of these waterbodies, encouraging residents to appreciate and utilize these natural spaces for leisure and enjoyment.

The depicted model in Figure 9.3 outlines the process from the initial lack of awareness stage to the final stage of improved behavior among individuals. Firstly, the focus is on educating people about what, why, where, when, and how of water conservation practices, including objectives related to the restoration and rejuvenation of ponds. The second step involves encouraging individuals by inspiring and motivating them to adopt new behaviors in their daily lives. Thirdly, efforts are made to empower the masses with knowledge about water crisis issues and problems they may encounter, emphasizing how even small positive habits can prevent stress and health issues. Lastly, enforcement involves all stakeholders playing their respective roles in fostering a water-conscious district [1].

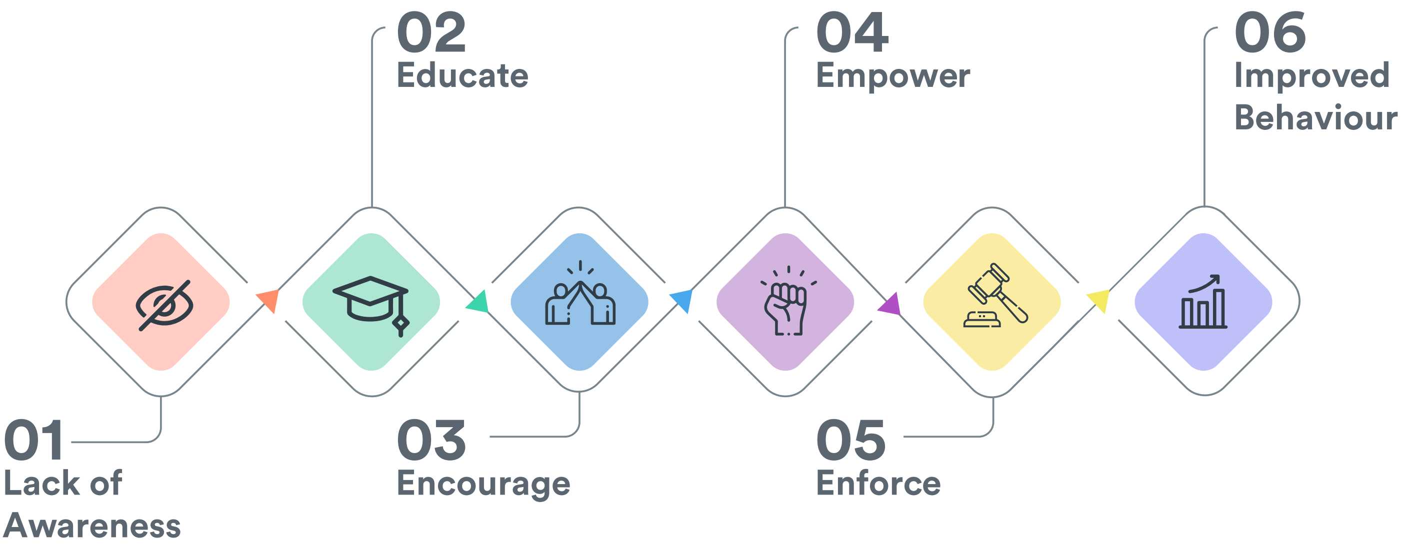

Figure 9.3 E's of Behavior Changes [1]

Awareness-building measures will be undertaken to create interest among farmers in the excavation of the farm pond. It could be through electronic mass media, newspaper publications, leaflets, Street plays public address systems, etc. At the grassroots level, the field level officials like Village Agriculture Workers (VAW), Horticulture Extension Workers (HEW), SCEW, and Women self-help groups shall mobilize the farmers in their respective localities. The field level officials like VAW, HEW, and SCEW shall participate to create awareness during Gram Sabha each year [11].

By involving a diverse range of stakeholders in awareness programs and implementing best practices for pond maintenance, communities can ensure the long-term health and sustainability of their rejuvenated ponds.

9.5 Alternate Interventions for Ponds

Table 9.4 outlines some of the alternate interventions for ponds along with concise descriptions and references for detailed information.

Table 9.4 Alternate Interventions for Ponds

Sr. No.	Structure	Details
1.	Gabion Wall	The gabion structure is a simple, flexible gravity-retaining system, which retains soil using its weight. Gabion walls are designed on a similar principle as gravity mass walls. Designing the gabion structure involves ensuring that the gabion mesh can securely contain the rocks with minimal deformation, maintaining both aesthetics and internal stability [29]. For detailed information, refer to IRC: SP:116-2018.
2.	Bench Terracing	Bench terracing is a method used to level sloping lands with surface gradients of up to 8 percent, provided they have adequate soil cover for bringing them under irrigation. This technique aids in soil conservation by preventing erosion and retaining runoff water on the terraced surface for longer durations, leading to increased infiltration and groundwater recharge [26]. For detailed information, refer to Manual on Artificial Recharge of Ground Water, CGWB, 2007.
3.	Contour Bunds	Contour bunding, which is a watershed management practice involves the construction of small, narrow-based trapezoidal embankments (bunds) along contours of equal land elevation across the slope of the land aimed to impound water behind them, which infiltrates into the soil building up soil moisture storage and ultimately augments groundwater recharge. This method is typically adopted in low rainfall areas (usually less than 800 mm) and gentle-sloping agricultural lands with long slopes, provided the soils are permeable. It is not advisable for soils with inadequate internal drainage, e.g. clayey soils [26]. For additional information, refer to Manual on Artificial Recharge of Ground Water, CGWB, 2007.

Sr. No.	Structure	Details
4	Contour Trenches (Continuous Contour Trench (CCT), Intermittent Contour Trench)	Contour trenches are utilized for rainwater harvesting and can be built on hill slopes as well as degraded wastelands in both high and low-rainfall regions. The trenches should be constructed along the contours and may be continuous or interrupted. Continuous contour trenches (CCT) are used for moisture conservation in areas with low rainfall, while intermittent contour trenches are suitable for high-rainfall regions. The trenches reduce the velocity of surface runoff by breaking the slope at intervals. The water retained in the trench will contribute to conserving soil moisture and groundwater recharge [26]. For a detailed understanding, refer to Manual on Artificial Recharge of Ground Water, CGWB, 2007.
5	Gully Plugs, Nallah Bunds, or Cement Nallah Bunds (CNB), Check Dams	Bench terracing is a method used to level sloping lands with surface gradients of up to 8 percent, provided they have adequate soil cover for bringing them under irrigation. This technique aids in soil conservation by preventing erosion and retaining runoff water on the terraced surface for longer durations, leading to increased infiltration and groundwater recharge [26]. For detailed information, refer to Manual on Artificial Recharge of Ground Water, CGWB, 2007.
6	Percolation Tanks	Percolation tanks, akin to nallah bunds, are widely used as runoff harvesting structures in India. These tanks are designed to submerge permeable land areas, allowing surface runoff to percolate and recharge groundwater storage. They differ from nallah bunds in featuring larger reservoir areas. They aren't provided with outlets (sluices) for discharging water from the tank for irrigation or other purposes. However, they may include provisions for diverting surplus water to prevent over-topping. Typically constructed on second or third-order streams, as the catchment area of such streams would be of optimum size [26]. For additional information, refer to Manual on Artificial Recharge of Ground Water, CGWB, 2007.
7	Stream Channel Modification / Augmentation	In areas where streams meander through wide valleys, occupying only a part of the valley, natural drainage channels can be altered to enhance infiltration. This modification involves detaining stream flow and expanding the streambed area in contact with water. By this greater infiltration can be achieved [26]. For detailed information, refer to Manual on Artificial Recharge of Ground Water, CGWB, 2007.
Subsurface Techniques		
8	Injection Wells or Recharge Wells	Injection wells are designed to augment groundwater storage in deeper aquifers through a supply of water either under gravity or under pressure. The aquifer to be replenished is generally one with considerable desaturation due to overexploitation of groundwater. Additionally, these wells are utilized in coastal regions to prevent seawater intrusion and address land subsidence issues in areas with heavily pumped confined aquifers [26]. For a detailed understanding, refer to Manual on Artificial Recharge of Ground Water, CGWB, 2007.

Sr. No.	Structure	Details
9.	Gravity Head Recharge Wells	In regions where aquifers have undergone significant desaturation due to over-exploitation of groundwater, existing abstraction structures offer a cost-effective means of artificial recharge. This approach facilitates the replenishment of phreatic or deeper aquifer zones, addressing issues such as dried-up dug wells and decreased piezometric heads in bore/tube wells [26]. For additional information, refer to Manual on Artificial Recharge of Ground Water, CGWB, 2007.
10.	Recharge Pits	Recharge pits are excavated pits designed to penetrate low-permeability layers above unconfined aquifers. Similar to recharge basins, they facilitate infiltration but are deeper and have a restricted bottom area. In these structures, lateral infiltration through the pit walls is predominant, especially in layered sedimentary or alluvial materials where lateral hydraulic conductivity is higher than vertical conductivity [26]. For a detailed understanding, refer to Manual on Artificial Recharge of Ground Water, CGWB, 2007.
11.	Sub-Surface Dykes / Ground Water Dams / Underground Bandharas	A sub-surface dyke / groundwater dam is a sub-surface barrier constructed across a stream channel for stopping the groundwater flow thereby increasing the groundwater storage [26]. For detailed information, refer to Manual on Artificial Recharge of Ground Water, CGWB, 2007.
Rainwater Harvesting		
12.	Water Harvesting/ Rooftop Rainwater Harvesting	Rainwater harvesting involves collecting rainwater from various surfaces where it falls. This technique utilizes localized catchment surfaces like roofs or sloping areas to capture rainwater for direct use or to recharge groundwater, depending on local conditions. Constructing small barriers across small streams to store running water is considered a form of water harvesting. Roof-top rainwater harvesting is particularly effective in urban areas for augmenting groundwater recharge, and it can also meet domestic needs in rural settings [26]. For additional information, refer to Manual on Artificial Recharge of Ground Water, CGWB, 2007.

10.0 Conclusion

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This technical reference manual serves as a comprehensive guide for the rejuvenation of waterbodies (particularly, ponds and small lakes), offering a systematic approach to addressing the various challenges faced by ponds and similar ecosystems. Through its detailed exploration of the rejuvenation framework, site selection methodologies, data collection, and processing techniques, as well as strategies for both protecting and improving ponds, this manual equips practitioners with the necessary guidelines to undertake successful restoration projects. Moreover, its emphasis on sustaining the restored ponds through effective management practices underscores a commitment to long-term environmental health. By integrating outreach and awareness initiatives, this manual extends its impact beyond the technical realm, fostering community engagement and ensuring the collective stewardship of precious water resources for generations to come.

Furthermore, this manual emphasizes the importance of collaboration and interdisciplinary approaches in the rejuvenation process. By encouraging the involvement of stakeholders from diverse backgrounds, including local communities, government agencies, and environmental organizations. It promotes a holistic understanding of the complex dynamics inherent in waterbody restoration. Through shared knowledge and expertise, combined with a commitment to adaptive management practices, one can navigate the evolving challenges posed by environmental degradation and ensure the sustainable revitalization of water ecosystems. To manage water resources, good utilization of the insights provided in this manual will help to enact positive change and preserve the health and vitality of waterbodies for future generations.

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S. No	Content	Documents
Protection Phase:		
15	Overall Improvement in the Waterbody	• Advisory on Urban Waterbodies (MOHUA) https://mohua.gov.in/upload/uploadfiles/files/Advisory%20on%20Urban%20Water%20Bodies.pdf
Protection Phase:		
16	Steps for Sustaining the Waterbodies	• Indicative Guidelines for Restoration of Waterbodies (CPCB) https://cpcb.nic.in/wqm/Ind-Guidelines-RestWaterBodies.pdf

General Notes:

- This report has been prepared based on the data received or collected by Walter P Moore from the client or sources stated in this report.
- This report is a procedural manual and all procedures stated herein have been prepared assuming standard site conditions. Depending on varying conditions at sites, the procedures stated herein may need modification, amendments, or additions/deletions. Walter P Moore shall does not take responsibility for adequacy, accuracy and applicability of contents of this report to any specific site conditions.
- Opinions and recommendations contained in this report are the professional opinion of Walter P Moore and in making this report Walter P Moore relies on the accuracy and adequacy of such data and the information shared by the Client and scope of this report as stated by the client. Walter P Moore bears no liability for any inaccuracy, inadequacy, loss, damages, penalties, expenses, or cause of action in respect of this report or arising out of any action, inaction, omission, or commission by any person or parties based on this report.
- The purpose of this report is a limited preliminary risk assessment study which is meant to give basic recommendations for a preliminary design of the proposed development at the site.
- This report and any recommendations contained herein are subject to change on account of any change in data, assumptions stated herein, in the conditions, boundary, and topography of the site and its neighbouring areas and the event of any force majeure at or in the vicinity of the site. Subject to such conditions remaining unchanged, this report shall be valid for a period of six months from the date hereof.
- The National Disaster Management Authority (NDMA) guidelines have been referred for this study.
- Any re-assessment, revision, or additional study including that arising out of such change is not covered under this scope and shall be the additional scope of services.

Appendices

APPENDIX - A

This appendix provides a hydrological analysis using the Rational Method and through a practical example with detailed calculations. It demonstrates how to apply this method to estimate peak flow from catchments, essential for effective hydrological planning and management. One of the Pond located in Amravati is used as an example project site for this analysis.

HYDROLOGICAL ANALYSIS

Step 1: Obtain historical rainfall data of 30 years or more for the given project site.

Maximum daily rainfall data for the last 30 years (1994-2023) duration is obtained for the analysis. Rainfall data is acquired from the India WRIS website from the IMD source (Chapter 6).

Table A-1: Maximum Daily Rainfall for Project Site for the Past 30 Years

Year	Maximum Daily Rainfall (mm)	Year	Maximum Daily Rainfall (mm)
1994	171.62	2009	69.90
1995	82.38	2010	92.39
1996	75.98	2011	56.21
1997	133.46	2012	91.24
1998	160.06	2013	125.49
1999	43.31	2014	179.84
2000	54.67	2015	139.65
2001	152.62	2016	99.79
2002	127.53	2017	55.81
2003	70.13	2018	83.87
2004	76.78	2019	116.07
2005	95.29	2020	94.29
2006	65.67	2021	167.24
2007	172.41	2022	147.40
2008	51.16	2023	230.34

Considering a 25-year return period for the analysis.

Step 2: Prepare the IDF curve for the above return period.

The Gumbel method, a probability distribution function for extreme values in hydrologic and meteorological studies for the prediction of maximum rainfall, etc. is used for calculating the 25-year return period value.

Gumbel Method

The equation is given as: $X_T = u + \alpha y_T$

- N = Sample size = **30**
- $\bar{X}$ = Mean of the N observations = **109.42**
- X = Rainfall Event
- σ = Standard deviation of N observations = $\sqrt{(x\text{-}\bar{x})^2/(N\text{-}1)}$ = **47.33**
- α = Sample moments = $(\sqrt{6}/\Pi)\sigma$ = **36.92**
- u = Mode of distribution = $\bar{X} - 0.5772\alpha$ = **88.11**
- T = Recurrence interval (Storm Return Period)
- y_T = Reduced variate calculated for a 25-year return period
- $y_T = -ln\,[ln\,(T/(T\text{-}1))]$ = **3.20**

From these, the 25-year return period value can be calculated as:

$X_T = u + \alpha y_T$ = 88.11 + (36.92 X 3.20) = **206.25 mm**

Preparation of short-duration rainfall data

The 24-hour duration rainfall for a 25-year return period is 206 mm. To determine the short-duration rainfall for various durations, such as 5, 10, 15, 20 min, etc., based on the calculated 24-hour duration rainfall for a 25-year return period, the following IMD (Indian Meteorological Department) 1/3 rd rule formula can be applied (Table A-2).

The example calculation is shown for 5 min = 0.0833 hr

$P_t = P_{24}\,(t/24)^{1/3}$ = 206.25(0.0833/24)$^{1/3}$ = **31.22 mm**

Where,

- P_t = Rainfall in mm for t hours duration
- P_{24} = 24-hour duration rainfall for the given return period
- t = Shorter duration in hours

Table A-2 Maximum rainfall depth

						mm						
Min	**5**	**10**	**15**	**20**	**30**	**60**	**120**	**180**	**360**	**720**	**1080**	**1440**
Hr	**0.0833**	**0.1667**	**0.2500**	**0.3333**	**0.50**	**1**	**2**	**3**	**6**	**12**	**18**	**24**
	31.22	39.35	45.04	49.58	56.75	71.50	90.09	103.13	129.93	163.70	187.39	206.25

To obtain intensity per hour for rainfall events of 5, 10, 15, 20, min, etc. intervals can be calculated by the following formula, and it is illustrated in Table A-3 for a 25-year return period.

Intensity mm/hr = 31.22/0.0833 = **374.78** mm/hr

Table A-3 Intensity in mm per hour

	Intensity (mm/hr)											
Min	5	10	15	20	30	60	120	180	360	720	1080	1440
Hr	0.0833	0.1667	0.2500	0.3333	0.5000	1	2	3	6	12	18	24
	374.78	236.10	180.18	148.73	113.50	71.50	45.04	34.38	21.65	13.64	10.41	8.59

The IDF curve illustrates the relationship between rainfall intensity, duration, and frequency of occurrence. The x-axis represents rainfall duration (minutes), the y-axis denotes rainfall intensity (mm/hr), and different curves on the graph signify varying return periods or frequencies of rainfall events. The below figure shows the Intensity-Duration-Frequency (IDF) Curve for the above obtained values for a 25-year return period.

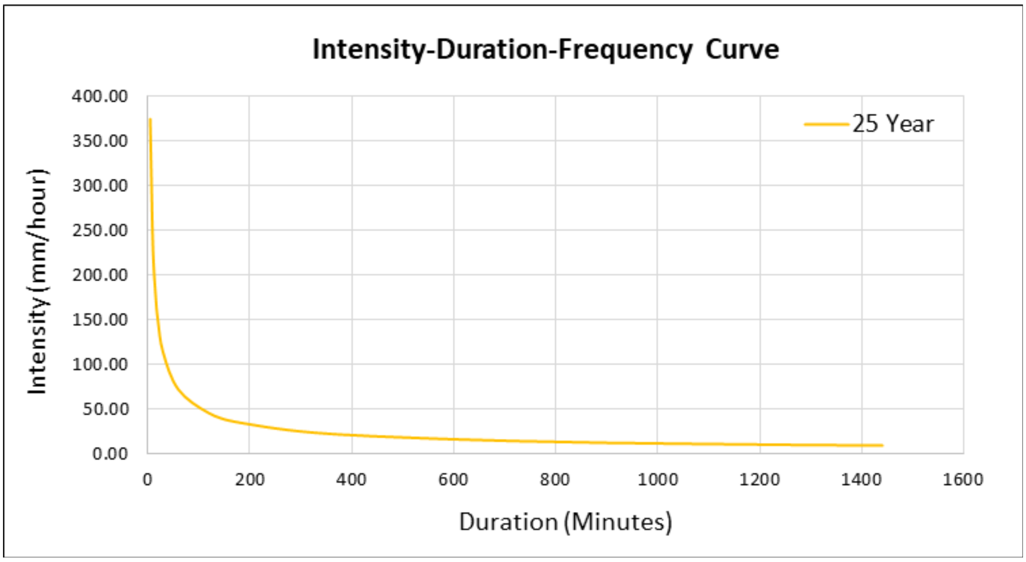

Figure A-1 IDF Curve

Step 3: Demarcate the catchment.

Demarcation of the catchment can be done as explained in Section 6.3.1. The Pond's catchment is of 118.02 acres, which is considered as an example for the calculations.

Step 4: Determine runoff coefficient (C) from Table 6.7 and calculate the time of concentration (t_c)

The Runoff Coefficient 'C' for the catchment area is used as 0.10, considering the area as a recreational area (as seen in the Google Earth imagery).

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Time of Concentration

The time of concentration (t_C) is when rainwater travels from the farthest point of the catchment area to the outfall. It is calculated as the sum of time required for the surface and conduit flow. t_C can be calculated as follows:

Time of surface flow (t_0):

The formula to calculate the time of surface flow (t_0) is given as follows:

$t_0 = (0.994(1.1\text{-}C)\ L^{0.5})/S^{0.333} = (0.994(1.1\text{-}0.10)94.70^{0.5}/9.42^{0.333} = 4.58$ min

Where,

- t_0 : Time of surface flow (Minutes)
- C : Rational Method runoff coefficient
- L : Length of surface flow (m)
- S : Surface Slope, in percentage (%)

Time of Flow (t_f):

To compute the time of flow, need to begin by determining the velocity of the flow (V), which requires calculating the hydraulic radius (R).

The hydraulic radius (R) refers to the cross-sectional area of flow divided by the wetted perimeter. It represents the average depth of flow in an open channel or conduit. The formula for calculating the hydraulic radius involves dividing the cross-sectional area of the flow by the wetted perimeter.

R=A/P = **0.35 m**

The velocity of flow in m/s is computed from Manning's equation.

$V = (1/n)\ R^{0.67}\ S^{0.5} = 1/0.05\ (0.35)^{0.67}\ (0.086)^{0.5} = 2.92$ m/s

Where,

- V : Velocity of Flow, m/s
- t_f : Time of travel, minutes
- n : Manning's roughness coefficient
- R : Hydraulic radius, m
- S : Longitudinal slope of open channel or conduit

Therefore, the formula for calculating the time of flow involves dividing the length of the open channel or conduit by the velocity of flow. This calculation helps determine the time it takes for water to travel through a given channel or conduit.

t_f = Ldrain/V = 1000.34/(2.92×60) = **5.72 min**

Time of Concentration = $t_c = t_0 + t_f$ = 4.58 + 5.72 = **10.30 min**

Step 5: Determine rainfall intensity against the time of concentration from the IDF curve.

The rainfall intensity (I) in the rational formula is the average rainfall intensity over a given duration equal to the time of concentration for the catchment area. Therefore, interpolate the rainfall intensity for the calculated time of concentration (tc) i.e. 10.30 min duration. The interpolated rainfall intensity for the 10.30 min tc for a 25-year return period is calculated as 232.73 mm/hr by using the values obtained in Table A-3.

Step 6: Calculate peak flow by Rational formula.

The peak flow can be calculated by multiplying the determined runoff coefficient, the area of the catchment, and the computed rainfall intensity for a specific return period.

Q_p = C I A = 0.10 * 232.73 * 47.76 = **1111.52** m^3/hr
Where,

- Q_p : Peak flow at the point of design, m^3 /hr
- C : Runoff coefficient, dimensionless
- I : Average rainfall intensity should be taken for the duration of rainfall equal to the time of concentration, mm/hr
- A : Catchment area, hectares

To obtain the result for a 25-year return period in cubic meters per second, divide the peak flow by 360.
= 1111.52/360 = 3.09 m^3/s

The peak flow for the Pond catchment in Amravati is determined to be 3.09 m^3/s for a 25-year return period. This result exemplifies the practical application of hydrological analysis in estimating peak flows for pond catchment. These calculations demonstrate the steps for the Rational Method, that can be utilized to determine peak flow for any pond's catchment in various scenarios.

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APPENDIX - B

This appendix provides tentative unit costs of various waterbody restoration techniques and interventions.

Sr. No.	Activity	Specifications	Tentative Unit Cost (Rs.)	References
1	Gabion wall	Gabion wall structure (10 meters in length, 0.6 meters thick, and 0.3 meters in depth) including sunken pit (8*8*1 meter)	4,500 to 5,500 /cubic meter	Purnima Mishra and R.R. Babu.pdf (ijcmas.com)
2	Bench Terracing	3 m width, 0.5% longitudinal gradient and 1.5% inward gradient	8 to 10 /square meter	SKRay.pmd (isss-india.org)
3	Gully Plugs	For a unit capacity	150 to 200 /cubic meter	cgwb.gov.in
4	Nallah Bunds	For a unit capacity	100 to 115 /cubic meter	
5	Check Dams	For a unit capacity	25 to 70 /cubic meter	
6	Percolation Tanks	For a unit capacity	40 to 70 /cubic meter	
7	Injection Wells or Recharge Wells	For a unit depth	5,750 to 9,200 /meter	
8	Gravity Head Recharge Wells	For a unit capacity	60 to 100 /cubic meter	
9	Sub-surface dyke/Bandharas	For a unit capacity	530 to 600 /cubic meter	
10	Recharge Pits	For a unit capacity	5300 to 7500 /cubic meter	urbanwaters.in
11	Water Quality (20 water quality test)	Parameters like pH, TSS, COD, BOD, O&G,Hardness,Total Coliform,E. Coli etc.	80 to 1000 /test	CSIR-CMERI
12	Deweeding	The cost of weed control was associated with manual-cum-mechanical.		
	Manual Deweeding	Labor Cost: The daily wage for manual laborers in agriculture can range from ₹300 to ₹800 per day, depending on the region and demand for labor. Area Covered: On average, a laborer can deweed about 200 to 500 square meters in a day, again depending on the density of weeds and terrain.	1.50 to 3.00 /square meter	
	Mechanical Deweeding	Labor and Equipment cost	1.00 to 3.00 /square meter	
	Desiltation	The unit is given as cost per quantity of silt removed		
	Manual Desiltation	Labor Cost: Daily wages range from ₹300 to ₹800 per laborer. Area Covered: Typically, a laborer can remove silt from about 50 to 100 cubic meters in a day.	6.00 to 7.00 /cubic meter	

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Sr. No.	Activity	Specifications	Tentative Unit Cost (Rs.)	References
13	Mechanical Desiltation	Using machinery like excavators or dredgers to remove silt. Machinery Rental and Labor: Approximately ₹2,000 to ₹5,000 per day, depending on the machine and labor costs. Volume Covered: Machinery can often handle 300 to 1,000 cubic meters per day.	6.00 to 10.00 /cubic meter	
14	Outfall culvert	RCC Culvert Pipes with 450 mm to 1800 mm diameter	160 to 6500 /meter	
15	Concrete Outfall weir		3000 to 6000 /cubic meter	
16	Pond clay lining		50 to 150 /square meter	
17	Pond grass lining		30 to 100 /square meter	
18	Pond side slope stabalization		900 to 2500 /cubic meter	
19	Protection of Drainage Basin		60 to 130 /square meter	
20	Stream Channel Modification / Augmentation		500 to 30000 /meter	

Appendix C

Example Case Studies

AIRPORT POND

Project Name and Purpose

The study consists of redesigning of Airport Pond grading and proposing a change to the outfall assembly of the Airport Pond to increase the water surface elevations in the pond. The increase in water surface elevation is expected to increase the rainwater harvesting storage at the Pond of the proposed terminal at the Airport. The increase in volume in the proposed condition will be compared with the as-built model to determine an optimum solution. This study also includes the structural designing of a raiser weir, intake well, and jack well for the collection and transfer of stored water from the pond. The runoff will be stored and reused for irrigation, potable, and non-potable activities within the site.

Project Area

The project site is located in the north of the city. The overall site is a combination of the aeronautical and non-aeronautical zones with a total area of 1622 Ha. The pond is located towards the northeast side of the Airport and collects runoff from the inlet located towards the west side which are 3 barrels of box culverts. The pond collects runoff from a total drainage area of around 567 Ha.

Methodology

The project study area contributing flow to the Pond is from the southeast portion of the drainage area as per the detailed study on drainage network and rainwater harvesting systems. As per the as-built condition, the southeast portion of the drainage area does not contribute flow to the Pond and directly flows to the outfall located in the northeast corner of the project site. Hence the total drainage area that contributes inflow to Pond corresponds to 567 Ha. For the detailed study of Pond design, the catchment area has been subdivided into 2 sub-catchments based on topography and storm drainage network. The runoff from each of the sub-catchments will be captured via a storm drainage network and drain to Pond. The stored water in Pond will be used to satisfy the maximum possible onsite demand, with potable water demand being the priority and detention storage.

Peak flows were computed using the Rational Method by estimating the weighted runoff coefficients for each of the 2 sub-catchments draining to the Pond and Zone which is flowing towards north from east of the Pond.

Hydrology and Hydraulic Methods and Parameters

• The runoff coefficient for each of the sub-catchments is based on the Manual on Storm Water Drainage System, CPHEEO.

• The topography of the project site was studied, obtained from the Airport's drawing.

• Rainfall data from the India Meteorological Department (IMD) and daily rainfall data provided by the Airport was processed to generate design rainfall events.

• The Runoff Coefficient was computed based on the drawing file Land Use/Development Plan.

• The outfall structure and grading of the Pond was designed based on the survey drawing.

• The cross-section details of the east box drain were received.

• All the analysis was done for 3 return period storm events i.e., 1 in 100 Year, 1 in 25 Year, and 1 in 10 Year.

• The 1 in 25-year return period storm event is used as a design storm for the study.

Hydrologic analysis

- **Rainfall Analysis**

The rainfall data from IMD was analysed to understand the varying trends and rainfall patterns in the recent past to derive suitable numbers. The monthly rainfall data for 32 years starting 1985 to 2017 was obtained from IMD and daily rainfall data (1985-2016) was provided by the Airport. The Gumbel method was used to develop Intensity Duration Frequency for 2 Year to 100 Year return period storm events. Gumbel distribution is widely used in the Indian sub-continent. Table 1 shows the estimated rainfall depths for the 24-hour duration.

Table 1: 24-Hr Rainfall Depth

Return Period (Yr)	2	5	10	25	50	100
Depth (mm)	73	96	112	131	146	161

- **Time of Concentration Calculations**

The time of concentration is calculated based on methodology from the manual on Storm Water Drainage Systems, Volume 1 by the Central Public Health and Environment Engineering Organization (CPHEEO). The total time of concentration is calculated as two components, which are the surface flow and storm drainage system flow. Surface flow is calculated based formula developed by the Corps of Engineers (USA) from airfield drainage data and the storm network drainage flow is calculated based on Manning's Equation. Table 2 shows the calculated time of concentrations for all catchments.

Table 2: Time of concentrations

Sub-catchment	T_c(min)
Sub-catchment 1	27.59
Sub-catchment 2	37.21
Sub-catchment 3	20.54

- **Runoff Calculation**

The surface excess runoff that occurs when the soil is saturated is collected via the drainage system. The excess peak runoff is calculated using the Rational method as per the manual by the Central Public Health and Environment Engineering Organization (CPHEEO). Rainfall intensities were estimated for each of the sub-catchments using Intensity Duration Frequency curves and calculated Time of Concentration. Table 3 shows Rainfall intensities and Peak flow for each of the sub-catchments. A combined Rational method Runoff coefficient is calculated for each sub-catchment based on the Land Use/Development Plan provided by the Airport.

Table 3: Rational Method Parameters and Results

Sub-catchment	Total Area (Ha)	Runoff Coefficient	Rainfall Intensities (mm/hr)			Peak Flow (m^3 /s)		
			10-Yr	25-Yr	100-Yr	10-Yr	25-Yr	100-Yr
Sub-catchment 1	256.27	0.72	66.13	77.78	95.00	33.8	39.8	48.5
Sub-catchment 2	310.57	0.70	56.05	65.92	80.51	34.0	40.0	48.8
Sub-catchment 3	78.99	0.79	79.59	93.60	114.32	13.8	16.2	19.8

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Hydraulic Analysis

A detailed hydraulic analysis was performed to verify the impacts on the existing drainage system and Pond storage for as-built conditions and the proposed mitigation plan. The hydraulic models for all the storm events (10-Yr, 25-Yr, and 100-Yr return period), were used to verify that the proposed mitigation plan does not cause an adverse impact on the adjacent development to the pond by keeping the desired storage for Rainwater Harvesting.

Pune: Jambhulwadi Lake

Jambhulwadi Lake is located in the south of Pune, on the outskirts. It is close to Katraj Chowk and is surrounded by many residential housing societies and a bypass road passes over the lake. Jambhulwadi is a fast-developing area. The rapid growth of adjoining areas has worked as a precursor to a drastic increase in the populace here. This area is known to be one of the most inhabited neighborhoods. The process for the rejuvenation of the Jambhulwadi Lake is explained below. **Figure 1** shows the vicinity of the Jambhulwadi Lake.

Figure 1: Vicinity of Jambhulwadi Lake (Source: Google Earth)

Assess Current Condition

Assess the current condition of the Jambhulwadi Lake using the checklist given in **Section 1.2**. In this step, a team will conduct a comprehensive survey and assessment of the lake to understand its current condition, including the name of the lake, type of waterbody, water quality, biodiversity, surrounding land use, etc. e.g.

Name of waterbody: Jambhulwadi Lake

Location: Jambhulwadi village, Haveli tehsil, Pune district, Maharashtra

Latitude and Longitude: 18.436449˚, 73.841906˚

Type of waterbody: Natural

Figure 2: Jambhulwadi Lake (Source: Google Earth)

Engage stakeholders and Allocate Resources

After the assessment of the current condition of the waterbody, the team will collaborate with local communities, environmental groups, government agencies, developers/contractors, and/or non-government organizations to garner support and resources for the rejuvenation project as given in **Section 3.1**. Restoration team composition will be built by the Project Manager, Environmental Engineer, Civil Engineer, Geotechnical Engineer, Surveyor, Community Outreach Coordinator, Ecologist/Biologist, Finance Manager, and Construction Supervisor as explained in **Section 3.2**. The team will secure funding, equipment, and manpower necessary for the assessment and subsequent restoration phases.

Site Selection

During the site selection process for Jambhulwadi Lake, the team will carefully analyze the assessment findings and actively seek input from stakeholders. Depending upon its ecological importance, social and economic significance, importance of the waterbody to local communities, hydrological characteristics/connections, community engagement, accessibility of the site, and the availability of infrastructure, and resources, the site will get selected with the aim to maximize the impact of restoration efforts and address the most pressing environmental challenges facing Jambhulwadi Lake. Selecting a site can be carried out using the guidelines outlined in **Section 5.5**.

Detailed Analysis

- Geographical details of Jambhulwadi Lake: Mapping waterbodies and open spaces is important in understanding the efforts taken or required for their rejuvenation and conservation. Mapping will be conducted as per **Section 5.1**.
- Groundwater prospect mapping: As explained in **Section 5.2**, CGWB (Aquifer Atlas | CGWB) and Aquifer Atlas and Maps – Aquifer Systems of India can be used to collect the maps and groundwater information.
- Hydrological description of Jambhulwadi Lake: This assessment will provide a detailed account of the hydrological characteristics of Jambhulwadi Lake. It will include information on the sources of water inflow, such as rainfall, surface runoff, groundwater recharge, seepage/catchment, the category of the waterbody (natural or man-made), area, average and maximum depth of stored water (during monsoon and non-monsoon periods), total storage capacity, the status of the waterbody in terms of percentage of open water and aquatic vegetation, as well as the lake's outflow, evaporation rates, and water quality parameters (**Section 5.3**).
- Topographic analysis: This analysis will involve an examination of the surface features and elevation variations within the area surrounding Jambhulwadi Lake. It typically includes the mapping (DEM processing) and characterization of landforms, slopes, and contours, which are crucial for understanding water flow patterns and drainage networks. The procedure for downloading DEM data from Bhuvan and DEM processing is explained in **Section 6.3.1**.
- Soil analysis: This analysis will work on the properties and composition of soils within the catchment of Jambhulwadi Lake. Soil analysis helps to assess factors such as permeability, infiltration rates, nutrient content, and soil erosion potential, all of which influence the hydrological processes, water quality within the catchment area, and side slopes (**Section 6.3.2)**.
- Rainfall analysis: This assessment will help to examine historical rainfall data for the region surrounding Jambhulwadi Lake. Daily maximum rainfall data for the past 30 years can be downloaded from IMD. It typically involves the analysis of rainfall patterns, frequencies, and intensities. This information is important for understanding the water input to the lake and for estimating potential runoff volumes. This analysis can be carried out by rational method, by which flows can be calculated, as explained in **Section 6.3.3**.
- Capacity of waterbody: The capacity of Jambhulwadi Lake will be evaluated by the formula given in **Section 6.4** to understand the maximum storage capacity of Jambhulwadi Lake. It involves the measurement or estimation of the volume of water that the lake can hold under various conditions, such as normal water levels and during extreme events like floods. This information helps in managing water resources and planning for flood mitigation measures.

- Catchment description: Delineation of the catchment of Jambhulwadi Lake will be conducted as per Section 6.3.1. The characteristics of a catchment directly impacting runoff yield include the slope of the terrain, soil infiltration capacity, vegetation cover, land use patterns, and the shape of the catchment. These will be assessed for the Jambhulwadi Lake (**Section 5.4**).

Problems/ Key Issues Identification

Key issues observed in Jambhulwadi Lake are listed below.

- Sedimentation: Sediment deposition is taking place in the Jambhulwadi Lake due to rapid growth of urbanization, deforestation, road construction, dumping of construction debris, etc. which reduces water storage capacity, degrades habitat, and impairs water quality. (Sedimentation/Siltation explained in detail in **Section 5.6.1**).
- Weeding: Due to the entry of untreated sewage, the lake is a breeding ground for water hyacinths, also water hyacinths decomposing on the lake's surface, which can lead to decreased oxygen levels in the water and increased foul odors. **Figure 3** shows the weeding in Jambhulwadi Lake. (Weeding explained in **Section 5.6.2**).

Figure 3: Weeding in Jambhulwadi Lake (Source: Google Earth- Street View)

- Discharges and Waste Disposal: The dumping of construction debris, plastic waste, and unkempt surroundings has already damaged the water body. **Figure 4** shows waste disposal in the lake. The lake is getting polluted by washing activities, sewage and industrial effluents. Sharp rise in slum population in the vicinity of the lake adding the constant flow of sewage water into the lake. (Discharges and waste disposal explained in **Section 5.6.3**).
- Eutrophication: Discharge of the chemical-laden water in the lake causing eutrophication, resulting in the sight of hundreds of dead fish floating on Jambhulwadi Lake. (Eutrophication described in **Section 5.6.4**).

- Encroachment: Encroachment is observed in the Jambhulwadi Lake, as shown in **Figure 5**. (**Section 5.6.5** explains encroachment in detail).
- Uncontrolled Inflow/Outflow: There are no inlets or outlets. (Described in **Section 5.6.6**).

Figure 4: Waste Disposal in Jambhulwadi Lake (Source: Google Earth- Street View)

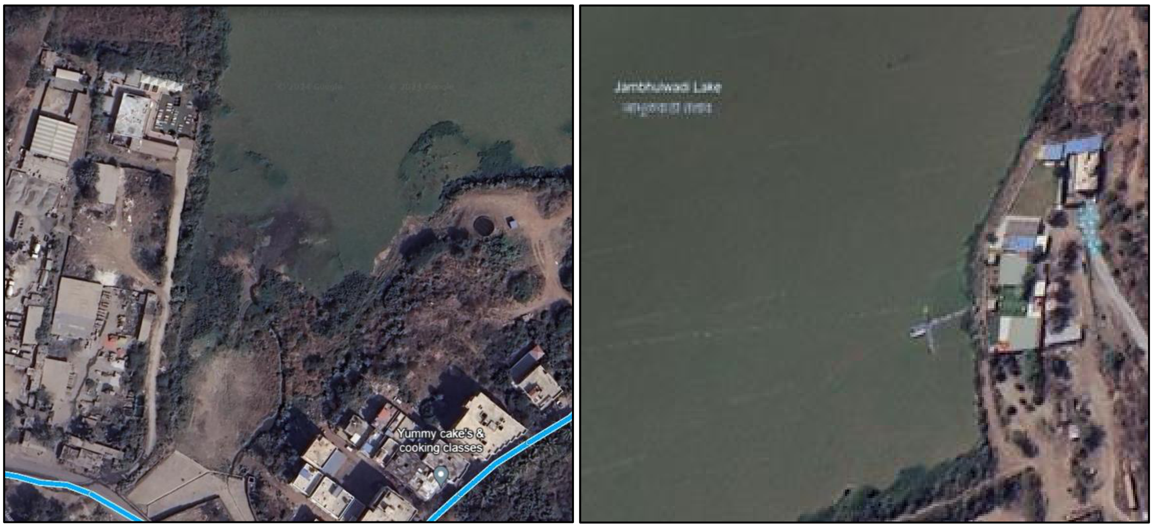

Figure 5: Encroachment in Jambhulwadi Lake (Source: Google Earth)

Design and Planning, Drawings

If a modification to the lake is necessary, the subsequent step involves designing the lake, cross-section, and preparing its drawings. **Sections 6.1**, **6.5**, and **6.6** can be referred for the guidelines of the design procedure and design drawings.

Site Preparation

Rejuvenation work for the Jambhulwadi lake will begin once the water table in the surrounding area goes down. The summer season, allowing for complete drying of the waterbody, is ideal for this purpose, ensuring efficient and cost-effective rejuvenation.

Restoration Techniques

- Desiltation: Desilting is the removal of fine silt and sediment that has collected in a waterbody, to restore its natural capacity. As the Jambhulwadi Lake is large, mechanical dredging or vacuum-out pond sludge methods will be incorporated. Mechanical dredging uses machinery such as dredgers or excavators equipped with buckets or suction pumps to remove silt mechanically (**Section 7.3.2**). Vacuum-out pond sludge collects sludge and dirty water. Water then discharged through a drain hose located at the back. Desilting frequency would be 10-20 years (**Section 7.3.6**).
- Deweeding: Mechanical control measures will be implemented for the deweeding of Jambhulwadi Lake. Motor-driven underwater weed cutters, floating weed rotavators, draglines for underwater dredging, or dry-land excavation machinery like bulldozers for drained ponds, are effective methods for large-scale weed and sediment management. Deweeding frequency would be every 2-3 years (**Section 7.4.2**).
- Prohibition of Discharges or Waste Disposal or Washing Activity: The discharge of industrial effluent, sewage or waste into lakes is often against government guidelines and should be closely monitored. Strict enforcement actions should be taken by the SPCB or Pollution Control Committee (PCC) against industries found violating environmental regulations outlined in the Water (Prevention and Control of Pollution) Act, 1974, and Environment (Protection) Act, 1986 (**Section 7.5**). The team will plan to create awareness for disposing of solid waste in an environmentally responsible manner, such as recycling or landfill disposal, can prevent contamination of the lake and surrounding ecosystem (**Section 7.2**).
- Removal of Encroachments and Blockages: The state government or local administration should maintain records of the boundaries of each pond or lake within their jurisdiction. They should take necessary measures to remove any encroachments within the waterbody spread area or boundary as needed (**Section 7.8**).
- Control Inlet and Outlet: For design of inflow, outflow structures guidelines will be followed from **Section 6.1**. Controlled gates should be provided to manage excess floods from drainage basins, ensuring a smooth flow of runoff during the monsoon season (**Section 7.9**).

Water Quality Check

It is necessary to monitor and assess the water quality of the waterbodies that undergo restoration and rejuvenation in order to protect them for their long-term usability. After rejuvenation, an assessment will be conducted for water quality checks. In the absence of specific water quality criteria developed with respect to waterbodies, CPCB’s guidelines for designated best-use criteria for surface waters should be considered for improving the water quality of waterbodies. For water quality testing procedures, IS 10500 can be referred. The sampling points will be chosen to represent various ecological zones within the lake, allowing for a thorough assessment of water quality parameters (**Section 7.1**).

Preventive Measures

Desilting using a nicospan membrane (**Section 7.3.8**) or filter to prevent pond sludge (**Section 7.3.7**) will be used for preventing sedimentation/siltation in the future. Overall improvement of the lake will be achieved by adopting of in-situ techniques for in-situ remediation, drainage basin management, and providing green or buffer zones (**Section 8.0**).

Best Practices

For sustainability effective operation and maintenance plan is essential. Following do's and don'ts will lead to a sustainable waterbody for the long term, which is explained in **Section 9.1**. Regular maintenance activities will be scheduled such as sediment removal, vegetation management, and infrastructure repairs.

Monitoring and Evaluation

Continuous monitoring activities will be scheduled to monitor the ecological health and water quality of Jambhulwadi Lake to evaluate the success of restoration efforts. Flow monitoring and water quality monitoring will be conducted to maintain the efficiency and functionality of the lake. GIS, monitoring unit will be used to remotely monitor the water level, groundwater level, surface water flow, pipe flow, water pressure, etc. (**Section 9.2**).

Awareness, Community Education, and Training

Outreach programs and educational initiatives will be conducted to raise awareness about the importance of Jambhulwadi Lake and the benefits of its rejuvenation. Training opportunities will be provided for local residents and stakeholders to participate in monitoring, and restoration activities (**Section 9.4**).

Documentation

Comprehensive reports will be compiled, documenting the entire rejuvenation process, including assessment findings, restoration activities, monitoring results, and community engagement efforts. These reports will be shared with relevant stakeholders and the broader community to promote transparency and accountability. The report format can be referred from **Section 6.9.2**.

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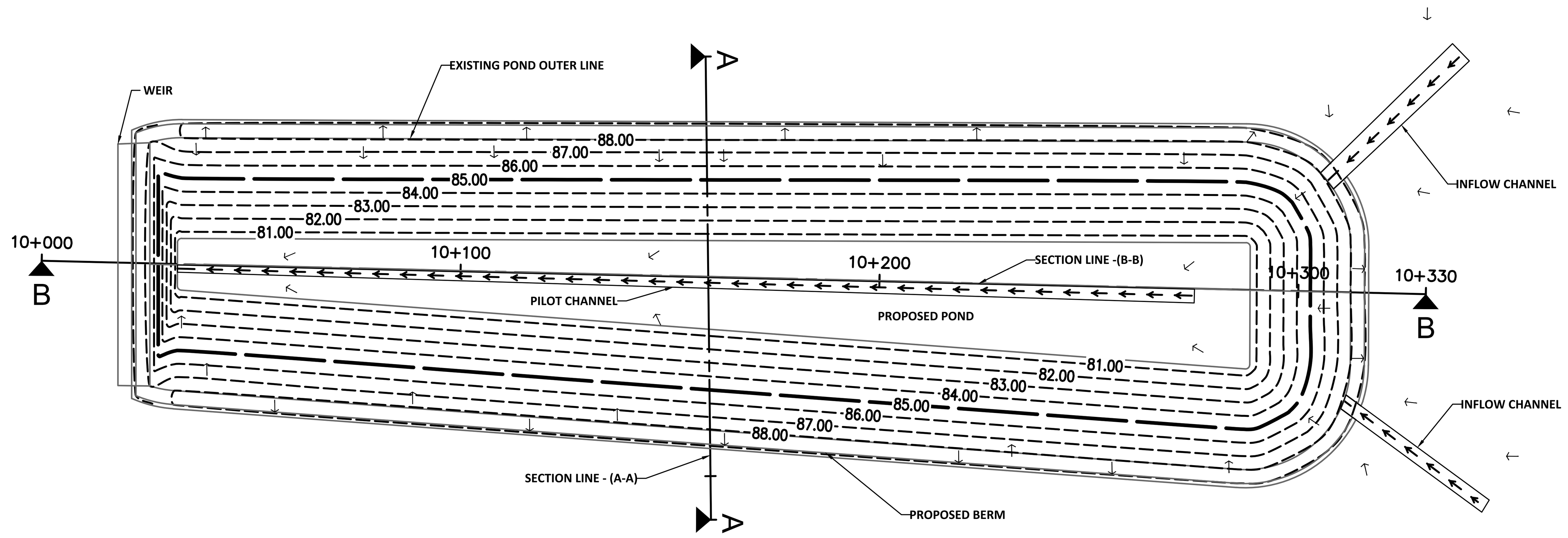
The below table provides an overall tentative costing range for various tasks involved in a (Jambhulwadi Lake, Pune) waterbody rejuvenation case study. This estimation is performed assuming the tentative area and depth of the lake.

Sr. No.	Activity	Specifications	Tentative Unit Cost (Rs.)	References
1	Topographic analysis (DEM data)		600 to 6000/ map	Pricing Of Digital Data (surveyofindia.gov.in)
2	Soil Testing		200 to 4000/ test	mpcb.gov.in
3	Water Quality Check	Parameters like pH, TSS, COD, BOD, O&G,Hardness,Total Coliform,E. Coli etc.	80 to 1000 / test	CSIR-CMERI
4	Desiltation	The unit is given as cost per quantity of silt removed		
	Manual Desiltation	Labor Cost: Daily wages range from ₹300 to ₹800 per laborer. Area Covered: Typically, a laborer can remove silt from about 50 to 100 cubic meters in a day.	6.00 to 7.00/ cubic meter	
	Mechanical Desiltation	Using machinery like excavators or dredgers to remove silt. Machinery Rental and Labor: Approximately ₹2,000 to ₹5,000 per day, depending on the machine and labor costs. Volume Covered: Machinery can often handle 300 to 1,000 cubic meters per day.	6.00 to 10.00/ cubic meter	
5	Deweeding	The cost of weed control was associated with manual-cum-mechanical.		
	Manual Deweeding	Labor Cost: The daily wage for manual laborers in agriculture can range from ₹300 to ₹800 per day, depending on the region and demand for labor. Area Covered: On average, a laborer can deweed about 200 to 500 square meters in a day, again depending on the density of weeds and terrain.	1.50 to 3.00/ square meter	
	Mechanical Deweeding	Labor and Equipment cost	1.00 to 3.00/ square meter	
6	Control Inlet and Outlet	Setup of both a manual inlet and outlet, including installation and site preparation	30,000 to 70,000	
7	Installation of directional signs and warning messages		500 to 900/ piece	
8	Electronic Water Level Indicator		20,000 to 22,000/ piece	liquidlevel.co.in
	Tentative Total Cost for the project (Rs.)		**50,00,000 to 88,00,000**	

Additional Techniques to Protect the Waterbody

Sr. No.	Activity	Specifications	Tentative Unit Cost (Rs.)	References
9	Protective barriers	eg. high walls	600 to 1,200/ square meter	
10	Rainwater harvesting system		25,000 to 1,00,000	cgwb.gov.in
11	Piezometer		5,000 to 38,000/ piece	exportersindia.com
12	Sewage Treatment and Solid Waste Management	Small capacity (up to 1 MLD)	50,00,000 to 90,00,000	

Exhibits



POND - PLAN

30 0 30 60

1:1000

HORIZONTAL SCALE: 10mm=10m
VERTICAL SCALE: 10mm=1m

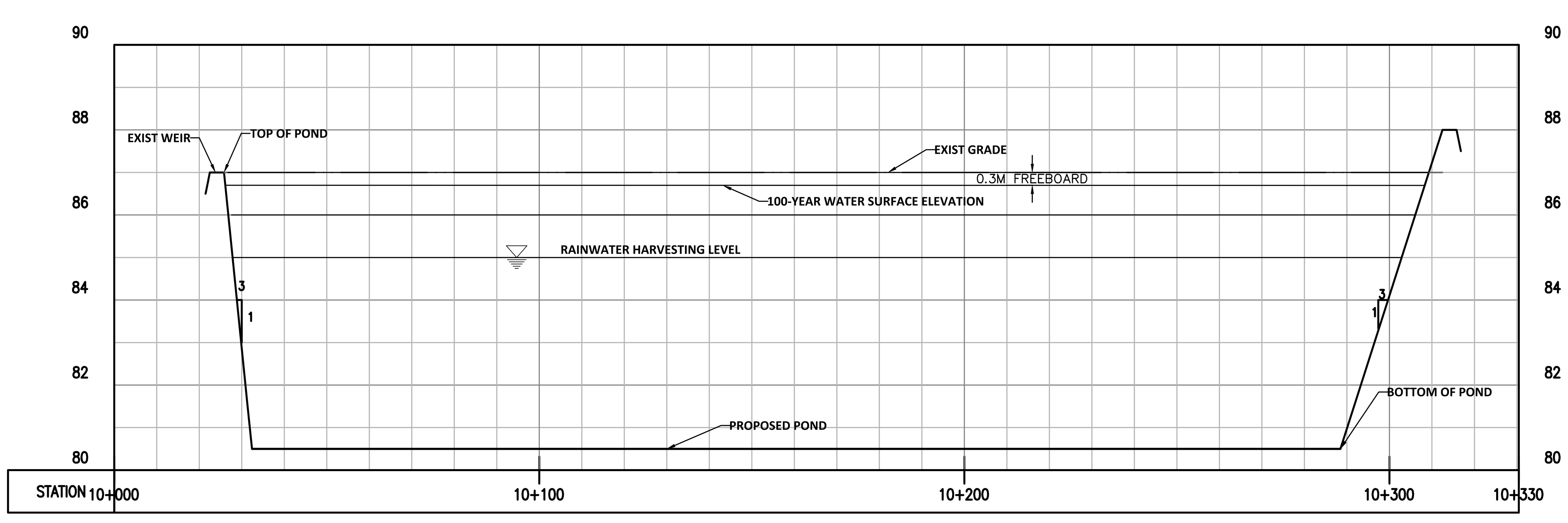
LEGEND	
STORM MANHOLE/CATCH BASIN (OR INLET)	
EXISTING FENCE	
EXISTING CONTOUR	XX.XX
EXISTING POND OUTER LINE	
PROPOSED CONTOUR	XX.XX
TOP OF PROPOSED GROUND	FGXX.XX
TOP OF PAVEMENT	TPXX.XX
TOP OF GRATE	TGXX.XX
INVERT LEVEL	IL XX.XX
MATCH EXISTING	MEXX.XX±
FFE	FINISH FLOOR ELEVATION
→	DRAINAGE ARROW

NOTES:

A. ALL DIMENSIONS ARE IN MM UNLESS NOTED.

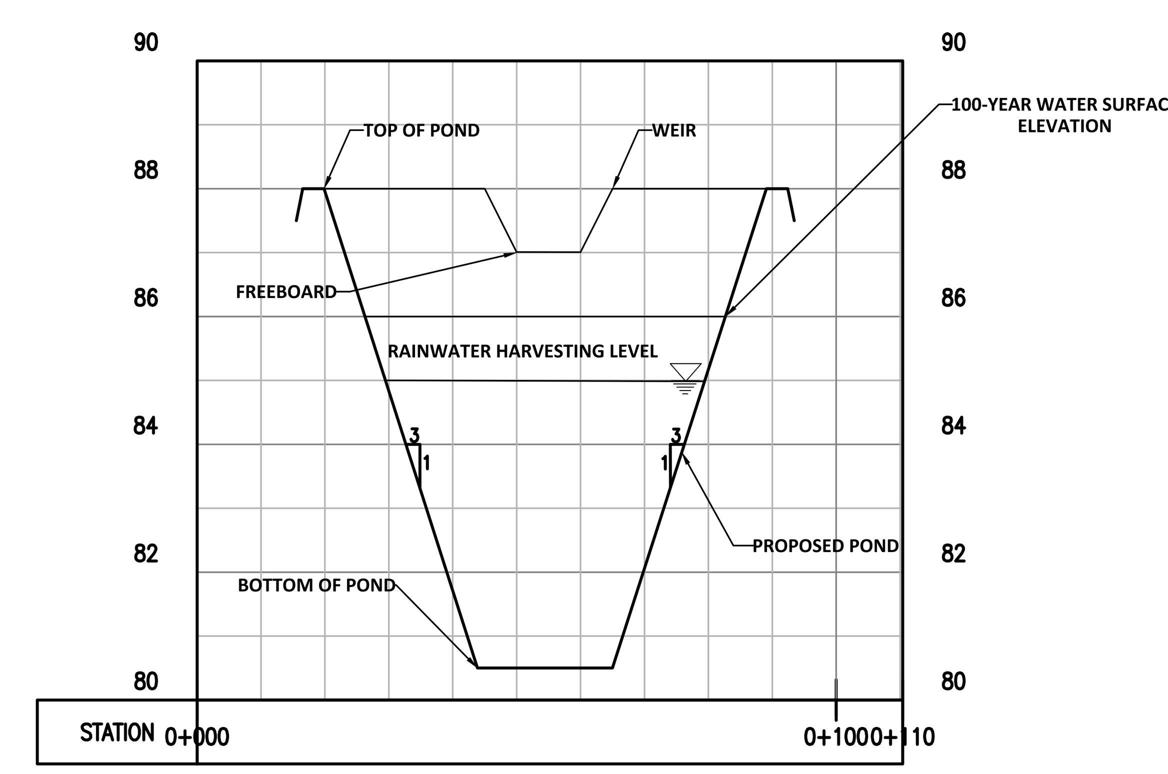
B. ALL ELEVATIONS/GRADES PROVIDED ARE IN METERS.

ALLIGNMENT-1 PROFILE



POND CROSS SECTION SECTION- (B-B)

ALLIGNMENT-2 PROFILE



POND CROSS SECTION SECTION- (A-A)

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PROJECT NAME

POND REJUVENATION MANUAL

IN ASSOCIATION WITH

KEY MAP

SEAL

NO.	DATE	REVISION

PROJECT NO.	DESIGNED BY	REVIEWED BY	DRAWN BY	DATE
H16-23015-00	RK	HS	PK	

ORIGINAL ISSUE

SCHEMATIC DESIGN

PROPOSED POND - PLAN AND PROFILE

H1.0

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Apr 17, 2024 - 7:02pm






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020.2544.8288

Who We Are

Walter P Moore is an international company of engineers, architects, innovators, and creative people who solve some of the world's most complex structural, technological, and infrastructure challenges. Providing structural, diagnostics, civil, traffic, parking, transportation, enclosure, technology consulting, and construction engineering services, we design solutions that are cost- and resource-efficient, forward-thinking, and help support and shape communities worldwide. Founded in 1931, our 800+ professionals work across 24 U.S. offices and seven international locations.

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KANSAS CITY
LAS VEGAS
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