Guidelines for Constructed Wetland Systems for Treatment of Sewage in India

National Mission for Clean Ganga
Ministry of Jal Shakti,
Government of India

175 YEARS OF IIT ROORKEE Estd. 1847

Department of Hydro and Renewable Energy
Indian Institute of Technology Roorkee

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sponsor:

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By

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Indian Institute of Technology Roorkee
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August 2023

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जी अशोक कुमार, भा.प्र.से.
विशेष सचिव एवं महानिदेशक
राष्ट्रीय स्वच्छ गंगा मिशन
G Asok Kumar, IAS
SPECIAL SECRETARY & DIRECTOR GENERAL
NATIONAL MISSION FOR CLEAN GANGA

सत्यमेव जयते

आज़ादी का अमृत महोत्सव

भारत सरकार
जल शक्ति मंत्रालय
जल संसाधन,
नदी विकास और गंगा संरक्षण विभाग
GOVERNMENT OF INDIA
MINISTRY OF JAL SHAKTI
DEPARTMENT OF WATER RESOURCES,
RIVER DEVELOPMENT & GANGA REJUVENATION

FOREWORD

National Mission for Clean Ganga (NMCG) is leading India's efforts in sustainable and natural based solutions for rejuvenation and conservation of river Ganga and its tributaries. Efforts are underway to ensure all sewage is treated before joining the rivers. The "Guidelines for Constructed Wetland Systems for Treatment of Sewage in India" developed by the Department of Hydro and Renewable Energy (HRED), IIT Roorkee under the aegis of the NMCG are a significant milestone in our collective efforts to address the pressing issue of sewage treatment and water resource management in India.

These Guidelines shall be helpful in establishing nature-based, robust and sustainable sewage management infrastructure by addressing the urgent problem of insufficient sewage treatment capacity. Implementing these Guidelines is not just a regulatory measure, it signifies a commitment to adopting nature-based techniques that will transform our approach to sewage management. Using nature's power, these Guidelines aim to ensure comprehensive treatment and interception of sewage before it enters our rivers and lakes.

Recognition of the complexities and challenges associated with sewage treatment, these Guidelines advocate for a comprehensive, holistic and integrated perspective that considers the technical aspects along with environmental, social and economic dimensions.

I am happy to learn that these Guidelines are the result of an exhaustive evaluation process carried out by a coalition of prestigious organizations dedicated to environmental stewardship and after incorporating the feedback from various central and state agencies, including National Mission for Clean Ganga (NMCG) & National River Conservation Directorate (NRCD), Ministry of Jal Shakti, Central Public Health and Environmental Engineering Organization (CPHEEO), Ministry of Housing and Urban Affairs, Central Pollution Control Board (CPCB), State Pollution Control Boards (SPCBs), IIT Bombay, Aligarh Muslim University, MNIT Jaipur, National Institute of Hydrology, Roorkee, and State agencies dealing the subject of river and lake conservation in the country.

Together, with the implementation of these Guidelines and a collective commitment to environmental stewardship, we can usher in a new era of pollution abatement, where Constructed Wetlands can become integral components of our sustainable water management strategies.

I congratulate the Prof. Sanjeev K Prajapati and Prof. Arun Kumar along with team that has put together these Guidelines and look forward to their faithful implementation.

10/10/23

(G Asok Kumar)

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ACKNOWLEDGEMENTS

The National Mission for Clean Ganga (NMCG), the Ministry of Jal Shakti, Government of India has our sincere gratitude for entrusting the Department of Hydro and Renewable Energy with the development of the " Guidelines for Constructed Wetland Systems for Treatment of Sewage in India." The given assignment reflects their commitment to addressing the critical issue of sewage treatment and promoting sustainable solutions for water resource management. Which would serve as a guideline to be used by State and Central line agencies, NGOs, Industries & Consultants to prepare constructed wetlands.

Survey of existing constructed wetland-based sewage treatment facility was one of the crucial parts of this project. We are sincerely thankful to different organizations which allowed us to visit their facility and provided the relevant data.

We extend our heartfelt gratitude to all the experts from different sectors, including National River Conservation Directorate (NRCD), National Mission for Clean Ganga (NMCG), Department of Drinking Water and Sanitation, Ministry of Jal Shakti, Ministry of Housing and Urban Affairs (MoHUA) and Department of Drinking Water and Sanitation, Central Pollution Control Board (CPCB), State Pollution Control Boards (SPCBs) who actively participated in the various discussions and shared their valuable insights, expertise, requirements, challenges and experiences. The discussions played a pivotal role in shaping the guidelines. Suggestions from Mr G Ashok Kumar, DG NMCG, Mr Brijesh Sikka, Senior Consultant, NMCG and Mr Ashwini Dubey, Urban Planner at NMCG, Mr VK Chaurasia from CPHEEO, Mr SK Srivastava, Dr Sabita M Singh from NRCD and Dr RK Singh from CPCB are sincerely appreciated. These guidelines have been prepared to ensure practicality, effectiveness, and utmost relevance to the Indian context.

Our heartfelt thanks also extend to Prof. Pradip Kalbar, IIT Bombay, Prof. Nadeem Khalil, Aligarh Muslim University, Prof. Akhilendra Bhushan Gupta, and Mr. Abhishek Soti at MNIT, Jaipur and, Scientists from National Institute of Hydrology, Roorkee for sharing their valuable knowledge and insight.

We sincerely express our heartfelt gratitude to Mr. Ganges Reddy, BlueDrop Enviro Private Limited, and Ms. Sayali Joshi, Shrishti Eco-Research Institute for extending their field level experience that helped us in considering the most practical scenarios.

At the end we would like to thank all those people who have helped us directly or indirectly towards completion of this Guideline. There is no doubt that we gained so many insights, ideas, suggestions, as well as comments from our colleagues, participants and staff for which we will always remain indebted to them.

(Sanjeev Kumar Prajapati) (Arun Kumar)
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ABBREVIATIONS

ABR	Anaerobic Baffle Reactor
ASP	Activated Sludge Process
BOD	Biochemical Oxygen Demand
CFC	Chlorofluorocarbon
COD	Chemical Oxygen Demand
CPCB	Central Pollution Control Board
CPHEEO	Central Public Health & Environmental Engineering Organization
CW	Constructed Wetland
DBT	Department of Biotechnology
DO	Dissolved Oxygen
DWWTs	Decentralized Wastewater Treatment system
EPA	Environmental Protection Agency
ET	Evapotranspiration
HF CW	Horizontal Flow Constructed Wetland
HLR	Hydraulic Loading Rate
HRT	Hydraulic Retention/ Residence Time
MLD	Millions of Liter Per Day
MoEFCC	Ministry of Environment, Forests and Climate Change
MSW	Municipal Solid Waste
NLCP	National Lake Conservation Plan
NMCG	National Mission for Clean Ganga
NPCA	National Plan for Conservation of Aquatic Eco-system
NRCS	Natural Resources Conservation Service
NWCP	National Wetlands Conservation Programme
O & M	Operation and Maintenance
OLR	Organic Loading Rate
PVC	Polyvinyl chloride
SBR	Sequential Batch Reactor
SS	Suspended Solids
SSF	Subsurface Flow
STP	Sewage Treatment Plant
TDS	Total Dissolve Solids

TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TP	Total Phosphorous
TSS	Total Suspended Solids
VF CW	Vertical Flow Constructed Wetland System
VSSFCWs	Vertical Subsurface Flow Constructed Wetlands
WW	Wastewater
WWT	Wastewater Treatment
WWTP	Wastewater Treatment Plant

1 INTRODUCTION

1.1 Background

Constructed wetlands (CWs) are artificially created man-made systems for wastewater treatment by utilizing natural processes, involving filter media, vegetation, and microbial communities. CWs are becoming increasingly popular for the treatment of wastewater. Several configuration and operation conditions have been explored for treatment of various types of wastewaters including sewage and industrial effluent. CWs provide an eco-friendly approach for wastewater treatment and are easy to maintain. The wastewater gets treated by filtration, adsorption, precipitation, ion exchange, plant uptake, and microbial degradation (both aerobic and anaerobic). CWs have been noticed to require low capital and operational cost compared to conventional treatment systems and are easy to maintain. Therefore, being eco-friendly and affordable in nature these CWs have a strong potential for application in developing countries like India.

To date, several programs have been undertaken for the treatment of wastewater using CWs at the International and National level:

- In 1991, the Natural Resources Conservation Service (NRCS) (then the Soil Conservation Service) developed technical guidelines for the design of CWs used to treat wastewater from livestock facilities (USDA 1991). The design criteria in that document were based on state-of-the-art information at that time.
- In 1997, the Environmental Protection Agency’s (EPA) Gulf of Mexico Program (GMP) sponsored the publication of a literature review, database, and research synthesis on animal waste CWs throughout the United States and Canada (CH2M-Hill and Payne Engineering 1997). The Livestock Wastewater Wetland database presents information from more than 70 sites, including pilot and full-scale facilities.
- In 2019, the manual on CWs as an Alternative Technology for Sewage Management in India provided a comprehensive idea about the wetlands, the type of wetlands, and applications and challenges to the treatment of sewage, along with the plethora of new technological developments. Subsequently, the manual depicts in details how engineered wetlands can be constructed, with the intent to guide the design, the construction, operation, and maintenance along with a limited number of case studies.
- Under the National Water Mission of the Ministry of Jal Shakti, Department of Water Resources, RD and GR (strategy 1.4), two Programme (i) developing Inventory of Wetland and (ii) National Plan for Conservation of Aquatic Eco-system (NPCA) has been launched to create an inventory of wetlands including Ramsar Wetlands and to identify 115 wetlands in 24 states and 2 UT for conservation and management respectively.

Several configurations of CWs are available for the treatment of sewage based on the water flow patterns, configuration, type, and composition. However, selection of a suitable CW system depends on various parameters, such as characteristics of sewage, desired treatment ranges, geographical and climatic conditions. Considering the sewage characteristics and various geospatial conditions across the nation throughout the year, the present guidelines aim to provide a holistic instruction, recommendations, and checkpoints to opt the CW technology for sewage treatment with a greater transparency. Principally from construction to operation and maintenance of CWs, it will support effective development and efficient management of CWs.

1.2 Purpose of Guidelines

The sewage treatment infrastructure cope with the increasing sewage generation. Due to the wide gap between sewage generation and available treatment facilities, a high fraction of untreated or partially treated sewage released into water bodies, causing water pollution, and posing a threat to aquatic life and public health. The presence of untreated sewage in water sources is also responsible for spreading waterborne diseases and detrimentally impacting the overall ecosystem. Therefore, to address sewage problems, authorities need to invest in expanding and upgrading existing STPs or developing new technologies to meet the growing demands of sewage treatment. Subsequently as a nature-based technology CWs could be one of the options to handle the sewage treatment in India. Under the flagship program of the NMCG on effective abatement of pollution, conservation, and rejuvenation of National River Ganga, several initiatives have been taken for proper treatment of sewage. Further, along with the conventional STP, based on the biological treatment such as activated sludge process (ASP) and sequential batch reactor (SBR) CW technology has been adopted for sewage treatment.

In India, the use of CWs for sewage treatment is limited due to several factors such as (a) Lack of awareness and knowledge, (b) Social acceptance, (c) Regulation and policy frameworks, and d) Unavailability of proper guidelines for selection, construction as well as operation and maintenance of CW based STPs. Promoting the adoption of CWs for sewage treatment in India demands collective actions to raise awareness, involve local communities, create supportive policies, and offer detailed guidelines. By implementing these efforts, India can effectively utilize CW technology for sustainable sewage treatment solutions. Hence, there is a dire need for standardization of CW systems for efficient utilization of their potential in sewage treatment under the ongoing efforts of NMCG.

The purpose of CWs guidelines is to provide guidance and information to engineers, planners, designers, scientists, non-government organizations, local urban bodies, and stakeholders on the planning, design, construction, operation, and maintenance of CWs. The guidelines aim to ensure that CWs are appropriately designed and implemented to effectively treat wastewater, storm water, and other types of water while minimizing environmental impact and maximizing cost-effectiveness.

The selection and design guidelines will help in designing and building new CWs systems in India:

- Sustainable development and enhanced water quality through the design acceptance process for sewage wastewater treatment in India
- It will provide cost-effective management via design, construction, operation, and maintenance.
- It will provide the baseline for the selection of treatment facilities based on land availability, wastewater type, and climatic condition.
- Will ease up the selection process by having clarity and consistency in decision making.

The guidelines cover various aspects of CWs, including site selection, design considerations, construction techniques, substrate and plant selection, operation and maintenance, and performance monitoring. It provides a framework for designing and implementing CWs that are tailored to specific needs and local conditions and meet regulatory and environmental requirements.

India recognizes the importance of CWs and their role and function in wastewater treatment. Hence to emphasize the contaminant removal using nature-based methods CWs design principles are outlined in this guide. Subsequently, it will assist the organizations in delivering the best CWs designs. The presented guidelines will help in achieving the shared objectives of sustainable development and improved water quality. Overall, it could maximize the number of successful systems in Indian conditions.

CWs are significant in addressing India's water and wastewater management challenges, conserving the environment, adapting to climate change, promoting sustainable agriculture, improving rural sanitation, and engaging local communities. Since India faces significant challenges in wastewater management due to rapid urbanization, industrial growth, and inadequate sanitation infrastructure. CWs offer a sustainable and cost-effective solution for treating wastewater.

CWs provide multiple environmental benefits. As they act as natural filters, help to restore and protect water bodies such as rivers, lakes, and ponds from pollution. Wetlands promote biodiversity by creating habitats for various plant and animal species, including migratory birds. They also help in groundwater recharge and mitigate the impacts of flooding and erosion. Additionally, in rural areas of India, where access to conventional sanitation infrastructure is limited, CWs can provide decentralized and low-cost wastewater treatment solutions. They can be used for treating household wastewater and improving sanitation conditions, thereby reducing waterborne diseases and improving public health.

The ultimate purpose is to provide greater transparency for the construction of CWs systems for sewage treatment in India. Principally from construction to operation and maintenance of CWs, it will support effective and efficient management of CWs.

1.3 Constructed Wetland Technology

CWs are a basin, i.e., excavated and filled with commonly used substrate material: rock, sand, pebbles, gravel, and soil. Apart from that, the CWs system also consists of vegetation tolerant to saturated conditions. The design and operation of CWs are based on natural wetland principles to treat wastewater from various anthropogenic sources like urban sewage water, industrial effluents, agriculture, urban runoff water, and landfill leachates. These systems involve complex chemical, physical, and biological steps to reduce the various pollutants from wastewater. CWs wetlands are mainly two segments of surface flow and subsurface flow CWs as classified in Figure 1. Different types of CWs have been used for the treatment of wastewater as follows:

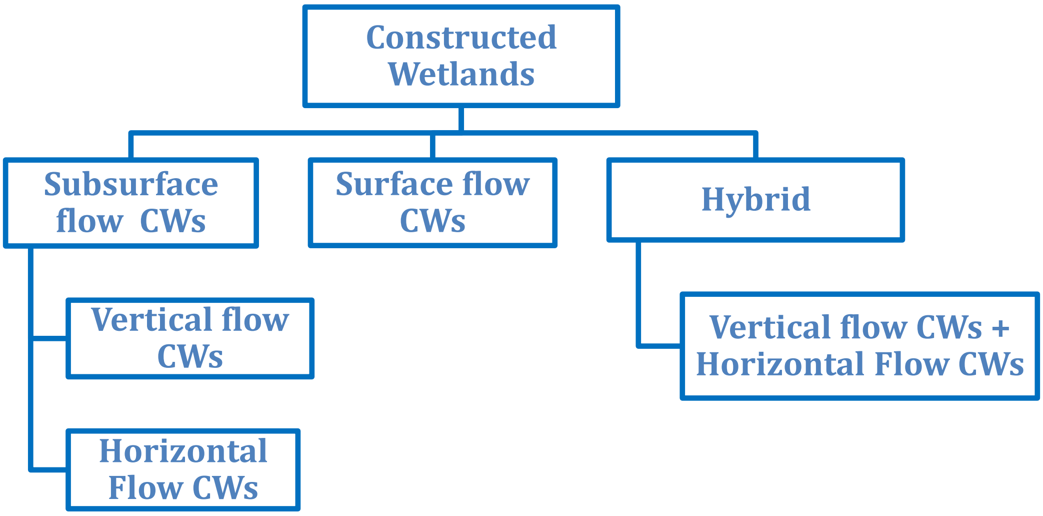

Figure 1: General classification of Constructed wetlands

a) **Subsurface flow constructed wetlands** are basically of two types, namely vertical flow and horizontal flow CWs (Figure 2 & 3). The systems are designed to keep the water level below the top of the rock or gravel media, thus minimizing human and ecological exposure.

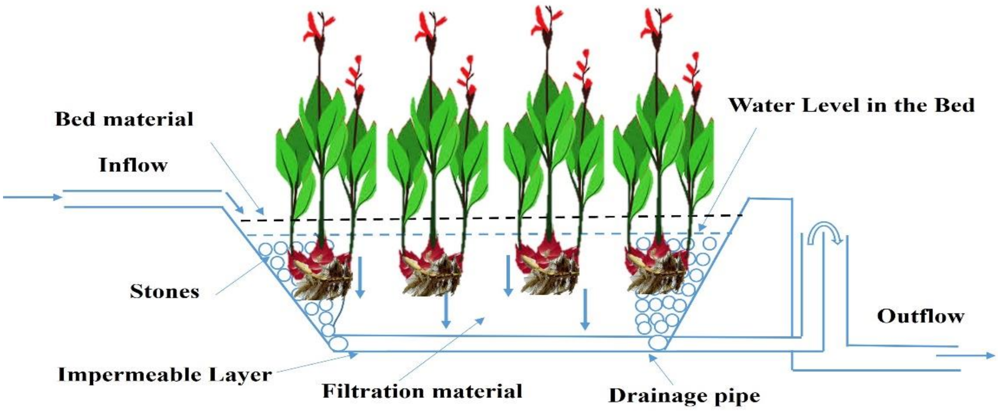

Figure 2: Basic design configuration of vertical flow constructed wetlands

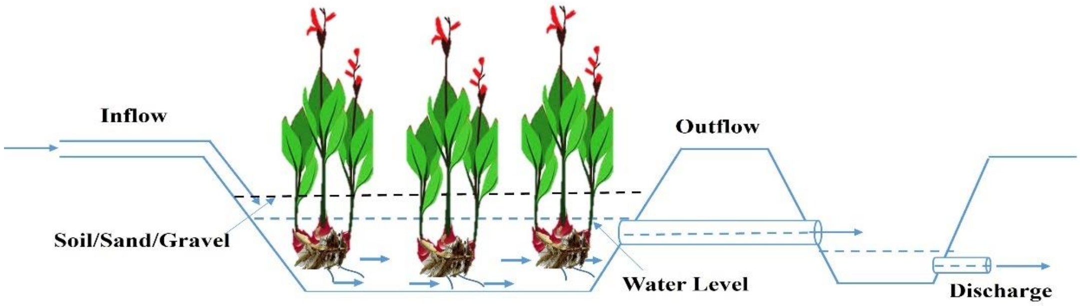

Figure 3: Basic design configuration of horizontal flow constructed wetlands

b) **Surface flow constructed wetlands** the configuration of surface flow CWs is designed so that water flows above ground (Figure 4). The systems are designed to keep the water level above the top of the rock or gravel media and require much more land area than then subsurface flow CWs.

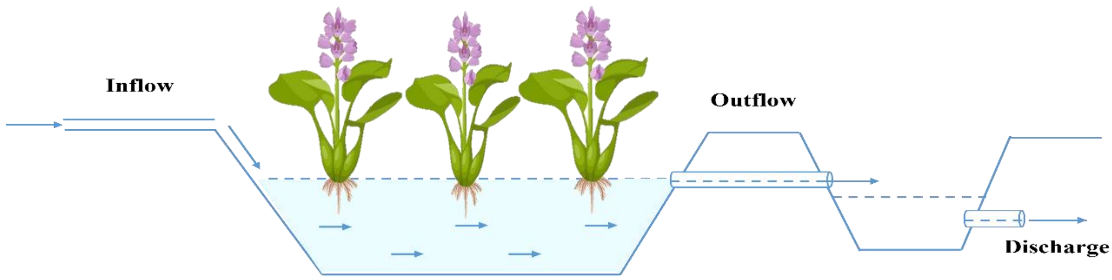

Figure 4: Basic design configuration of free surface water constructed wetlands

c) **Hybrid Constructed wetlands:** These systems are combined to treat wastewater, for example, HFCW followed by the VFCW (Figure 5).

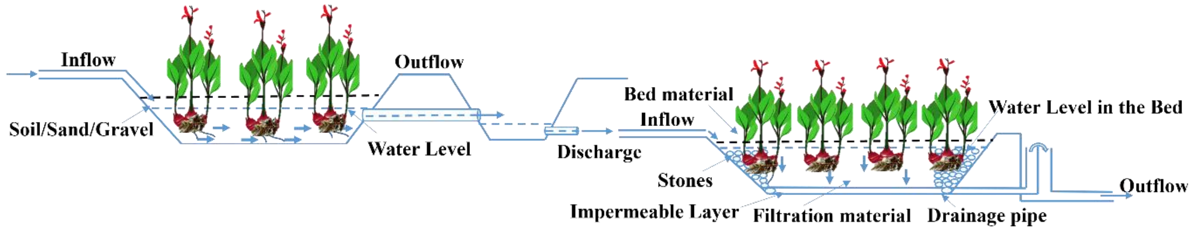

Figure 5: Basic design configuration of hybrid constructed wetlands

d) **Other Constructed Wetlands Designs:**

Various designs of CWs exist, however, certain limitations and specific conditions can render some designs impractical. For instance, Tidal flow CWs might not be feasible due to minimal tidal fluctuations and potential adverse effect on environmental (Wang et al., 2018). Similarly, Upflow vertical CWs, reliant on external energy, could face hindrance in India due to frequent power outages or electricity scarcity, making their widespread use less viable. Likewise, Free water surface CWs utilize shallow basins where wastewater flows over the surface, necessitating a large land area. However, this design can lead to unpleasant odors, potential waterborne diseases, and aesthetic concerns. Due to these challenges and limitations associated with open water surface treatment, including hygiene issues and reduced treatment efficiency, it is advisable to avoid using free water surface CWs for sewage wastewater treatment. Instead, the focus in sewage treatment within India predominantly centers around VFCWs, HFCWs, hybrid systems, and aerated CWs. These options have undergone extensive research and practical application due to their proven effectiveness, manageable maintenance, and adaptability to diverse wastewater treatment scenarios. The survey conducted, for preparation of these guidelines also confirmed this trend, as only VFCWs, HFCWs, hybrid systems, and aerated CWs were observed across all visited Indian sites. This underscores the prevalence of these designs, which align with local constraints and offer optimal sewage treatment solutions.

1.4 Constructed Wetlands Versus Conventional Technology

Comparing treatment technologies, CWs emerge as a cost-effective option when compared with alternatives such as the Activated Sludge Process (ASP), Moving Bed Biofilm Reactor (MBBR), Trickling Filter, and Sequential Batch Reactor (SBR). Though CWs may require more land area, unlike ASP, MBBR, Trickling Filter, and SBR. However, this apparent drawback is counterbalanced by the significantly by low operational and maintenance expenses associated with CWs, amounting to a mere 1%–2% of the capital cost. For a comprehensive comparison, considering an example: when contrasting a CWs system with an SBR configuration, energy utilization and labor costs come into focus. The energy demand for a CWs stands at 2,60,000 KW/year, a stark contrast to the 75,00,000 KW/year demanded by an SBR. Similarly, labor costs are significantly reduced, with CWs requiring a mere 0.75 Full-Time Equivalent (FTE)/year, whereas SBR necessitates 12 FTE/year. Even the environmental implications, too, diverge between these two systems. Taking into account global warming potential, the emission associated with a 1cubic meter of treated water from SBR design is estimated at 3.7 kg CO_2-eq. In contrast, a CWs contributes only 1.5 kg CO_2-eq per cubic meter, showcasing its low impact on global warming. Furthermore, examining their impact on ozone depletion, SBR has been found impact about 3.3×10^{-7} kg CFC — eq. Conversely, the influence of CWs on ozone depletion is notably lower, registering at 6.6×10^{-9} kg CFC — eq. This discrepancy underscores the more favorable environmental footprint of CWs (Parde et al., 2021).

2 PLANNING AND SELECTION OF CWS FOR SEWAGE TREATMENT

The Construction of CWs based STP technology for new sites should be based on the need for wastewater treatment for many people, institutes, small housing societies, villages, etc. As a developing nation, India faces various issues related to water and sanitation. Subsequently, the greatest challenge in the water and sanitation sector over a few decades will be implementing low-cost sewage treatment. However, selection of CWs as a treatment facility, for sewage wastewater, rigorous assessment of the treatment processes, such as preliminary treatment (e.g., screening), primary sedimentation, septic tank, anaerobic baffled reactor, and tertiary treatment methods (e.g., filtration, UV disinfection), to form a comprehensive and efficient wastewater treatment system has to be done (Figure 6).

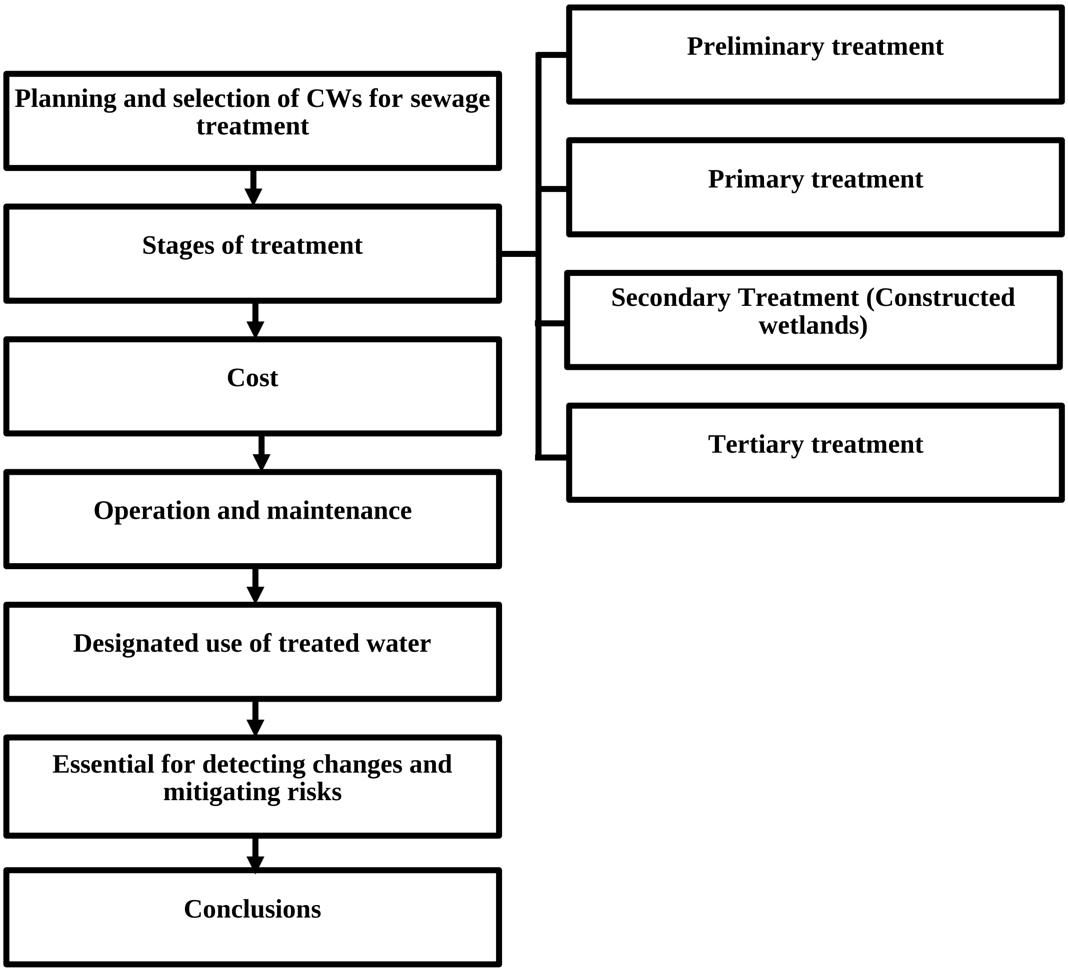

Figure 6: Planning and selection of CWs for sewage treatment

2.1 Need and Selection

Constructed wetlands technology holds great promise for wastewater treatment in India due to its suitability for addressing the country's pressing water pollution and scarcity challenges. With rapidly growing urbanization and industrialization, India faces significant issues related to inadequate sewage treatment and the discharge of untreated wastewater into rivers and water bodies. This has led to severe contamination of water sources, posing risks to both human health and the environment. Constructed wetlands offer an environmentally friendly and cost-effective solution to this problem. By harnessing natural processes involving wetland vegetation and microorganisms, these systems can effectively remove pollutants from wastewater, including nutrients and organic matter. Additionally, constructed wetlands can be tailored to local conditions and integrated with traditional treatment methods to provide a sustainable approach to wastewater management. Given India's diverse geography and water pollution challenges, the adoption of constructed wetlands technology could play a crucial role improving the overall quality of water available for various uses.

The selection of a treatment facility for domestic wastewater depends on various factors, including the wastewater characteristics, treatment objectives, regulatory requirements, available space, and budget. Some critical considerations for selecting a treatment facility for domestic wastewater are illustrated in Figure 7.

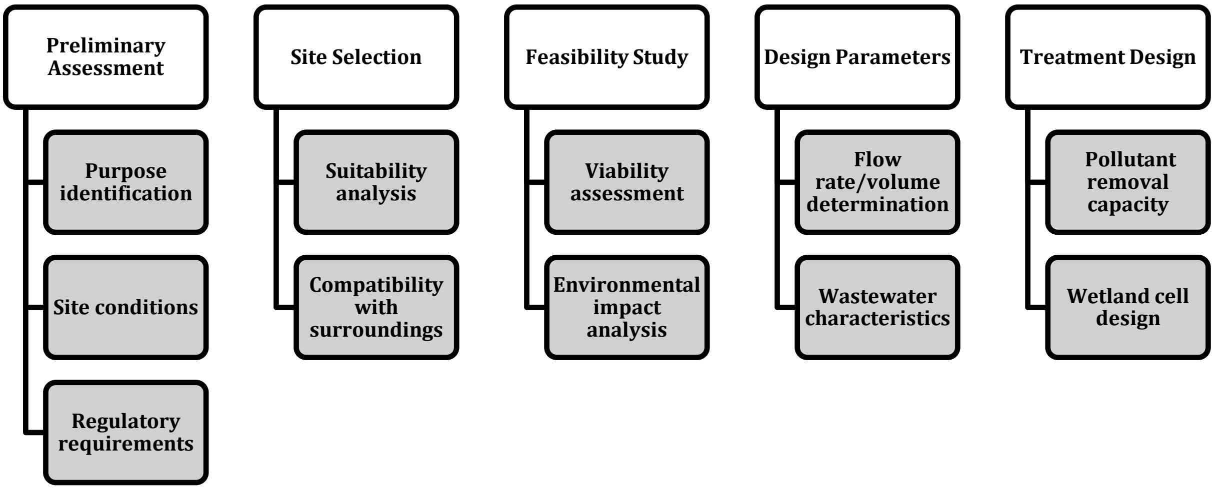

Figure 7: Basic strategy for selection of constructed wetlands

2.2 Planning

Planning is quite important for establishing CWs based STPs. Basically, it starts with walk-over survey serves as an essential preliminary step in conducting a feasibility assessment for CWs projects. Through careful on-site observation and evaluation, this survey aims to get insights into the project's viability and potential challenges. During the survey, the surveyor examines the physical characteristics of the site, including topography, existing structures, and natural features. Environmental factors are assessed, considering nearby water bodies, habitats, and regulatory concerns. Infrastructure accessibility and the availability of utilities are also considered, providing an understanding of the practical feasibility of the project's implementation. The surveyor notes potential risks, market dynamics, and even estimates preliminary costs, all of which contribute to a comprehensive assessment. By documenting findings and insights, the surveyor prepares a feasibility report that informs stakeholders about the project's strengths, weaknesses, opportunities, and threats. This invaluable groundwork aids decision-makers in determining whether to proceed, modify, or reconsider the project, shaping the path forward for sound and well-informed CWs project planning. Further details are outlined in Figure 8.

Walk-Over Survey	• Conduct an initial site visit to observe the landscape, soil conditions, hydrology, vegetation, population, and small industries around.
Feasibility Assessment	• Evaluate project goals and determine if a CWs is feasible. • Consider regulatory requirements, environmental impact, and technical feasibility.
Wastewater Characterization	• Collect and analyze influent wastewater samples for pollutants, nutrients, organic matter, and other suspected parameters. • Understand the quality and quantity of wastewater entering the wetland.
Site Selection Criteria	• Define criteria for site selection, such as proximity to pollution sources, local hydrology, land availability, and community impact.
Site Selection Process	• Evaluate potential sites for construction. • Rank sites based on factors like site characteristics, environmental impact, and treatment potential.
Detailed Site Analysis	• Conduct a comprehensive analysis of the shortlisted sites. • Consider factors like soil permeability, water table depth, and existing vegetation.
Hydrological Assessment	• Evaluate the site's hydrological characteristics, including water flow patterns and retention potential. • Determine the suitability of the site for different wetland types (e.g., HFCWs, VFCWs).
Preliminary Design	• Develop preliminary designs for wetland cells based on the site's hydrology and available space. • Estimate treatment area requirements based on wastewater characteristics.
Final Site Selection	• Compare the feasibility and effectiveness of wetland designs for each site. • Choose the site with the most suitable conditions for achieving treatment goals.

Figure 8: Steps for Planning of Constructed wetlands

3 STAGES OF TREATMENT

CWs are engineered systems that use natural processes to treat wastewater. The design requirements for CWs depend on several factors, including the system's size, the wastewater's characteristics, and the desired level of treatment. The CWs treatment technology may involve a series of networks of pipes, pumping stations, and primary treatment, secondary and tertiary treatment depending upon the end use. Process flow of CWs based STPs is given in Figure 9.

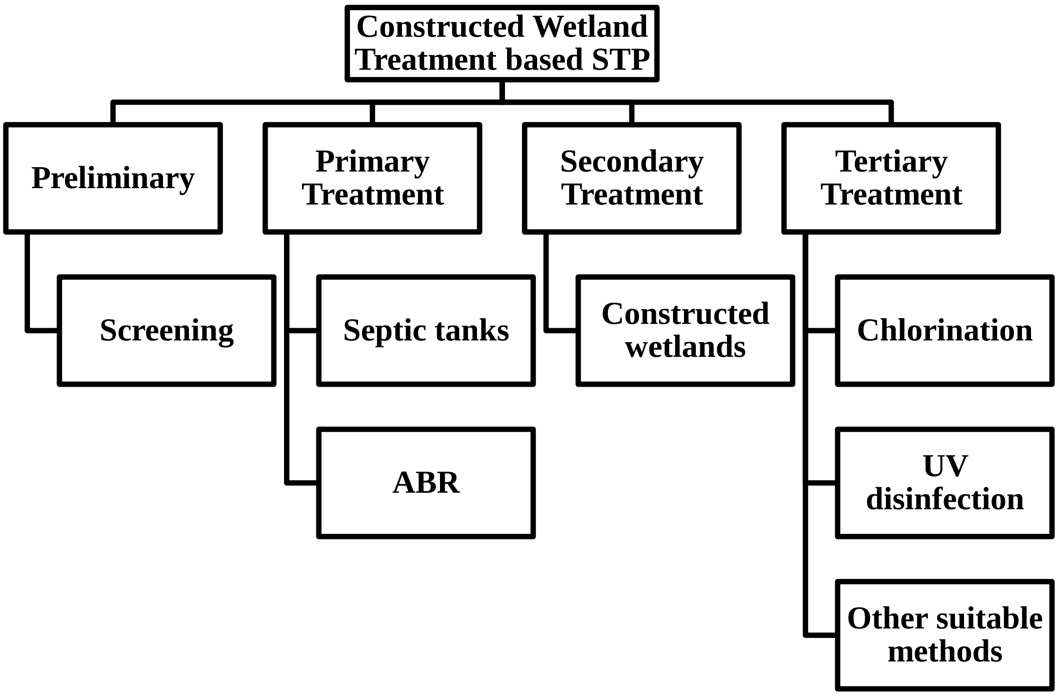

Figure 9: Process flow of CWs based STPs

3.1 Preliminary treatment and Primary treatment

The CPHEEO 2013 manual offers comprehensive guidance on the design and construction of screening chambers and septic tanks, crucial components in the early stages of wastewater treatment. These structures are essential for effectively removing larger debris and solid materials from incoming sewage flows, preventing their entry into deeper treatment processes. The manual delves deeply into various facets of screening chamber design, encompassing aspects like sizing, layout considerations, and recommended construction materials. Furthermore, the manual extends its coverage to septic tanks, emphasizing their role in wastewater treatment. It delves into design considerations such as size determination, inlet and outlet configurations, and provisions for sludge accumulation and removal.

3.1.1 Characterization of raw sewage wastewater

Domestic wastewater, also known as sewage or sanitary wastewater, is generated from households and typically contains a mixture of organic matter, nutrients, pathogens, and other contaminants. The strength of domestic wastewater can vary depending on factors such as water usage patterns, population density, and the presence of industrial or commercial activities.

The first step in designing a treatment facility is identifying the wastewater's strength. Identifying the strength of wastewater involves determining the concentration of pollutants present in the wastewater. The strength of wastewater is typically measured in terms of various parameters such as BOD, COD, TSS, TN, TP, pH, and other specific contaminants of concern.

Determining water quality of the sewage is crucial for designing and operating effective treatment systems, as it helps to determine the appropriate treatment processes and technologies required to achieve desired effluent quality and regulatory compliance (Table 1). Monitoring of wastewater quality should be conducted for a year, as it will provide valuable information about the composition and variations/fluctuations in the wastewater throughout different seasons. The data collected will help in accurately sizing and designing the treatment system, selecting appropriate preliminary, primary secondary and tertiary set ups, and optimizing the overall performance of the CWs.

Table 1: Suggested water quality parameters for raw sewage

Parameters	**Monitoring**			
	Month 1	Month 2	Month3	Month……..
pH				
Temperature (ºC)				
Colour				
Odour				
Alkalinity (mg/l)				
TSS (mg/l)				
BOD (mg/l)				
COD (mg/l)				
Total Nitrogen (mg/l)				
Sulphate (mg/l)				
TDS (mg/l)				
Total Coliform				
Phosphorus (Ortho-P) (mg/l)				
Nitrate (mg/l)				
Ammonia (mg/l)				
Note: Analysis of other parameters e.g., Heavy metals etc. be taken up when suspected to be in wastewater				

3.2 Scenario based selection of preliminary and primary treatment

The selection of preliminary and primary treatment facilities for domestic wastewater is essential in the overall wastewater treatment process. Preliminary treatment focuses on the removal of large solids and debris, while primary treatment involves the removal of settleable organic and inorganic solids. Some scenario-based selection of treatment system is illustrated in Table 2.

Table 2: Selection of primary treatment stages based on TSS load

TSS Load (mg/L)	Preliminary/Primary Treatment	Secondary Treatment
TSS Concentration: 0-200	Screen chamber + Septic Tank	Constructed wetland configurations be selected as per land available and desired output.
TSS Concentration: 200-500	Screen chamber + Septic Tank (or Anaerobic Baffled Reactor)	
TSS Concentration: 500-1000	Screen chamber + Anaerobic Baffled Reactor (or ABR + Septic tank)	
TSS Concentration: >1000	Screen chamber + Septic tank + Anaerobic Baffled Reactor	

Note*: All these considerations are suggested but not mandatory and they can be changed and adjusted as per requirement.

These are some general factors to be considered when selecting the primary treatment facility are given in Figure 10.

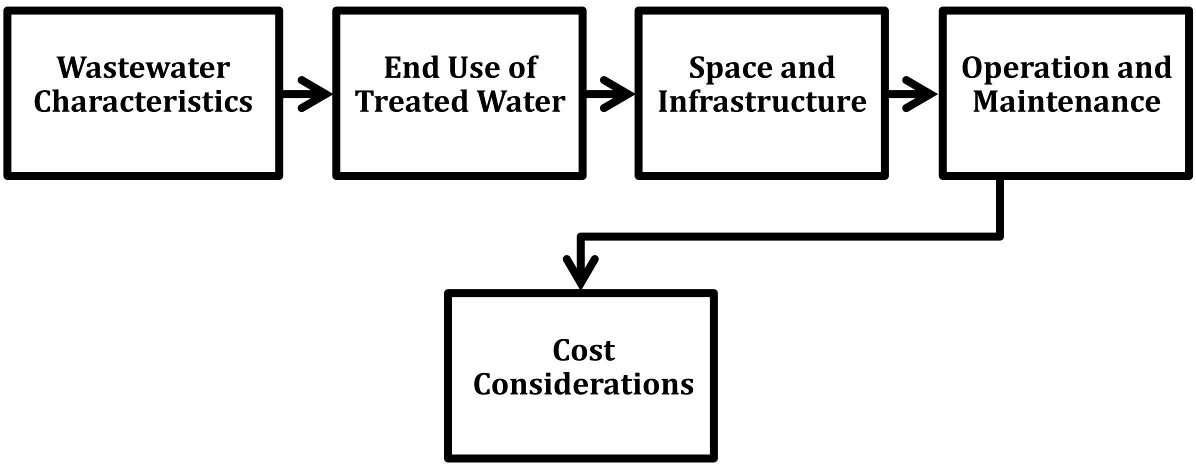

Figure 10: General factors for selecting treatment facility

Integrated treatment set up with CWs is shown in Figure 11.

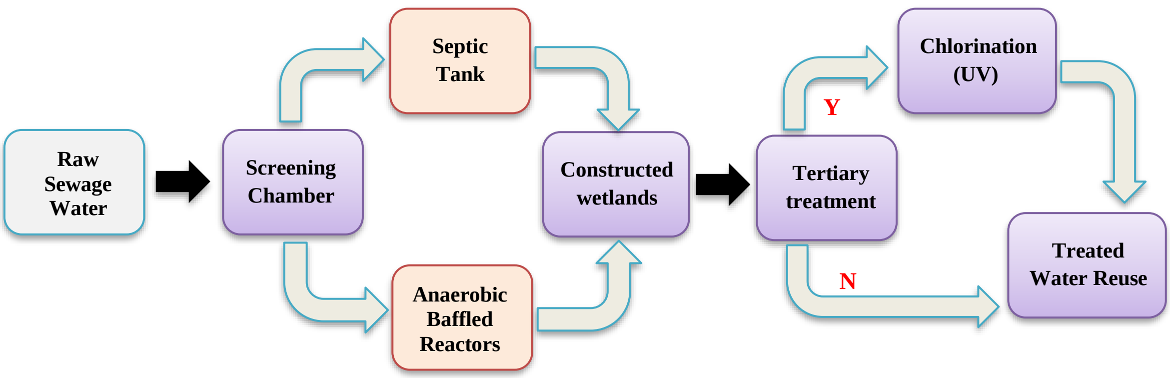

Figure 11: Integrated treatment set up with CWs

3.3 Selection based on end use of treated water

When selecting a treatment facility for domestic wastewater based on the end use of water, it's important to consider the specific water quality requirements for that particular use. It is important to consider water quality standards and the specific characteristics of the receiving water bodies when selecting the treatment processes for irrigation, toilet flushing, potable, no-potable use, river discharge, or groundwater recharge (CGWB, 2007 manual on ground water recharge). Hence the selection of CWs treatment facility will depend on the effluent quality received after primary treatment and the desired treatment goals to be achieved with respect to the designated best use of water as recommended by CPCB (Table 3).

Table 3: Designated-best-use of treated water

Designated-Best-Use	Class of water	Water Quality Parameters
Drinking Water Source without conventional treatment but after disinfection	A	• Total Coliforms Organism MPN/100ml shall be 50 or less • pH between 6.5 and 8.5 • Dissolved Oxygen 6mg/l or more • Biochemical Oxygen Demand 5 days 20C 2mg/l or less
Outdoor bathing (Organized)	B	• Total Coliforms Organism MPN/100ml shall be 500 or less pH between 6.5 and 8.5 Dissolved Oxygen 5mg/l or more • Biochemical Oxygen Demand 5 days 20C 3mg/l or less
Drinking water source after conventional treatment and disinfection	C	• Total Coliforms Organism MPN/100ml shall be 5000 or less pH between 6 to 9 Dissolved Oxygen 4mg/l or more • Biochemical Oxygen Demand 5 days 20C 3mg/l or less
Propagation of Wild life and Fisheries	D	• pH between 6.5 to 8.5 Dissolved Oxygen 4mg/l or more • Free Ammonia (as N) 1.2 mg/l or less
Irrigation, Industrial Cooling, Controlled Waste disposal	E	• pH between 6.0 to 8.5 • Electrical Conductivity at 25C micro mhos/cm Max.2250 • Sodium absorption Ratio Max. 26 • Boron Max. 2mg/l

(**Source:** CPCB, **https://cpcb.nic.in/water-quality-criteria/**)

3.3.1 Preliminary treatment

3.3.1.1 Screening Chamber

A screening chamber is an essential component of a wastewater treatment system that is designed to remove large solids and debris from the incoming wastewater. The primary purpose of a screening chamber is to protect downstream equipment and processes from damage and clogging caused by large objects that could enter the CWs system.

Moreover, following are some general design criteria that have been provided for the development of screening chamber:

1. **Screen Type**: The screen type and opening size will depend on the type and size of the solids that need to be removed. Several types of screens are available, such as bar screens, fine screens, and drum screens.
2. **Channel Design**: The channel design should be such that it allows for an even flow of wastewater through the screen. The channel should be wide enough to accommodate the screen and allow for maintenance and cleaning.
3. **Screen Angle and Speed**: The angle and speed of the screen should be designed to optimize the removal of solids while minimizing the loss of wastewater. The angle should be such that the solids can slide off the screen easily, and the speed should be sufficient to keep the solids moving but not too fast that they get carried away with the wastewater.
4. **Screen Cleaning Mechanism**: The screen should be equipped with a cleaning mechanism that can remove the collected solids from the screen. Various types of cleaning mechanisms are available, such as rake systems, brushes, and air scouring.
5. **Screen Size**: The screen size should be based on the expected flow rate and the size of the solids that need to be removed. The screen should be sized such that it can handle peak flow rates without causing excessive head loss or bypassing of solids.
6. **Access and Maintenance**: The screening chamber should be designed with easy access for maintenance and cleaning. The screen and cleaning mechanism should be easily removable for cleaning and repair.

There are several important design factors to consider in designing a screening chamber for wastewater treatment, and each of these factors may require different formulas or calculations.

a) **Screen Open Area**: The screen open area is the percentage of the screen surface that is open to the wastewater flow. It is important to ensure that the screen open area is sufficient to allow for the expected flow rate and the size of the solids that need to be removed Table 4.

Table 4: Required area for screen open area

Parameters	Formula for Calculation
Screen open area	(Screen Slot Width × Screen Length ×Number of Slots) / (Screen Width ×Screen Length) ×100
Number of Slots	Number of screen slots per unit length of the screen
Screen Velocity	Screen Velocity = Flow Rate / Screen Open Area
Flow Rate	Wastewater flow rate (m^3/hr)
Head Loss	(K x Screen Velocity^2) / (2 x g)

Note: Screen slot width, Screen Length, and Screen Width all are taken in mm; K = Screen loss coefficient; g = Acceleration due to gravity (m/s^2)

b) **Screen Velocity**: The screen velocity is the velocity of the wastewater through the screen, and it should be sufficient to keep the solids moving without allowing them to pass through the screen.

c) **Head Loss:** Head loss is the pressure drop across the screen, and it should be minimized to ensure the efficient operation of the screening chamber.

It is important to note that these formulas are just basic guidelines, and there may be additional factors to consider in the design of a screening chamber, such as screen angle and speed, channel design, and screen cleaning mechanism.

3.3.2 Primary treatment

3.3.2.1 Septic tank

A septic tank stands as a prevalent approach to wastewater treatment, particularly in residential settings. These systems hold the capability to be integrated into CWs systems, enriching the overall treatment process.

In general, the basic design for screening chamber as follows:

- **Determine the population**: The size of the septic tank is usually based on the population size, as this is a good indicator of the amount of wastewater that will be generated.
- **Calculation of total volume of wastewater generated per day**: This is typically based on the population size and their average water usage.
- **Determine the retention time required for treatment**. It is the amount of time that wastewater must stay in the septic tank for the solids to settle and for the bacteria to break down the organic matter.
- **Calculation of minimum size required**: This is based on the retention time required and the total volume of wastewater generated per day.
- **Selection of septic tank on a site basis:** There are various types of septic tanks, including single-chamber tanks, dual-chamber tanks, and aerobic treatment units. The type of tank chosen will depend on the site conditions and size of the tank required.
- **Design the inlet and outlet pipes**: The inlet pipe should be located near the top of the tank, while the outlet pipe should be near the bottom. The pipes should be sized appropriately to ensure that the tank can handle the maximum flow rate.

The design of a septic tank involves several calculations to determine the appropriate size and dimensions of the tank Table 5.

Table 5: Design calculations of a septic tank

Parameters	Formula for Calculation
Sewage flow (m^3/d) Average Volume of wastewater (Q)	$Q = \frac{\text{Population} \times \text{Volume per person per day} \times \text{Kz}}{1000}$
Hydraulic Retention Time	1.5 days (or as per requirement)
Volume required for Septic Tank	Volume Required = Q×HRT
Length	Minimum septic tank volume / (Width x Depth)
Depth	2 to 3 feet (or as per requirement)
Width	2 to 2.5 times the depth (or as per requirement)
Pipe sizing	Q max = 2 x Q avg
Outlet pipe	Q outlet = Q max / 4

Note: Q max is the maximum flow rate, and Qavg is the average daily flow rate; Kz= Peaking factor

These dimensions may vary depending on the specific site conditions. Further, the septic tank should have a maintenance hole or access port to allow for inspection, maintenance, and cleaning. It is essential to have a professional engineer or designer with experience in septic tank design review and approve the design before installation.

Example: Sample calculations for sizing of a two-chambered septic tank for a population of 400 with specific c wastewater flow of 80 litres per person per day **(**UN-HABITAT, 2008).

Average volume of wastewater (Q)	= 400 x 80 / 1000 = 32 m^3/d
Hydraulic Retention time (HRT)	= 1.5 day = 36 hours (assumed)
Required volume of septic tank	= Q x HRT = 32 x 1.5 = 48 m^3
Volume of 1st compartment	= 2/3 of required volume = 2/3 x 48 = 32 m^3
Volume of 2nd compartment	= 1/3 of required volume = 1/3 x 48 = 16 m^3
Depth of septic tank	= 2 m (assumed)
Width of septic tank	= 4 m (assumed)
Then, • Length of 1st compartment = Volume/(Depth x Width) = 32/(1.7* x 4) = 4.7 m • Length of 2nd compartment = Volume/(Depth x Width) = 16/(1.7* x 4) = 2.35 m ** Please note that the depth of septic tank is taken as 1.7 m after deducting a free board of 0.3 m)*	

Check the HRT after sludge accumulation:

Sludge accumulation rate	= 70 litres/person/year
Desludging interval	= 1 year
Sludge volume	= sludge accumulation rate x number of users x desludging interval = (70 x 400 x 1)/1000 = 28 m^3
Available volume for wastewater in septic tank	= Total volume – sludge volume = 48 – 28 = 20 m^3
HRT after sludge accumulation = Available volume for wastewater in septic tank/Average volume of wastewater = 20/32 = 0.625 days = 15 hours (Since HRT > 12 hours, the design is OK)	

3.3.2.2 Anaerobic baffle reactor

An Anaerobic Baffle Reactor (ABR) design involves several considerations to ensure the system can efficiently treat organic wastewater. Here are some basic steps in designing an ABR:

- Determine the wastewater characteristics: Collect samples of the wastewater to be treated and have them analyzed for parameters such as pH, TSS, COD, and BOD. This will help determine the size and number of compartments required.
- Determine the required retention time: The retention time is the amount of time the wastewater must remain in the reactor for the anaerobic digestion process.
- Determine the number of compartments: The ABR typically consists of three to six compartments, each providing additional digestion time. The number of compartments needed will depend on the wastewater characteristics and the required retention time.

- Determine the reactor's size: The reactor's size is based on the required retention time and the flow rate of the wastewater. The minimum size of each compartment should be at least twice the width and length of the inlet and outlet pipes.
- Design the baffle system: The baffle system is the key element of the ABR, and it is used to promote the settling of solids and the retention of wastewater in each compartment. The dimensions and spacing of the baffles will depend on the wastewater characteristics and the desired hydraulic retention time.
- Provide for biogas collection and management: Biogas generated during anaerobic digestion can be collected and used as a renewable energy source. The design of the biogas collection system will depend on the size of the reactor and the expected biogas production.
- Provide for effluent treatment and disposal: The effluent from the ABR are fed to the CWs before it can be discharged into the environment.

An ABR design involves several calculations and considerations to ensure that the system can efficiently treat organic wastewater. Some basic formulas that are used in an ABR design are given in Table 6 and Table 7 given insights on basic design criteria.

Table 6: Design calculations of ABR

Parameters	Formula for Calculation
Hydraulic Retention Time	Reactor Volume / Flow Rate
Reactor Volume	Total Number of Compartments x Volume of each compartment
Flow Rate	Wastewater flow rate (m^3/day)
Organic Loading Rate (OLR)	(Influent COD Concentration x Flow Rate)/ Reactor Volume
OLR is the amount of organic matter that can be added to the reactor per unit volume per unit time	

Example: Sample calculation for sizing of a 4-chambered Anaerobic Baffle Reactor

Average volume of wastewater (Q)	= 32 m^3/d
Required volume of ABR (m^3)	= length (m) × width (m) × depth (m) × number of chambers
Length (assumed)	=1m
Width (assumed)	=2 m
Depth (assumed)	=2.4m
number of chambers	=4
volume of ABR (m^3)	=19.2
sludge volume (m^3)	= 5% × actual volume of ABR (m^3)=0.96
water volume (m^3)	= actual volume of ABR (m^3) − sludge volume (m^3) =18.24
HRT (h)	= water volume of ABR (m^3)/ wastewater flow (m^3/d)=0.57= 13.68 hours

(Source: National Institute of Urban Affairs; **https://scbp.niua.org/sites/all/themes/c4ksubtheme/pdf/CoEP_4.pdf**)

Table 7: Basic design criteria for an anaerobic baffle reactor

Hydraulic retention time	> 24 hours at maximum sludge depth and scum accumulation
Sludge accumulation rate Depending on TSS removal rate and wastewater flow	70 – 100 litres/person/year
Sludge and scum accumulation volume Sludge accumulation rate multiplied by sludge accumulation rate	
Desludging interval	> 1 year
Number of up-flow chambers	> 2
Maximum up-flow velocity	1.4 – 2 m/h

(**Source:** UN-HABITAT 2008)

3.3.3 Design and Selection of Constructed Wetlands for sewage treatment

Designing and selecting CWs for sewage treatment involves a thorough understanding of the site conditions, treatment goals, and the specific requirements of the sewage being treated. CWs are a nature-based approach to wastewater treatment, mimicking the processes that occur in natural wetlands to remove pollutants. Some of the commonly used CW designs are as follows:

1. *HFCWs* are typically better suited for larger, flatter sites with lower elevations, where space is not limited. They are also better suited for treating organics in wastewater, as the horizontal flow allows for longer hydraulic retention times (site-specific) and greater contact between the wastewater and the treatment media. HFCWs can be designed with multiple cells or compartments to increase treatment efficiency, and they are generally easier to construct and maintain.
2. *VFCWs,* on the other hand, are better suited for sites with limited space and higher elevations. They can be built in a smaller footprint than HFCWs and can be designed to treat a wide range of pollutants. VFCWs have shorter hydraulic retention times than HFCWs, but they offer greater treatment efficiency due to the vertical flow of wastewater through the media, which allows for greater aeration and biological activity.
3. *Hybrid CWs* are better suited to achieve higher removal efficiency where space is not a constraint.
4. *Aerated CWs:* Aerated CWs can potentially reduce the area requirement compared to traditional non-aerated CWs for certain wastewater treatment scenarios. This reduction in area requirement is primarily due to the enhanced treatment efficiency achieved through the introduction of aeration

The choice between HFCWs, VFCWs, Aerated and Hybrid CWs will generally depend on the specific treatment goals, site conditions, and available resources for construction and maintenance.

3.4 Design criteria for CWs

The existing design approach is predominantly based on hydraulic considerations or to some extent organics removal, which makes it highly empirical and conservative. This is described in detail in the next few sections for HFCWs and VFCWs. Basic recommendation on design for SSF CWs is given in Table 8.

Table 8: Recommendation on design for SSF CWs

Parameter	Design criteria
Bed size (m^2)	<2500
Length-to-width ratio	<3:1
Water depth (m)	0.4–1.6
Hydraulic slope (%)	0.5–1
Hydraulic loading rate (m/day)	<0.5
Hydraulic retention time (day)	2–5
Media	Natural media such as coarse sand and gravels preferred, porosity 0.3–0.5, particle size <20 mm (50–200 mm for the inflow and outflow)
Vegetation	Native species preferred, plant density 5-6 plants sq. meter

3.4.1 Horizontal Flow CWs Design

As a secondary treatment process, HF systems can remove BOD and TSS effectively, but the performance greatly depends on the pollutant concentration in the influent and HLRs. Existing design guidelines for HF wetlands vary greatly, generally giving high weightage to hydraulic considerations. They can be sized using simple, specific surface area requirements (m^2/PE), maximum areal loading rates (for example, g BOD_5/m^2. d), or more sophisticated methods such as loading charts or the P-k-C* approach. Further, the design of CW treatment systems depends on the treatment target in terms of organics and nutrients and the flow rate and quality of the influent.

Length-to-width ratios for secondary HF wetlands generally fall between 2:1 and 4:1, whereas for tertiary systems, the width is typically more significant than the length to maximize the cross-sectional area and reduce clogging potential with the higher hydraulic rates applied. According to many design guidelines, the maximum loading rate should be specified on the basis of the wetland plan area as it is easy to construct HF beds provided with a standard depth of 0.6 m media, and this value is assumed as the maximum root depth penetration. Using a maximum cross-sectional area loading, i.e., the load applied at the inlet width and depth, moves away from this assumption and provides an opportunity to modify bed length and depth to allow sustainable wastewater treatment. The design of a horizontal flow constructed wetland involves several calculations and considerations. Here are some of the critical calculations that may be used in the design process:

3.4.1.1 Sizing of the HFCWs by Rule-of-Thumb

Rule-of-thumb is the most commonly adopted and existing design for constructing a CW system. The major design criteria of the Rule of thumb include land requirement per equivalent (m^2/PE). The other parameters used in designing an HF CW are; HRT, BOD loading rate, HIR, and areal requirements and design are summarized in Table 9.

Table 9: Rule of thumb design criteria for horizontal subsurface flow constructed treatment wetlands

S.N.	Description	Value Range	
		Wood (1995)	Kadlec and Knight (1996)
1.	Hydraulic retention time (days)	2-7	2-4
2.	Max. BOD loading rate (kg BOD ha day^{-1})	75	-
3.	Hydraulic loading rate (cm day^{-1})	0.2-3.0	8-30
4.	Areal Requirement (ha m^3 day)	0.001-0.007	-

(**Source:** Rousseau et al., 2004)

Benefits:

It is very simple to use and does not account for different water usage practices, pre-treatment technologies, or non-ideal flow.

Limitations:

1. Different methods of using water, pre-treatment technologies, and influent wastewater concentrations are not taken into consideration.
2. Non-ideal flow is not taken into consideration.
3. It does not consider the geometry of wetland cells or design approaches to reduce the risk of clogging.

3.4.1.2 Sizing of the HFCWs based on the Kikuth approach

The size of the wetland is based on the expected flow rate and the required hydraulic retention time (HRT). Calculation of wetland surface area (A) is calculated using eq. 1.

$$A = \frac{Q * (InC_i - InC_e)}{K_A H \alpha} \qquad (1)$$

Where, A is the Area of the constructed wetlands (m^2), C_i and C_e are the influent and effluent concentration of the concerned pollutants (mg/L), and K_A is the areal removal rate coefficient (m/day), H is Depth (m) and α is Porosity of CW.

Example: Sample calculations for sizing of HFCWs

Average volume of wastewater (Q)	= 32 m^3/d
Required Area (m^2)	$A = \frac{Q * (InC_i - InC_e)}{K_A H \alpha}$
Porosity α (assumed)	0.75
H is Depth (m) (assumed)	0.50 m
K_A	0.86
C_i	200
C_e	20

Area Required (m^2)	=(32 * (5.2983 - 2.9957)) / (0.86 * 0.50 * 0.75) = 231.14 m²

The major drawback of this approach for sizing the constructed wetland is choosing the areal removal rate coefficient (K_A value) since there is no guidance on which K_A value to choose, especially when a range of reaction rate coefficients is reported. According to the study by Kadlec and Knight in 1996, the K_A value for BOD ranges from 0.085 to 1.0 m/day, while for TN, it ranges from 0.007 to 0.1 m/day. A study by Singh et al. (2022) calculated the K_A values by assessing the secondary dataset of 74 VFCWs and revealed a large variation (0.006–0.40 m/day) in the K_A value.

3.4.1.3 Hydraulic Retention Time

The hydraulic design of the wetland involves determining the flow path and ensuring that the wastewater is evenly distributed across the wetland. The hydraulic retention time (HRT) can be calculated using the eq. 2.

$$HRT = V_{eff} / Q \qquad (2)$$

Where; V_{eff} is the effective volume of the wetland (m^3) = ф*V, Φ is the porosity of the filter media, V is the total volume of the wetland, and Q is the design flow rate (m^3/day).

where porosity (ф) for horizontal flow CWs could be considered approximately 40% or as per design requirement.

3.4.1.4 Media Design

The media in a horizontal flow-constructed wetland serves as a substrate for microbial activity and physical filtration. The media depth is typically based on treatment requirements, and the media void space (porosity) should be at least 40%. The media surface area (A) can be calculated using the eq. 3.

$$A = V / d \qquad (3)$$

Where; V is the wetland volume (m^3), and d is the media depth (m).

3.4.1.5 Inlet and Outlet Design

The inlet and outlet structures should ensure that the wastewater is evenly distributed across the wetland and that there is adequate overflow capacity to handle peak flows. The inlet and outlet structures should be designed based on the design flow rate and the wetland surface area.

It is important to note that these calculations are general guidelines, and the specific design requirements will depend on the site-specific conditions and the regulatory requirements in the area.

3.4.2 Vertical Flow CWs

VFCWs offer a significant advantage over HFCWs with their higher oxygen transfer capacity due to the nearly instantaneous flooding of the bed surface. Additionally, they require smaller area demands (up to 1.2-5.0 m² per population equivalent) compared to HSFCWs (usually 3-10 m² per population equivalent), leading to lower construction costs. The typical design of VFCWs involves a flat bed of substrate (coarse, sand, or gravel) with increasing gradation with depth, planted with macrophytes. A slight slope (0.5-1%) is provided at the bottom of the bed for efficient treated water collection and drainage. The bottom is covered by a geo-membrane or made of reinforced concrete to prevent uncontrolled seepage into the groundwater.

The key mechanism in VFCW design is to create a bed matrix that allows the wastewater to pass through before the next dose arrives, providing sufficient contact time with the bacteria growing on the media for treatment. The adequate surface area allows for oxygen transfer, creating favourable aerobic conditions for ammonia nitrogen oxidation (nitrification) and organic matter decomposition compared to HSFCWs (Kadlec and Wallace, 2009).

Here are some design considerations for a VFCWs:

3.4.2.1 Sizing of the VFCWs

The sizing of the vertical flow constructed wetland based on the following approach should be selected with a certain level of flexibility and be willing to make adjustments if the actual performance deviates from the design expectations. While these approaches may result in slightly larger wetland areas or higher initial costs, it enhances the wetland's resilience and minimizes the risk of underperforming or failing to meet treatment objectives.

3.4.2.2 Sizing of the VFCWs based on the Rule-of-Thumb

Rule-of-thumb is a prescriptive and existing design approach based on a particular wetland application in a specific climatic or geographical region.

a) Design is based on the area requirement per person equivalent (m^2 /PE), but the loading rate (g $BOD_5/m^2 \times d$ or g $COD/m^2 \times$ d) can also be used. This approach is a practical way of designing and can be effective when there is adequate knowledge of the application of the technology in the region under consideration.

b) Based on Specific Area Requirements per population equivalent

For Vertical Flow (VF) constructed wetland systems, the surface area of the bed required depends on the organic load and is typically expressed as unit area per population equivalent (m²/PE). The recommended range for the bed surface area is about 1.2 to 5.0 m²/PE for normal VFCWs (Hoffmann et al., 2011). However, for French VFCWs in temperate climates, the recommended surface area is slightly lower, ranging from 2.0 to 2.5 m²/PE (Molle et al., 2005)

3.4.2.3 Sizing of the VFCWs based on the Conventional formula (Kikuth approach)

The Kikuth approach is a widely used method for estimating the required surface area of a constructed wetland to achieve specific pollutant removal targets.

The Kikuth approach equation for sizing VFCWs typically is seen as eq. 4.

$$A = \frac{Q * (InC_i - InC_e)}{K_A} \qquad (4)$$

Where, A is the Area of the constructed wetlands (m^2), C_i and C_e are the influent and effluent concentration of the concerned pollutants (mg/L), and K_A is the areal removal rate coefficient (m/day).

By using this equation, you can determine the surface area required for the VFCW to achieve the desired pollutant removal efficiency based on the given influent and effluent concentrations and the flow rate of the wastewater being treated. It's important to select the appropriate K_T value to ensure accurate sizing and effective pollutant removal performance of the constructed wetland.

3.4.2.4 Hydraulic Design

The hydraulic design of the wetland is based on the expected flow rate, the wetland configuration, and the characteristics of the wastewater. The design should ensure that the wastewater is evenly distributed across the wetland and that the hydraulic retention time is sufficient for treatment. The length-to-width ratio refers to the proportion between the length and width dimensions of the wetland bed. An ideal length-to-width ratio helps ensure the even distribution and flow of wastewater across the entire surface of the bed, maximizing pollutant contact with the filter media. For typical VFCWs, a length-to-width ratio of around 3:1 or 4:1 is often recommended. This ratio provides good hydraulic flow patterns and efficient pollutant removal. A higher length-to-width ratio (e.g., 5:1 or more) may enhance flow uniformity but may not always be practical due to space constraints. Conversely, a lower length-to-width ratio (e.g., 2:1 or less) may cause uneven flow distribution and reduced treatment efficiency.

Example: Sample Calculation for sizing of a constructed wetland for a population of 400 with specific wastewater flow of 80 litres per person per day

Average volume of wastewater (Q)	= 400 x 80 / 1000 = 32 $m^{3/}$d
BOD_5 contribution	= 40 g BOD_5/pe.d
BOD_5 concentration	= 40 x 1000/80 = 500 mg/l
Let us assume that 30% BOD_5 is removed by the primary treatment unit, then the influent BOD_5 concentration to the wetland	
(Ci)	= 350 mg/l
Effluent BOD_5 concentration (Ce)	= 30 mg/l
K_{BOD}	= 0.15 m/d for HF wetland and 0.2 m/d for VF wetland
$A = \frac{Q\ (\ln Ci - \ln Ce)}{K_{BOD}}$	Substituting the values in the equation
Area for HF wetland	= 524.10 m^2
Specific area per PE for HF wetland	= 1.31 m^2
Area for VF wetland	= 393.08 m^2
Specific area per PE for VF wetland	= 0.98 m^2

Note: The local circumstances and standards need to be considered by the designer **(**UN-HABITAT, 2008).

3.5 Suggested approach for reducing land footprints of CWs based STPs

As indicated above, the existing design approach is highly empirical and hence leads to over-designing of the systems resulting in a general belief that CWs can have predominantly only rural applications due to their constraints of extensive area requirements. However, the recent compilation and assessment of the performance of about 200 field wetlands done by Soti et al. (2022) and Singh et al. (2022) showed a vast variation in their organics and nutrient removal. A systematic statistical approach was adopted to filter out the data to bring down the surface area requirements substantially which provides a customized design of CWs based on the desired standards.

3.5.1 Selection of the K_A value in the P-K-C*/Kikuth approach

Since there is no specific guidance on selecting a single K_A value in the P-K-C*/Kikuth approach for sizing the constructed wetlands, the choice may depend on various factors, including the specific characteristics of the pollutants in the influent, i.e., High organic loading system/low organic loading system, the design objectives of the constructed wetland, i.e., depth, and the local ambient environment condition, i.e., Temperature. Here are a few considerations in the next section to help make an informed decision:

The studies by Singh et al. (2022) and Soti et al., (2022) observed that the majority of the wetland systems, both horizontal flow and vertical flow, exhibited signs of being under loaded and overdesigned. In response, these studies conducted comprehensive mathematical analyses to systematically eliminate outliers from the 74 datasets of HFCWs and 82 datasets of VFCWs. This meticulous process led to the narrowing down in standard deviations, resulting in the identification of stable K_A values. These K_A values have been recommended for design approaches in the P-K-C* /Kikuth approach under various influent loading conditions., and they are presented in detail in Table 10 and Table 11. The influent loading in volumetric terms ($g/m^3\ d^{-1}$) which can be computed based on the Influent wastewater characteristic in mg/L, using eq. 5 assuming the area suggested by the Rule of thumb and using the most commonly adopted depth (0.6 to 0.8 m) when sizing the constructed wetland for municipal wastewater treatment (Table 10 and 11).

$$V_L = \left(\frac{C \times F}{A\ X\ d\ X\ 1000}\right) \quad (5)$$

where, V_L is Volumetric loading ($g/m^3\ d^{-1}$, C is concentration of pollutant (mg/L), F is flow rate of influent (L/d), A is wetland area (m^2) and d is depth (m) of the wetland.

Table 10: First-order areal removal rate coefficient (K_{20}) (Mean ± STD) for HFCWs, in m/day, considering the ideal plug flow condition.

Classification based on organic loading				
Classification	**$(K_{20})_{BOD}$**	**$(K_{20})_{NH4-N}$**	**$(K_{20})_{TN}$**	**$(K_{20})_{TP}$**
<5 g/m^3d^{-1}	0.192	0.126	0.102	0.021
5-30 g/m^3d^{-1}	0.178	0.117	0.107	0.097
30-100 g/m^3d^{-1}	0.174	0.114	0.096	0.095
>100 g/m^3d^{-1}	0.102	0.064	0.044	0.054
Classification based on the effective depth of filter media				
< 0.2 m	0.094	0.051	0.032	0.047
0.2-0.5 m	0.122	0.071	0.061	0.062
> 0.5 m	0.131	0.082	0.097	0.071

(**Source:** Personal Communication Prof. A.B. Gupta, Abhishek Soti, MNIT Jaipur dated- August 11, 2023)

Table 11: First-order areal removal rate coefficient (K_{20}) (Mean ± STD) for VFCWs, in m/day, considering the ideal plug flow condition

Classification based on organic loading				
Classification	**(K_{20}) BOD**	**(K_{20}) NH4-N**	**(K_{20}) TN**	**(K_{20}) TP**
<5 g/m^3d^{-1}	Not given	0.128	0.067	0.036
5-30 g/m^3d^{-1}	0.392	0.113	0.082	0.036
30-100 g/m^3d^{-1}	0.347	0.194	0.097	0.107
>100 g/m^3d^{-1}	0.363	0.093	Not given	0.222
Classification based on the effective depth of filter media				
< 0.2 m	Not given	0.142	0.008	Not given
0.2-0.5 m	0.348	0.135	0.026	0.255
0.5 m-0.85m	0.343	0.079	0.075	0.088

(**Source:** Personal Communication Prof. A.B. Gupta, Abhishek Soti, MNIT Jaipur dated August 11, 2023)

Once the appropriate K_{20} value is chosen from these reference studies, it can be converted to K_T using the eq. 6.

$$K_T = K_{20} * (\theta)^{(T-20)} \qquad (6)$$

where, K_T = Removal rate coefficient at T°C (m/day), K_{20} = Removal rate coefficient at 20°C (m/day), T= Temperature, θ = constant, which is taken 1.06 in the case of BOD, 1.048 in the case of NH_4-N, and 1.15 in the case of TN.

By applying the temperature correction coefficient to the K_{20} value, the appropriate K_T value for the specific environmental temperature at the project site can be obtained. This adjusted K_T value will be further used in the design and sizing of the constructed wetland to achieve the desired pollutant removal efficiency based on the prevailing temperature conditions. Therefore, the sizing of VFCWs and HFCWs can be accomplished by incorporating the above-calculated K_T value (areal removal rate coefficient), influent and effluent concentrations of the targeted pollutant, and discharge flow rate into the P-K-C*/Kikuth approach equation.

It is often safer to choose a K_A value on the conservative side from these tables. While these approaches may result in slightly larger wetland areas or higher initial costs, it enhances the wetland's resilience and minimizes the risk of underperforming or failing to meet treatment objectives. Still, the area requirements would be far lesser than adopted in the existing empirical approach. If possible, the constructed wetland should be designed with the flexibility to adjust or fine-tune the K_A value to incorporate future scenarios. The selection of K_A value is not an exact science, and there may be some uncertainties in the process. Therefore, it is essential to approach the design with a certain level of flexibility and accordingly make adjustments if the actual performance deviates from the design expectations. Moreover, the above-mentioned table can help choose a realistic range of K_A values for different pollutants or influent characteristics, providing a valuable reference for making an initial selection. However, it is crucial to consider other relevant factors specific to site conditions before finalizing the K_A value.

3.5.2 Design based on Artificial Intelligence applications to the CW data

The sizing of the Horizontal flow constructed wetlands can also be calculated using the regression equation developed by the machine learning approach by putting the effluent concentration as per the local regulations and standards (Table 12).

Table 12: Regression equation developed by the machine learning approach for sizing of HFCWs

S. N.	Parameter	Regression Equations	R^2	Range
1.	BOD	$(BOD)_{effluent} = -0.039 * X_1 + 0.040 * X_2 + 0.008 * X_3 - 0.234 * X_4 - 0.197 * X_5 + 0.471 * X_6 - 0.283 * X_7 + 0.125 * X_8 - 0.166 * X_9 - 0.091 * X_{10} - 0.07$	0.6	40<BOD<543 75<COD<960 2.2<TN<222 1<TKN<98 0.48<TP<25 (All concentrations are in mg/L) $0.2 m^2 < A < 624 m^2$ $0.004 m^3/d < Q < 100 m^3/d$ 1d<HRT<10d 5°C<T<34°C 0.2m<D<2.51m
2.	COD	$(COD)_{effluent} = -0.029 * X_1 + 0.315 * X_2 - 0.012 * X_3 - 0.884 * X_4 - 0.137 * X_5 + 0.174 * X_6 - 0.219 * X_7 + 0.093 * X_8 - 0.449 * X_9 - 0.088 * X_{10} - 4.737$	0.5	
3.	NH_4-N	$(NH_4^+ - N)_{effluent} = 0.069 * X_1 - 0.008 * X_2 + 0.020 * X_3 - 0.124 * X_4 + 0.058 * X_5 + 0.002 * X_6 - 0.218 * X_7 - 0.038 * X_8 + 0.239 * X_9 - 0.056 * X_{10} - 0.142$	0.8	
4.	TN	$(TN)_{effluent} = -1.040 * X_1 + 1.976 * X_2 + 0.330 * X_3 - 0.324 * X_4 + 0.081 * X_5 + 0.003 * X_6 - 0.124 * X_7 - 0.017 * X_8 + 0.2459 * X_9 - 0.034 * X_{10} - 0.448$	0.9	
5.	TP	$(TP)_{effluent} = 0.014 * X_1 - 0.006 * X_2 + 0.007 * X_3 - 0.131 * X_4 + 0.046 * X_5 - 0.046 * X_6 - 0.025 * X_7 - 0.286 * X_8 + 0.020 * X_9 - 0.025 * X_{10} + 0.114$	0.7	

Note; X_1 = HRT (days), X_2 = Temperature (◦C), X_3 = Design Flow Q (m^3 /day), X_4 = Depth of media (m), X_5 = Wetland area (m^2), X_6 = BOD Influent (g/m^3 -d), X_7 = NH_4^+-N Influent (g/m^3 -d), X_8 = TN Influent (g/m^3 -d), X_9 = COD Influent (g/m^3 -d), X_{10} = TP Influent (g/m^3 - d). (Singh et al., 2022)

3.5.3 Depth of the filter media in CWs

The depth may reduce the contact time and, subsequently, the pollutant removal efficiency. On the other hand, a deeper bed can accommodate a higher organic load and provide better treatment as it provides the anaerobic/anoxic stretch at the bottom zone of the VFCWs that is beneficial for nitrogen and phosphorus removal, but it also requires more space and may increase construction costs.

A study by Singh et al., 2023 suggested that the depth of the filter media in the HFCWs can also be calculated using the regression equations that incorporate the removal rate coefficient of the concerned pollutant in the CW system (Table 13). According to this study, optimized depths for targeted pollutant removal, such as BOD, TKN, TN, TP, and combined pollutants in VFCWs, are suggested to be approximately 1.48 m, 1.71 m, 1.90 m, 2.09 m, and 2.14 m, respectively.

Table 13: Selection of effective depth of filter media of HFCWs using the regression equation

S.N.	Parameter	Regression Equation	R^2
1.	BOD	$(\text{Depth})_{BOD} = 0.203(K_{20})^4_{BOD} + 0.114(K_{20})^3_{BOD} - 0.095(K_{20})^2_{BOD} + 0.101\,(K_{20})_{BOD} + 0.073$	0.72
2.	TKN	$(\text{Depth})_{TKN} = -\,0.042(K_{20})^4_{TKN} + 0.195(K_{20})^3_{TKN} + 0.297(K_{20})^2_{TKN} + 0.156(K_{20})_{TKN} - 0.018$	0.68
3.	TN	$(\text{Depth})_{TN} = 0.081(K_{20})^4_{TN} + 0.354(K_{20})^3_{TN} - 0.041(K_{20})^2_{TN} + 0.193(K_{20})_{TN} - 0.022$	0.55
4.	TP	$(\text{Depth})_{TP} = 0.013(K_{20})^4_{TP} + 0.038(K_{20})^3_{TP} - 0.108(K_{20})^2_{TP} + 0.159(K_{20})_{TP} + 0.088$	0.41
5.	Combined	$\text{Depth} = -\,0.8216(K_{20})_{BOD} + 6.170\,(K_{20})_{TN} - 2.011(K_{20})_{TKN} + 0.927(K_{20})_{TP} + 0.952$	0.85

Note: K values are in the m/day and depth is in the m. (Singh et al., 2023)

After selecting the K_{20} value from the reference studies, it will be converted to K_T by the eq. 7.

$$K_T = K_{20} * (\theta)^{(T-20)} \qquad (7)$$

where, K_T = Removal rate coefficient at T°C (m/day), K_{20} = Removal rate coefficient at 20°C (m/day), T= Temperature, θ = constant, which is taken 1.06 in the case of BOD, 1.048 in the case of NH_4-N, and 1.15 in the case of TN.

By putting this K_T value in the above regression equations, the depth of the filter media can be suggested for the concerned pollutant removal or combined organic and nutrient removal. Similarly, the study by Soti et al., (2023) suggested the depth of the filter media for the removal of nutrients (N&P) in the VFCWs, which can also be calculated using the regression model given in the Table by putting the value of effluent based on the local standards and guidelines (Table 14).

Table 14: Selection of effective depth of filter media of VFCWs using the regression equation

S.N.	Parameter	Regression Equation	R^2	Range
1.	NH_4-N	$NH_4 - N_{effluent}$ (g/m^3- d) = − 0.688*Depth (m)− 0.195*HLR (m/d) − 0.119*Temperature (°C) + 0.512*$NH_4 - N_{inlet}$ (g/m^3- d) + 0.089*TN_{inlet} (g/m^3- d) − 0.288*TP_{inlet} (g/m^3- d) + 1.99	0.89	0.07<Depth<0.85, 0.004<HLR<0.36, 6<Temperature<30, 0<$NH_4 - N_{inlet}$ <43, 0<TN_{inlet}<50, 0<TP_{inlet}<3.15,
2.	TN	$TN_{effluent}$ (g/m^3- d) = 1.41*Depth (m)+0.025*HLR (m/d) +0.382*Temperature (°C) +0.601*$NH_4 - N_{inlet}$ (g/m^3- d) + 0.007*TN_{inlet} (g/m^3- d) +0.074*TP_{inlet} (g/m^3- d) - 6.97	0.90	
3.	TP	$TP_{effluent}$ (g/m^3- d) = − 0.029*Depth (m) − 0.246*HLR (m/d) − 0.0261*Temperature (°C) − 0.023*$NH_4 - N_{inlet}$ (g/m^3- d) + 0.029*TN_{inlet} (g/m^3- d) + 0.141*TP_{inlet} (g/m^3- d) + 0.505	0.87	

Some primary studies on full-scale field wetlands have been carried out to validate both the statistical and AI approaches, which have shown a close prediction of their performances for organics and nutrient removals, however more such work is needed before adopting them as standard design approaches.

3.6 Hybrid Constructed wetlands

Hybrid CWs combine two or more types of wetland systems to achieve better treatment performance. They can be designed in various configurations, including vertical-horizontal flow, aerated-un-aerated, free water surface-subsurface flow. The construction of hybrid CWs follows similar principles as conventional CWs but with additional design considerations as per requirement.

Kalbar, (2021) has introduced a new paradigm of Hybrid Treatment Systems (HTS) that couples mechanized treatment system (MTS) and natural treatment systems (NTS) (specifically CWs) (Table 15). Earlier studies have used the terminology of hybrid treatment systems to combine different mechanized treatment technologies; horizontal and vertical flow CWs; on-site and off-site technologies etc. However, the coupling of mechanized and natural treatment systems through hybrid treatment systems approach is suggested as a full-fledged strategy to achieve sustainable water management and meet the emerging stringent norms at a low cost.

Table 15: Proposed hybrid system approach

APPROACH	HTS-1			HTS-2		
BOD removal	Treatment system	Land requirement (m^2/ MLD)	O&M costs (INR/ m^3)	Treatment system	Land requirement (m^2/ MLD)	O&M costs (INR/ m^3)

APPROACH	HTS-1			HTS-2		
Up to 30 mg/L	MTS	1100	6	MTS	1100	6
Up to 10 mg/L	MTS + shallow bed CWs	3166	7	MTS + deep bed CWs	2029	7
Up to 5 mg/L	MTS + shallow bed CWs	4469	7	MTS + deep bed CWs	2616	7
Usefulness in different settings	Rural and peri-urban setting (both in centralized and decentralized manner) where land is available; suitable if STPs are located in main city or outskirts of city			Peri-urban and urban settings (both centralized and decentralized manner) in case of land constraint		

(**Source:** Personal Communication Prof. Pradip Kalbar, IIT Bombay, dated- July 18, 2023)

3.7 Aerated constructed wetlands

Aerated constructed wetlands (ACWs) are designed to enhance the treatment efficiency of traditional constructed wetlands by introducing aeration to support aerobic microbial processes. This can significantly improve the removal of pollutants and nutrients from wastewater. In addition to the regular components of constructed wetlands, ACWs require some additional elements to ensure proper functioning. Here are some factors to consider apart from the normal construction aspects:

1. Aeration System: The most crucial addition to ACWs is the aeration system. This includes diffusers or aerators that introduce oxygen into the wetland substrate. The aeration helps maintain aerobic conditions throughout the system, which promotes the growth of beneficial aerobic microorganisms that contribute to pollutant degradation.
2. Air Distribution Network: To effectively distribute air throughout the wetland substrate, a well-designed air distribution network is necessary. This may involve pipes, manifolds, and diffuser systems to evenly distribute air across the wetland area.
3. Monitoring and Control Systems: ACWs require monitoring and control systems to regulate the aeration process. Sensors for dissolved oxygen levels, water temperature, and other relevant parameters are essential for ensuring optimal treatment conditions.
4. Aeration Power Source: As ACWs require continuous aeration, a reliable power source is vital. This could be in the form of electricity, solar power, or other renewable energy sources, depending on the site's availability and constraints.

Standard types of CWs rely on the diffusion of oxygen from the air into the water column, which is a very slow process. This lack of oxygen transfer slows the removal of organic compounds and limits the removal of ammonia from wastewaters. Also, the larger footprint made the systems unviable in terms cost and space requirements. Further, their effective life was also limited and the systems were somewhat static with no controls available for the operator. However aerated Treatment Wetland systems rely on the ability to inject small quantities of air in a very uniform pattern throughout the wetland bed. This allows operator control over the entire oxidation process during wastewater treatment while only using a small fraction of the energy required by conventional STPs. Intermittent operation of the aeration system can be fined-tuned to optimize treatment goals such as total nitrogen removal.

Aerated wetlands are 3 to 5 times smaller than conventional passive wetlands. The reduced area saves construction costs and means that wetlands can be used in limited land areas. The systems do not produce excess sludge like conventional mechanical treatment plants and only use about 10% of the energy required for a comparable activated sludge process.

Treatment of high-strength wastes is also popular, with numerous systems operating for aircraft de-icing, oil & gas, chemical manufacturing, food & beverage, mining and landfill leachate applications.

The chart below provides a comparison of oxygen transfer rates seen in passive wetlands and aerated systems using Aerated Wetlands System (Figure 12).

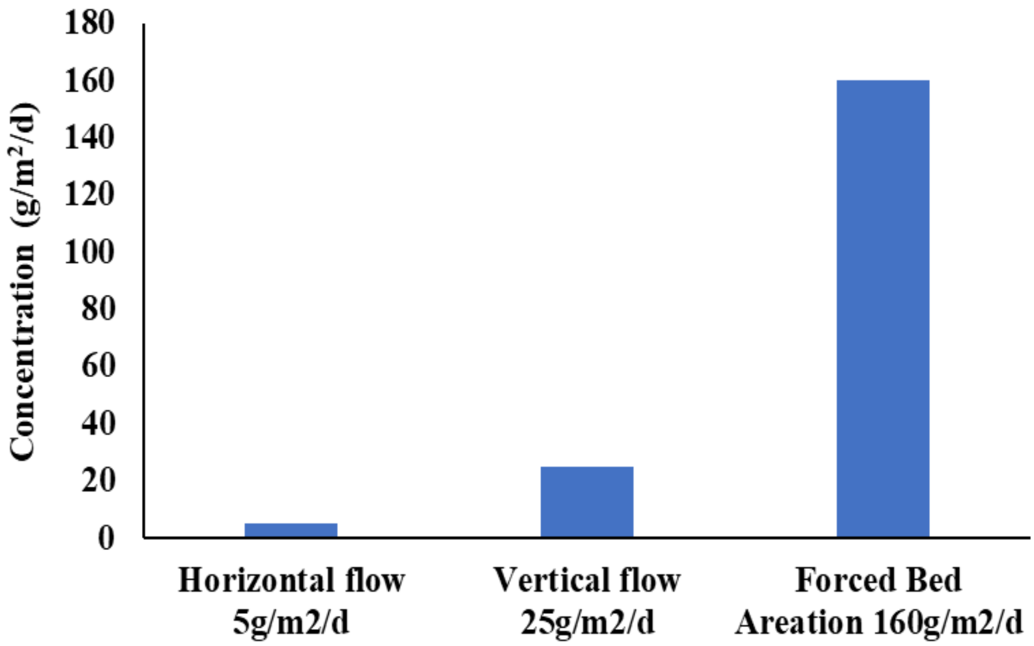

Figure 12: Comparison of oxygen transfer rates in CWs
(**Source:** Personal communication Sh. Ganges Reddy, dated- August 22, 2023)

Overall, the construction of an aerated constructed wetland involves careful planning and execution to ensure that the system is effective and long-lasting.

3.8 Selecting constructed wetland for optimal wastewater treatment

Selecting CWs based on area involves several steps to ensure an appropriate design that meets the treatment requirements and fits within the available space. Steps for selecting CWs based on area are listed below:

1. **Determine treatment objectives:** Define the specific treatment goals can be used to check the desired use and permissible water limit. This includes identifying the targeted pollutants, such as organic matter, nutrients, or pathogens, that need to be removed from the influent water.

2. **Assess site conditions:** Evaluate the available space and site characteristics where the CWs will be implemented.
3. **Calculate treatment capacity:** Estimate the required treatment capacity based on the anticipated influent flow rate and pollutant load. This involves determining the hydraulic loading rate (flow rate per unit area) and the pollutant loading rate (pollutant mass per unit area) that the wetland needs to handle.
4. **Determine area requirements**: Calculate the area required for the CWs based on the treatment capacity determined in the previous step. This calculation takes into account factors such as the desired HRT, treatment efficiency, and specific design considerations.
5. **Evaluate different wetland types**: Consider different types of CWs, such as horizontal flow, vertical flow, or hybrid systems, and their respective area requirements. Assess the advantages, disadvantages, and treatment efficiencies of each type to determine which is most suitable for the available space.
6. **Perform feasibility analysis**: Assess the feasibility of implementing the CWs design within the available area. Consider any potential constraints, such as land availability, regulatory requirements, construction costs, and maintenance requirements.
7. **Design optimization**: Fine-tune the design parameters, such as the layout, shape, and arrangement of cells or basins, to optimize the available area while meeting treatment objectives. This may involve adjusting the wetland system's dimensions, depths, and flow patterns.

3.9 Construction of CWs

Excavation is an important aspect of constructing CWs. The excavation process involves digging out the area where the CW will be located and shaping the bottom and sides of the basin to the desired dimensions and slopes.

Here are some general considerations for the excavation of a CW:

- **Site preparation**: Before excavation begins, the site should be cleared of any vegetation or debris. If the site is not level, it may need to be graded to create a level surface for the excavation.
- **Excavation depth**: The depth of the excavation will depend on the design of the CW. The excavation depth should be deep enough to accommodate the substrate layers and plants and to provide adequate storage capacity for the wastewater. The depth may also need to be adjusted to achieve the desired hydraulic retention time.
- **Excavation width**: The width of the excavation will depend on the design of the CW and should be wide enough to accommodate the desired flow rate and HLR. The width may also be adjusted to achieve the desired hydraulic retention time.
- **Excavation length**: The excavation length will depend on the design flow rate and the desired hydraulic retention time. The length may also be adjusted to achieve the desired surface area.
- **Slope**: The sides and bottom of the excavation should be sloped to prevent erosion and ensure proper drainage.

- **Soil stabilization**: The soil in the excavation should be stabilized to prevent erosion and ensure the long-term stability of the CW. This may involve lining the excavation with geotextile fabric or a liner.

The excavation process should be done carefully and accurately to ensure the CW functions appropriately. The excavated area should be inspected for any rocks, roots, or other debris that may interfere with installing the substrate layers or the growth of plants before proceeding with the construction of the CW.

3.9.1 Filter media selection strategies

Substrate selection can be a critical design consideration for certain types of CWs, such as sub-surface flow systems. For simple surface flow systems, substrate selection is not critical. Gravel is generally considered optimal and is often encountered when CWs are excavated, as they are typically located on the routes of historic water courses, but clay, sand, and silt are also acceptable. Substrates with varying particle sizes form a spatial network, which endows the filtration function for CWs. The larger particles and pollutants are removed initially by physical filtration and interception. Then, the smaller particles and colloidal substances can be removed by other processes. Further, factors that must be evaluated before the substrate selection are illustrated in Figure 13.

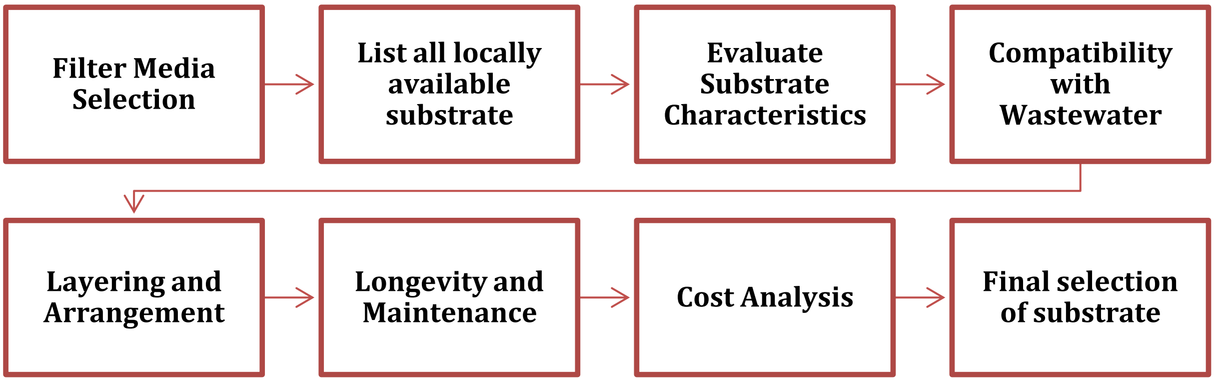

Figure 13: Indicative steps for substrate selection for constructed wetlands

Significance of substrate in CWs:

- They support many of the living organisms in wetlands
- Substrate permeability affects the movement of water through the wetland
- Many chemical and biological (especially microbial) transformations take place within the substrates
- Substrates provide storage for many contaminants

Choice of potential substrate for CWs is based on various criteria:

- **Wastewater characteristics**: The type and quality of wastewater to be treated will determine the choice of substrate. For example, for wastewater with high organic and nutrient content, a substrate with high porosity and surface area, such as gravel or expanded clay, may be preferred.

- **Site conditions**: The site's soil type, topography, and hydrology will also influence substrate selection. For example, a substrate with good drainage properties may be preferred if the site has a high-water table.
- **Plant species**: The plant species selected for the constructed wetland will also influence the choice of substrate. Different plant species have different requirements for substrate texture, nutrient availability, and pH levels.
- **Maintenance requirements:** The substrate should be easy to maintain and replace if necessary. Some substrates, such as coconut coir, may need to be replaced more frequently than others.
- **Cost:** The cost of the substrate should also be considered in the selection process. Some substrates, such as gravel, are relatively inexpensive, while others, such as expanded clay, may be more expensive.
- **Sustainability:** The sustainability of the substrate should also be considered, such as the environmental impact of sourcing and producing the material. Renewable and environmentally friendly substrates may be preferred over non-renewable options.

It is important to select a substrate that meets the specific requirements of the constructed wetland and is compatible with the plant species chosen for the project. The general consideration for filter media selection and depth are given in Table 16. Further it is reported that the diameter size of media used in HF wetlands varies from 0.2 mm to 30 mm (U.S. EPA, 2000).

Table 16: Recommendation on filter media (Gravel, sand etc.) and depth for CWs

CWs Type	Recommended size at Inlet and Outlet Zones (mm)	Recommended Range of Filter Media size at Treatment zone (mm)	Range Depth (cm)	Slope
HF-CW	40-80	5- 20	30-60	0.5 -1%
VF-CW	-	5-40	50-100	

The depth requirements can vary depending on factors such as hydraulic and organic loading rates and the desired treatment efficiency. Additionally, local regulations and site-specific conditions may influence the design and depth of CWs. Example for HF and VF media arrangement is given in Figure 14 and 15 **(**UN-HABITAT, 2008) further, proper wetland design it is essential to determine the appropriate depth for your specific project based objective, treatment goals and site characteristics.

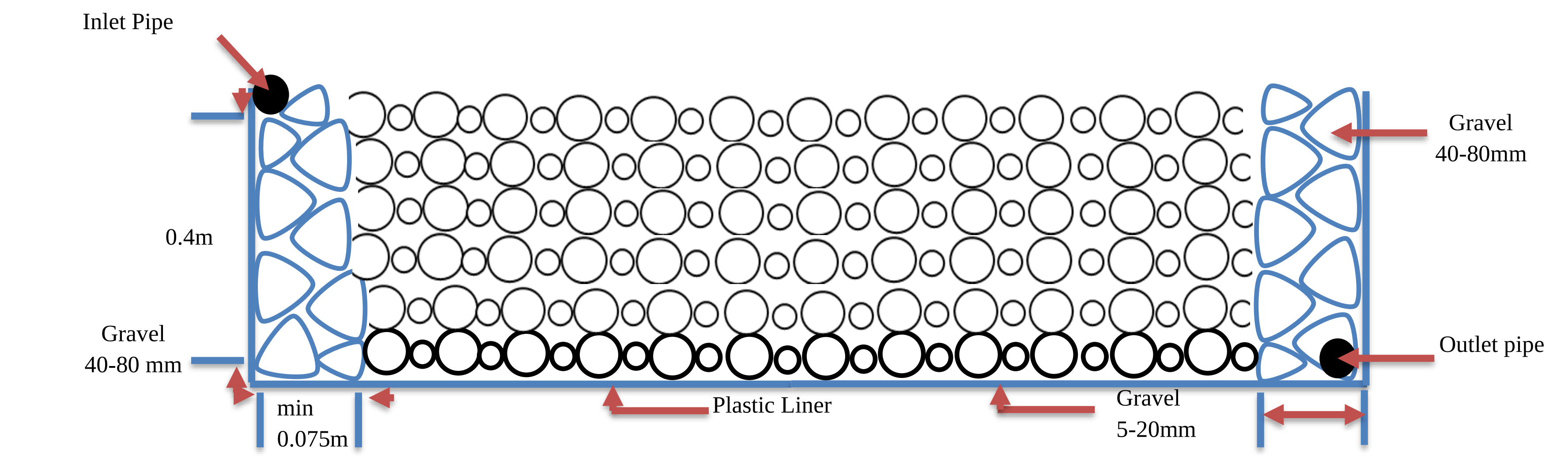

Figure 14: General view of media arrangement in HFCWs

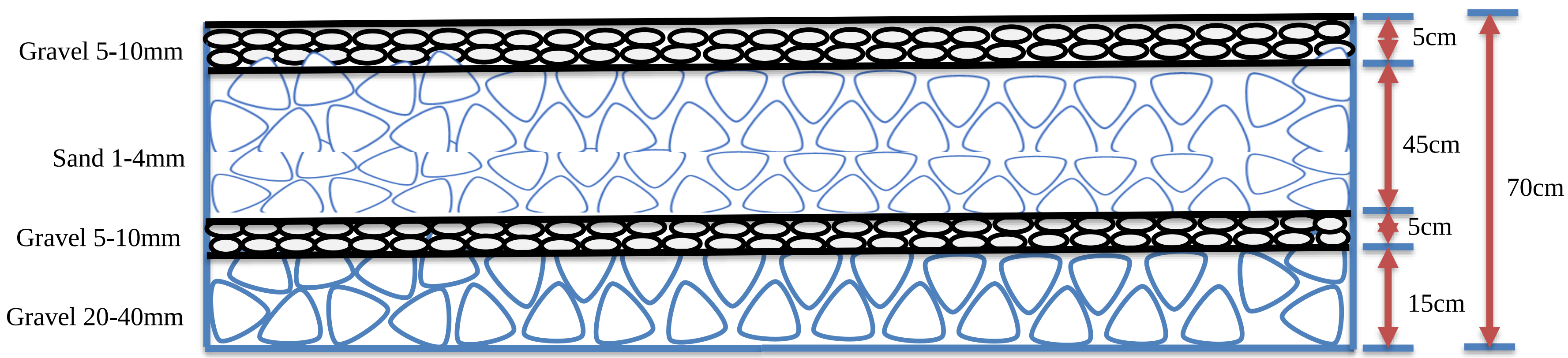

Figure 15: General view of media arrangement in VFCW

3.9.2 Inlet and Outlet Design

Inlet and outlet design in constructed wetlands is a critical aspect of the overall system design. Proper design of these components ensures efficient hydraulic flow, even distribution of wastewater, and optimal pollutant removal performance. Here are some considerations for inlet and outlet design in constructed wetlands:

1. **Distribution Structure:** An inlet distribution structure is used to evenly distribute the influent wastewater across the wetland surface. This can be achieved through various distribution methods, such as weirs, perforated pipes, or flow splitters.
2. **Influent Depth:** The depth of the influent flow should be carefully considered to avoid disturbance to the wetland bed. The influent depth is typically kept shallow (usually less than 30 cm) to prevent erosion and promote uniform flow distribution.
3. **Pre-Sedimentation:** In some cases, it may be beneficial to include a pre-sedimentation basin or settling chamber before the influent enters the wetland. This helps to remove larger solids and settleable particles, reducing potential clogging and enhancing overall treatment efficiency.
4. **Flow Regulation:** Flow regulators, such as adjustable weirs or gates, can be installed to control and adjust the flow rate entering the wetland. This helps maintain optimal hydraulic loading and prevents overloading the wetland during peak flow periods.
5. **Outlet Structure:** The outlet structure is used to collect and discharge treated effluent from the constructed wetland. It can consist of weirs, sluice gates, or submerged outlet pipes, depending on the design requirements.
6. **Effluent Depth:** Similar to the influent, the depth of the effluent flow should be considered to minimize turbulence and avoid erosion. Effluent depths are typically kept shallow to prevent scouring of the bed and maintain treatment efficiency.
7. **Flow Control at the outlet:** Flow control devices may be incorporated in the outlet structure to manage the discharge flow rate. This ensures that the hydraulic flow through the wetland is balanced and within the system's design capacity.
8. **Monitoring and Sampling:** Provision for monitoring and sampling points should be included in the outlet structure to assess the performance of the wetland regularly and ensure compliance with water quality standards.
9. **Vegetation Buffers:** In some cases, vegetation buffers may be established downstream of the wetland outlet to provide additional treatment and enhance the overall ecological benefits.

3.9.3 Liners

Liners may be required in CWs to prevent the seepage of wastewater into the surrounding soil and groundwater. The need for a liner will depend on various factors, including the type of soil, the depth of the water table, and the proximity of drinking water wells or other sensitive areas.

Here are some general considerations for the use of liners in CWs:

a) **Soil permeability**: If the soil at the site is highly permeable, a liner may be required to prevent wastewater seepage. A soil permeability test can be conducted to determine the need for a liner.
b) **Water table depth**: If the water table is shallow, a liner may be required to prevent groundwater contamination.
c) **Sensitive areas**: A liner may be required to prevent contamination if the CW is located near drinking water wells or other sensitive areas.
d) **Regulatory requirements**: The use of liners should be in accordance to local or state regulations.

On-site soils can be used if compacted to a permeability of <108 ft/sec (<10^{-6} cm/sec). Soils that contain more than 15% clay are generally suitable. Bentonite, as well as other clays, provide adsorption/reaction sites and contribute to alkalinity. Synthetic liners include asphalt, synthetic butyl rubber, and plastic membranes (0.5 to 10.0 mil high-density polyethylene). The liner must be strong, thick, and smooth to prevent root attachment or penetration. The liner should be covered with 3 — 4 inches of soil to prevent the roots of the vegetation from penetrating the liner.

If a liner is required, several types of liners can be used including:

- **Clay liner**: A layer of clay can be used as a liner. The clay should be compacted to prevent seepage.
- **Geotextile fabric**: A layer of geotextile fabric can be used as a liner. The fabric should be placed over a layer of sand or gravel to prevent punctures.
- **Synthetic liner**: A synthetic liner, such as HDPE and LDPE, can be used as a liner. The liner should be placed over a layer of sand or gravel to prevent punctures.

The choice of liner for a CW will depend on various factors, such as the site conditions, the type of wastewater being treated, and the regulatory requirements. Here are some considerations for choosing liners:

1. **Permeability:** The liner should have a low permeability to prevent wastewater seepage into the surrounding soil and groundwater. The permeability of the liner will depend on the material used and the thickness of the liner.
2. **Durability:** The liner should be durable and resistant to degradation, abrasion, and punctures. The liner should be able to withstand the weight of the substrate and plants without tearing or cracking.
3. **Chemical resistance:** If the treated wastewater contains chemicals or other contaminants, the liner should resist these substances to prevent degradation and failure.
4. **Regulatory requirements**: It is important to consult these regulations and ensure that the liner meets the requirements.
5. **Cost**: The cost of the liner will also be a factor in choosing a liner. Some materials may be more expensive than others but may provide better performance or longer life. Ultimately, the choice of the liner will depend on the specific requirements and

conditions of the CW project. It is important to follow regulatory requirements when selecting a liner. When choosing a liner for CWs, one of the most important factors to consider is the permeability of the liner material. The liner should have a low permeability to prevent the seepage of wastewater into the surrounding soil and groundwater. The permeability of the liner will depend on the material used and the thickness of the liner.

As a general guide, the following interpretations may be placed on values obtained for the *in-situ* coefficient of permeability:

$k>10^{-6}$ m/s	the soil is too permeable, and the wetlands must be lined
$k>10^{-7}$ m/s	some seepage may occur but not sufficiently to prevent the wetlands from having submerged condition
$k<10^{-8}$ m/s	the wetlands will seal naturally
$k<10^{-9}$ m/s	there is no risk of groundwater contamination (if $k>10^{-9}$ m/s and the groundwater is used for potable supplies).

3.10 Plant selection strategies

Wetland plants should be selected with water quality, people, and wildlife. Some plants thrive better than others in polluted water, and some prefer cleaner water. It often seems to be the case that the more colourful, flowering plants (such as Purple Loosestrife and Flowering-Rush) are less tolerant of pollution. In contrast, the hardier species (such as Common Reed and Sedge) tend to be less visually diverse. Non-native species should be avoided, with a focus placed on using suitable regionally or locally native plants. Hence, various plants have been used according to the Indian climatic conditions. Plants play a significant role in the removal of pollutants and in providing habitat to microorganisms. Hence selection of plants becomes crucial in the CWs system. Figure 16 illustrates the selection criteria to get the best available option.

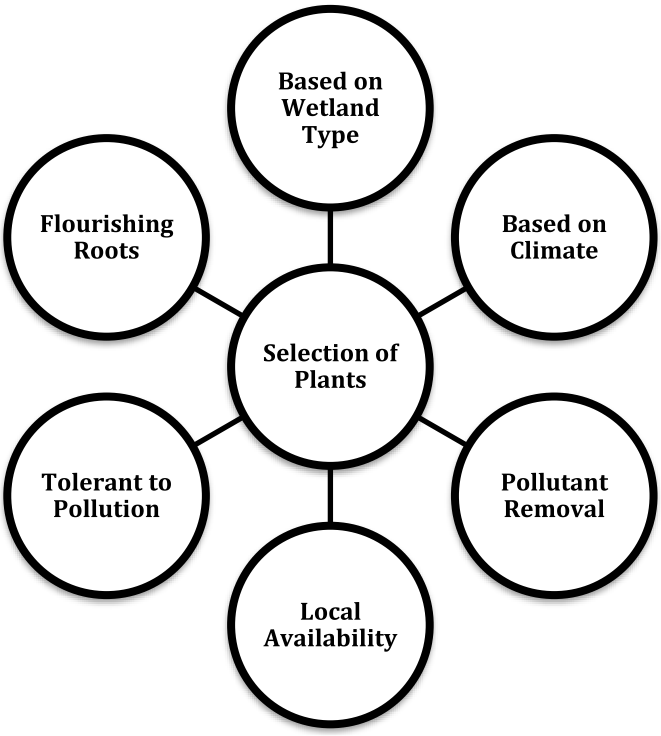

Figure 16: Factors to be considered for selection of plants for constructed wetlands

3.10.1 Type of Plants

The plants that thrive and flower in soil that is saturated for long periods can be considered wetland plants (Sainty and Beharrel, 1998).

The selection of plants for CWs is an important aspect of the design process, as they play a critical role in wastewater treatment. The following are some of the criteria to consider when selecting plants for CWs:

1. Tolerance to wet conditions: Wetland plants must tolerate waterlogged conditions without drowning or rotting. Plants that are adapted to growing in marshes or swamps are typically good candidates.
2. Tolerance to pollution: The plants should be able to tolerate the specific pollutants found in the wastewater being treated. For example, plants can tolerate high levels of nutrient load commonly present in wastewater.
3. Root structure: The plants' root structures are important as they provide surface area for the growth of microorganisms that help break down pollutants in the water. Plants with deep and fibrous roots are preferred, as they provide more surface area for microbial growth.
4. Growth rate: Fast-growing plants are typically preferred for CWs as they help to remove pollutants more quickly.
5. Aesthetic value: The aesthetic value of the plants should also be considered, especially if the constructed wetland is located in a public area.
6. Availability: The plants selected should be readily available and easy to propagate.

3.10.2 Climate-based Plant Selection

Generally, Macrophytes are used in CW treatments, including emergent, submerged, floating leaved, and free-floating plants. Although more than 150 macrophyte species have been used in CWs globally, only a limited number of these plant species are optimally planted in CWs in reality. CWs in cold climates can face challenges when they are fully covered with snow, which can impact their functioning and effectiveness. The presence of snow can reduce oxygen exchange, limit sunlight penetration, and cause freezing of wetland components. To address these challenges, various measures can be taken in cold climates. These include implementing snow management strategies to prevent excessive accumulation and ensure proper water flow, incorporating insulation and heating elements into the design to prevent freezing, selecting cold-tolerant plant species, conducting regular monitoring and maintenance even during winter months.

3.10.3 Selection of plants based as per Indian conditions

When selecting plants for CWs in India, it is important to consider the climate and environmental conditions specific to the region. However, it's important to note that the specific plant selection should be based on the local climate, water quality parameters, and the objectives of the CWs project. Additionally, it's crucial to ensure that the selected plant species are native or non-invasive to the local ecosystem to avoid potential negative impacts on biodiversity.

Here are some plant species suitable for CWs in different regions of India based on their respective climates Table 17.

Table 17: Some common plants for CWs in different regions of India

North India	South India	East India	West India	North East India
Canna Indica (Indian shot)	*Canna Indica (Indian shot)*	*Canna Indica (Indian shot)*	*Canna Indica (Indian shot)*	*Canna Indica (Indian shot)*
Typha angustifolia (Narrow Leaf Cattail)	*Typha angustifolia (Narrow Leaf Cattail)*	*Typha angustifolia (Narrow Leaf Cattail)*	*Typha angustifolia (Narrow Leaf Cattail)*	*Typha angustifolia (Narrow Leaf Cattail)*
Phragmites karka (Indian Reed)	*Typha latifolia (Broad Leaf Cattail)*	*Phragmites karka (Indian Reed)*	*Typhalatifolia (Broad Leaf Cattail)*	*Phragmites karka (Indian Reed)*
Scirpus spp. (Bulrush)	*Phragmites karka (Indian Reed)*	*Cyperus papyrus (Papyrus)*	*Phragmites karka (Indian Reed)*	*Cyperus papyrus (Papyrus)*

These plant species are generally well-adapted to the climate conditions in their respective regions of India. However, it’s important to consider the specific local conditions, such as temperature, rainfall, and soil experts or authorities, to ensure that the chosen plant species are suitable for the specific site and are not invasive or harmful to the local ecosystem composition when making plant selections for CWs.

Horizontal Flow CWs:

1. *Typha angustifolia* (Narrow Leaf Cattail): It has a moderate root length, making it suitable for horizontal flow systems. It provides good pollutant removal, includes space for microbes, and a habitat for wildlife.
2. *Phragmites australis* (Common Reed): This plant has extensive root systems that can enhance pollutant removal in HFCWs.
3. *Scirpus spp.* (Bulrush): Bulrushes have fibrous root systems that are effective in nutrient uptake and pollutant removal.
4. *Acorus calamus* (Sweet Flag): Sweet Flag has a shallow but dense root system, making it suitable for nutrient uptake in HFCW.

Vertical Flow CWs:

1. *Phragmites australis* (Common Reed): The extensive root system of Common Reed enhances pollutant removal in VFCWs.
2. *Typha latifolia* (Broadleaf Cattail): Broadleaf Cattail has long and dense roots, providing excellent nutrient uptake and pollutant removal in vertical flow systems.
3. *Iris pseudacorus* (Yellow Flag Iris): Yellow Flag Iris has long, fibrous roots that can effectively take up nutrients in VFCWs.

4. *Juncus spp.* (Rushes): Rushes have deep, dense root systems contributing to efficient pollutant removal in VFCWs.

Including a mix of plants with different root, lengths can create a diverse root zone, leading to improved filtration, sediment retention, and stabilization of the wetland substrate. However, it's important to consider the specific requirements of the CWs, such as water depth and nutrient levels, when selecting plants based on root length. Additionally, consider the compatibility of the chosen plant species with the local climate and ecosystem to ensure their successful establishment and long-term benefits.

3.10.4 How to Plant

Planting is usually done manually by hand. Some general method for planting in wetland has been given in Figure 17.

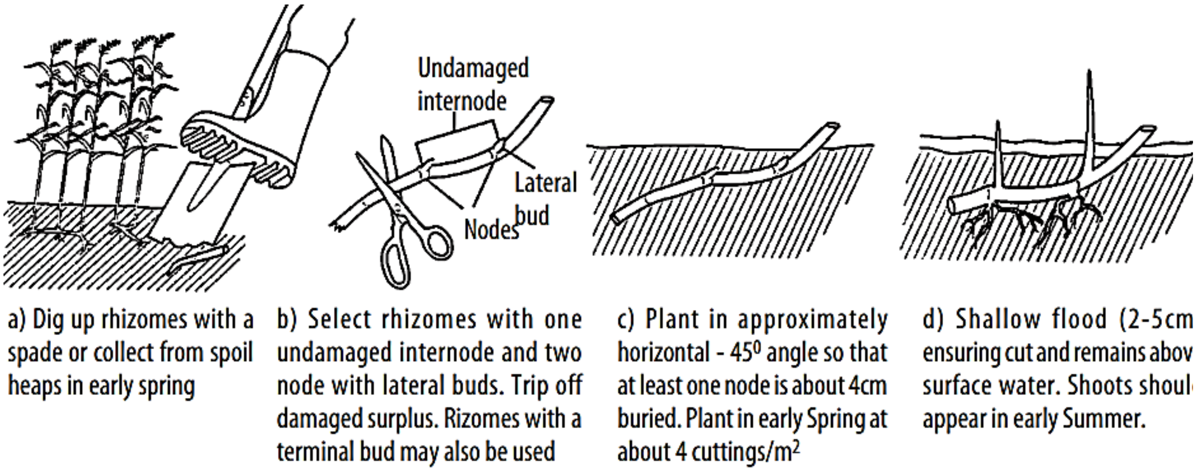

Figure 17: Technique for planting rhizome cuttings
(Source: Hawke and Jose, 1996)

- Most SSF wetlands are planted manually. Using individual root/rhizome material with growing shoots at least 8 inches (0.2 m) long is recommended.

  There are various planting options, including:

- Seeds – cheap but will take longest to establish
- Plug plants – cannot usually be planted directly into deep water
- Pot plants – suitable for marginal planting around the wetland edges
- Coir mats – semi-mature (typically 18-month-old) plants grown on coir matting can be relatively expensive, but they are very easy to install and, if planted near the start of the growing season, can establish a mature wetland within a few months.

The successful run of the CWs wetland depends on the plants, so it is mandatory to look after the plants. Here are a few things that have been observed during the survey that should be checked while designing CWs:

- Plant protection may be required in locations with existing wildfowl, o stray animal populations

- Fencing is often used to protect plants but can be hazardous to birds and other wildlife if not installed properly.
- Avoid the use of pesticides or chemicals around your wetlands.
- Plants should be periodically skimmed off, and remove decaying plant debris that may have accumulated.
- Full sun is recommended.

3.10.5 Recommendations for Maintaining Vegetation

For maintaining vegetation following is recommended:

- In SF wetlands, the water level is the most critical aspect of plant survival during the first year after planting. Water levels can be raised as the plants become well-established (2 — 3 months). Mechanical protection may be needed to prevent animals from damaging newly established plants.
- Plantings should be allowed to become well-established before the wastewater is introduced into the system since the plants need an opportunity to overcome the stress of planting before other stresses are introduced. The water must supply enough nutrients to support plant growth.
- The satisfactory establishment may take from several months to one or two full growing seasons.
- Water level management is key to maintaining wetland vegetation.
- Water quality also affects the health and survival of wetland plants. High nutrient loads, high or low pH, high dissolved solids concentrations, and buildup of heavy metals and other toxins can affect wetland vegetation.
- Harvesting or winter burning of above-ground. Biomass is sometimes used as a means of removing nitrogen and carbon and maintaining the wetland vegetation in a log (growth) phase of high physiological activity to enhance removal but may disrupt the wetland and the maturation of the plant community.

4 CW FOR UP-GRADATION OF EXISTING STPs

Integrating existing sewage treatment plants with CWs is an innovative approach combining conventional wastewater treatment methods with the natural purification capabilities of wetland ecosystems. This hybrid system can provide effective and sustainable wastewater treatment while offering additional benefits such as habitat creation, aesthetic improvement, and water conservation.

Many sewage treatment plants (STPs) in India are facing challenges due to receiving higher loads than their designed capacity. Rapid urbanization, population growth, and inadequate infrastructure planning have contributed to this issue. Integrating CWs with existing STPs can be a viable solution to address the increased load. Where CWs can serve as a supplementary treatment system to alleviate the load and improve treatment efficiency Table 18.

Table 18: Installation of CWs based on excess load

Name of STP	Capacity of existing STP	Average Flow	Excess load	Desired Water Quality	CWs Capacity Required

Steps for consideration for Integration of STPs and CWs

1. **Assessment of load and treatment requirements**: Conduct a comprehensive assessment of the increased load on the STP and determine the treatment requirements to achieve the desired effluent quality.
2. **Identify suitable locations for CWs**: Identify appropriate locations near the STP where CWs can be established. Factors such as available land, topography, soil conditions, and proximity to the existing infrastructure should be considered.
3. **Design and construction of CWs:** Develop a design plan for the CWs, considering parameters such as hydraulic retention time, dimensions, substrate composition, and appropriate wetland vegetation. Construction should follow engineering standards and environmental guidelines.
4. **Diversion of wastewater:** Modify the existing infrastructure to divert a portion of the wastewater flow from the overloaded STP to the CWs. This can be achieved through diversion structures, pumps, or gravity flow systems.
5. **Monitoring and optimization:** Regularly monitor the performance of the integrated system, including the STP and the CWs. Adjustments may be necessary to optimize the flow distribution, hydraulic conditions, and vegetation management for efficient treatment.
6. **Tertiary treatment and disinfection**: After passing through the CWs, the effluent is directed back to the STP for further treatment processes, including tertiary treatment and disinfection, to meet the required effluent quality standards.
   Integrating CWs with overloaded STPs can help relieve the excess load, enhance treatment capacity, and improve the overall performance of the wastewater treatment system. Ensuring proper planning, design, and monitoring is important to achieve optimal results. Even peak flow should be considered while designing Table 19.

Table 19: Installation of CWs based on Peak flow

Name of STP	Capacity of STP	Average Flow (MLD)	Peak Flow (MLD)	Non-peak Flow	Duration of Peak Flow	CWs Capacity Required to Handle Peak Flow

5 COST

The money and resources required to establish the CWs treatment system should be rigorously assessed. This includes equipment, people, and materials. An overview of the cost consideration is given in Table 20.

Table 20: Details of cost considerations for the development of constructed wetlands

Cost Considerations	Details
Design and Engineering	The initial design and engineering costs include site assessments, feasibility studies, hydrological analysis, and the development of detailed construction plans. These costs can vary based on the complexity and size of the CWs project
Land Acquisition	Acquiring suitable land for constructing the wetland can incur costs depending on the location and market prices
Construction Materials	The cost of construction materials such as gravel, sand, soil, and vegetation can contribute to the overall cost. The quantity and quality of materials needed depend on the project size and design specifications
Labor and Construction	The labor costs associated with the construction of the wetland, including excavation, installation of liners (if necessary), shaping the basins or channels, planting vegetation, and installing distribution systems, should be considered
Ancillary Infrastructure	Depending on the project requirements, additional infrastructure such as inlet and outlet structures, distribution pipes, monitoring equipment, and access roads may be necessary. These can contribute to the overall cost
Maintenance and Monitoring	CWs require ongoing maintenance and monitoring to ensure proper functioning. Costs can include vegetation management, sediment removal, periodic monitoring of water quality parameters, and repairs if needed
Operational Costs	Operational costs can include energy consumption for pumping systems, periodic testing and sampling, laboratory analysis, and administrative expenses related to compliance monitoring and reporting
Long-Term Costs	Consideration should be given to the long-term costs associated with the lifespan of the CWs, including potential replacement or rehabilitation expenses in the future

5.1 Land Cost

The capital costs of CWs are highly dependent on the costs of land. Financial decisions on treatment processes should not primarily be made on capital costs but also on net present value basis annual costs of operation and maintenance, interest and return on equity.

5.2 Cost Distribution

Costs typically include those for civil works, mechanical works, engineering designs and on-site supervision, start-up costs, and the cost of borrowings to provide for the working capital. In addition to these, there will usually be a number of local factors that increase the construction costs. The exception to this would be the substrate cost incurred in SSF wetlands. In the latter case, a 30–60 cm depth of gravel (porous substrate) typically fills the bed, whereas the medium for the FWS wetland usually consists of a 15 cm layer of top soil as growth media for the plants. Aside from the cost differentials caused by the substrate, the configuration of the wetland and the number of cells therein do affect the construction costs. For example, each cell would require its set of hydraulic control structures and liners (which extend up the dikes); obviously, additional sets of these will add to the cost. Basic cost considerations for the selection of CWs are given in the Table 21.

Table 21: Evaluating the cost-benefit analysis

Cost Considerations	**Selection of CWs based on Cost**				
	Preliminary/Primary treatment setup	**HFCWs**	**VFCWs**	**Hybrid**	**Others**
Design and Engineering					
Land Acquisition					
Construction Materials					
Labor and Construction					
Ancillary Infrastructure					
Maintenance and Monitoring					
Operational Costs					
Long-Term Costs					

5.2.1 Substrate Cost

The unit cost of these materials depends on the quality of the material, the volume needed, and the distance from the source to the wetland site. SSF wetlands require specific types of bed substrates. SSF bed substrates are the most expensive item in the construction of SSF wetland and may vary depending on site-specific conditions.

5.2.2 Plants and Planting Cost

There are many variables in calculating the total costs associated with the vegetation establishment phase of a wetland construction project. However, the following generalizations can be made:

- Large projects have a lower unit cost (cost/plant or cost/m^2) than small ones because of discounted materials costs and reduced mobilization costs.
- Projects having multiple goals (e.g., recreation and planting of commercial plant species) are generally more costly.
- Mechanized planting costs typically much less than planting by hand, particularly on large sites.
- Direct seeding is less expensive than transplanting from nurseries.

5.3 Possible cost reduction

Cost is an important factor while constructing CWs treatment facilities. But for the cost reduction, there should be valid consideration, and it should not compromise the overall effectiveness and long-term sustainability of the CWs. Following strategies could be taken into account to reduce the cost Table 22.

Table 22: Consideration for cost reduction

Strategies to reduce cost	Details
Site selection	Site with favorable characteristics may be selected that minimize the need for extensive earthwork or modifications.
Design optimization	Proper designing to optimize should be done for cost efficiency.
Utilize natural processes	Emphasize the use of natural ecological processes within the CWs, which could led to reliance on expensive engineered components.
Phased construction	Construction in phases may be undertaken to distribute costs over time and allow for better financial planning.
Selection of native plant	Native plant species selection could lead to being affordable, readily available, and well-adapted to local conditions.
Substrate selection	On-site soil or substrate could be used to reduce the need for purchasing new materials
Bulk purchasing	If required, purchase plants and substrates in bulk to take advantage of cost savings.
Involvement of volunteer	Engage volunteers or community groups to assist with planting and substrate preparation, reducing labor costs.
Proper management	Implement effective project management, reduce delays, and minimize labor costs.

6 Operation and Maintenance

Operation and maintenance can be classified in terms of start-up, routine, and long-term. There are important distinctions between these; start-up requirements will show more site-to-site variability, routine operations may be more affected by design details, and long-term operations reflect loading. In addition, thorough checkups should be done at least twice a year to effectively operate the wetland Table 23. The cost of entire O & M could depend on the frequency of monitoring and man power required.

Table 23: Key aspects of operation maintenance cost consideration

	Daily	Weekly	Quarterly	Monthly	Half yearly	Remarks
Primary components						
Septic tank					√	For primary treatment
Sludge height					√	More sludge height tends to the high TSS in wetland influent
Inlet pipe		√				
Inlet valve		√				
Effluent in flow rate	√					
Pumping	√					
Water sampling			√			Sampling duration depends upon economics. It could be done on daily bases too
Wetland components						
Vegetation		√				To see if any issue with plants health
Weeds		√				To ensure unhindered vegetative growth of wetland plants
Dead vegetation/biomass Removal			√			
Substrate				√		To know the clogging status
Nutrient level			√			If required to supply to ensure wetland plants growth
Hydrology			√			Flow rate, hydraulic loading rate etc.
Structures	√					Berm/walls to check if any erosion or damage occurred to take immediate action

	Daily	Weekly	Quarterly	Monthly	Half yearly	Remarks
Insects and animals		√				Presence of Burrowing animals and insects
Odor	√					To check if any anaerobic zone is created
Algae			√			
Soil		√				Texture, profile, nutritional composition, porosity etc.
Indicators		√				For the rapid, efficient and low-cost monitoring
Microbiology			√			Micro-flora management and study
Water sampling		√	√			Depends upon the hydraulic and contaminant loading rate
Efficiency and control components						
Alarm systems		√				
Plant efficiency		√				
Plant coverage		√				
Plant trimming			√			Note: Plant trimming is a visually guided practice, as different plants exhibit varying growth rates.

6.1.1 First-Year Maintenance Operations

Inspection and sampling of treated water during the initial phase after the establishing CWs I recommended as per Table 24.

Table 24: Inspection during the initial phase after the establishment

Steps	Time Frame	Remarks
Inspections	In 6 months and after every rainfall and storm for the initial two years	
Sampling	Weekly	
Watering	Initially, for one month	
Planting	Plants that are not grown should be replanted	

6.1.2 Maintenance Requirements

Maintenance requirements for constructed wetlands are essential to ensure their continued effectiveness and long-term performance. Regular maintenance is crucial for preventing clogging, maintaining proper hydraulic flow, and maximizing pollutant removal efficiency. The specific maintenance tasks will vary depending on the type of constructed wetland and its design, but here are some common maintenance activities for the CWs:

1. **Vegetation Management:** Regularly monitor and maintain the vegetation in the wetland to ensure it remains healthy and functional. This may involve pruning or trimming overgrown plants, removing dead vegetation, and replanting if necessary.
2. **Debris Removal:** Remove any debris or litter that accumulates in the wetland, as it can lead to clogging and hinder proper water flow.
3. **Inspection and Monitoring:** Regularly inspect the wetland to identify any signs of malfunction or issues. Monitor water levels, flow rates, and water quality parameters to assess the system's performance.
4. **Weed Control:** Control the growth of undesirable invasive plant species that can outcompete native wetland plants. Proper weed management helps maintain the wetland's ecological balance.
5. **Sediment Removal:** Periodically remove accumulated sediment from the bottom of the wetland to prevent clogging and maintain adequate water depth.
6. **Inlet and Outlet Maintenance:** Keep the inlet and outlet structures clear of obstructions to ensure proper flow distribution and discharge.
7. **Controlled Burning:** In some wetlands, controlled burning of dry vegetation may be necessary to maintain a healthy ecosystem and prevent excessive thatch buildup.
8. **Ponding Area Maintenance:** If the constructed wetland includes a ponding area, regularly inspect and maintain the pond liner or clay lining to prevent leakage.
9. **Water Level Management:** Adjust water levels as needed to optimize treatment performance and account for seasonal variations.
10. **Sampling and Analysis:** Periodically collect water samples for analysis to evaluate the wetland's pollutant removal efficiency and compliance with water quality standards.
11. **Infrastructure Inspection:** Check the condition of infrastructure components such as pipes, pumps, and valves to ensure proper functioning.
12. **Invasive Species Control:** Take measures to control and prevent the spread of invasive species that may disrupt the wetland ecosystem.

The frequency and extent of maintenance tasks may vary based on factors such as the size of the wetland, the influent characteristics, and the climate. Developing a well-documented maintenance plan is essential for efficient wetland management and to avoid potential issues that may arise due to neglect. Regular maintenance by trained personnel is vital to the sustained success of constructed wetlands as an eco-friendly and cost-effective wastewater treatment solution.

6.1.3 Substrate Management

Cleaning and reusing the substrate in CWs can be a beneficial approach to prolong its lifespan and ensure its continued efficiency. By following proper procedures, the substrate can be restored for reuse without the need for replacement.

- **Assessment of substrate**: Evaluate the condition of the substrate to determine if it is suitable for cleaning and reuse. Consider factors such as clogging, compaction, sediment accumulation, and overall treatment performance. In fact not all the substrate are suitable for the reuse and even for severely degraded or damaged, replacement may be necessary instead of cleaning.
- **Sediment Removal**: The accumulated sediments or organic matter from the substrate surface can be achieved manually through raking or by using equipment such as vacuum pumps or suction dredges.
- **Surface agitation:** Use of high-pressure water jets or mechanical agitation to dislodge and remove any remaining debris, biofilms, or clogging on the substrate surface. Ensure effective cleaning while avoiding excessive force that may harm the substrate.
- **Backwashing:** Reverse the flow of clean water through the substrate to flush out any particulate matter or clogging. Backwashing assists in removing finer materials that surface agitation may not dislodge easily.

6.1.4 Management of harvested plants

Managing harvested plants involves effectively handling and utilizing the plant material to maximize its value while minimizing waste. The harvested biomass can be used for soil amendment or fertilization or as livestock feed, offering a complementary approach to aquatic remediation, which could provide several ecosystem benefits. As aquatic plants are a reservoir of both energy and nutrients, after harvesting, they can be suitable candidates for application as feedstock in biogas plants, for production of both electric and thermal energy, as solid and liquid digestate.

- Soil Amendment and Composting: Harvested biomass can be used as a soil amendment to improve soil structure, water retention, and nutrient content. It adds organic matter, enhancing soil fertility and promoting beneficial microbial activity. The biomass can be composted or incorporated directly into the soil to release nutrients gradually over time.
- Livestock Feed: Depending on the composition and suitability of the harvested biomass, it can be used as feed for livestock. CWs plants can provide a source of nutrition for animals, serving as a supplement or primary feed source. However, it is important to ensure that the harvested biomass is safe and appropriate for the specific type of livestock being fed.
- Biogas Production: CWs biomass can be utilized as feedstock in biogas plants, where it undergoes anaerobic digestion to produce biogas. Biogas, primarily composed of methane, can be used as a renewable energy source for electricity generation or as a fuel for heating and cooking. The byproducts of anaerobic digestion, known as digestate, include solid and liquid forms, which can be used as organic fertilizers.

In order to ensure safe application of compost, the following specification for compost quality is given Table 25 of waste should meet the following criteria of MSW compost (MoEFCC, 1999)

Table 25: Specification for compost quality

Parameters	Maximum allowable value
Arsenic	10.00
Cadmium	5.00
Chromium	50.00
Copper	300.00
Lead	100.00
Mercury	0.15
Nickel	50.00
Zinc	1000.00
C/N Ratio	20-40
pH	5.5-8.5

Note* Concentration should not exceed (mg/kg dry basis, expect for pH value and C/N ratio)

7 POSSIBLE REUSE OF TREATED WATER

The NMCG 2022 National Framework on Safe Reuse of Treated Water and Ministry of Jal Shakti NATIONAL WATER POLICY (2012) provides comprehensive and detailed guidance on harnessing treated wastewater, a critical aspect of sustainable sewage treatment. This focuses on the effective utilization of treated water generated from sewage treatment processes, thereby contributing to water conservation and environmental protection. The framework National Water Policy covers various facets of treated water utilization, emphasizing responsible and safe practices for more details refer National Water Policy (2012) and National Framework on Safe Reuse of Treated Water (2022).

Using treated wastewater as an alternative water source has many benefits, but it's important to consider a few key things for it to work well. One of them is how much wastewater is available and how dependable its supply is. We need to make sure that the water, after being treated, is safe for both people and the environment. This is especially important if we plan to use it over a long period. We want to avoid any risks to health and the natural surroundings. In short, reusing wastewater is a great idea, but to make it work, we need to pay attention to how much wastewater we have and how safe the treated water is. This focus on quantity and quality will help us make the most of this alternative water resource while keeping everyone and everything protected.

7.1 Motivational Factors for Recycling/Reuse

The motivations for recycling and reusing water are diverse and compelling. As global water scarcity becomes increasingly pronounced, the imperative to maximize available water resources gains prominence. Recycling and reusing water emerge as pivotal strategies to address this challenge, allowing us to extract more value from every drop. By opting for these practices, we actively contribute to the conservation of vital natural water sources, such as rivers and groundwater, thereby promoting a sustainable approach to water management. Additionally, the environmental benefits of recycling water are evident in its potential to curtail the discharge of treated wastewater into delicate aquatic ecosystems, preserving their health and integrity.

The process of treating and transporting water demands energy, making the recycling of water an energy-conscious alternative that not only conserves resources but also contributes to a reduction in energy consumption and associated greenhouse gas emissions. From an economic standpoint, recycling and reusing water hold the promise of cost savings. For businesses and communities, these practices streamline water supply and treatment expenses, engendering more efficient operations.

In regions with stringent water scarcity or environmental regulations, water recycling becomes a pragmatic means of not only adhering to legal requirements but also embracing responsible resource utilization. As technology continues to advance, the feasibility and safety of water recycling are further bolstered by innovative water treatment methods, which pave the way for wider adoption and implementation.

7.2 Quality Issues of Wastewater Reuse/Recycling

Wastewater reuse/recycling introduces several critical quality issues that demand thorough consideration to ensure the protection of human health and the environment. Contaminant presence is a primary concern, encompassing a wide array of potential hazards such as pathogens, chemicals, heavy metals, and pharmaceutical residues. Effective treatment procedures are imperative to mitigate these risks and bring contaminants to safe levels for reuse.

Microbial pathogens, including bacteria and viruses, pose notable health threats if not adequately removed through disinfection processes. Additionally, the presence of chemical residues, like pharmaceuticals and industrial compounds, mandates advanced treatment methods to prevent their persistence in recycled water. Nutrient content, particularly elevated levels of nitrogen and phosphorus, can disrupt ecosystems through eutrophication, underscoring the importance of proper nutrient removal. Addressing high salinity and total dissolved solids (TDS) is crucial to prevent adverse effects on soil and vegetation in scenarios involving agricultural irrigation. Striking a balance between meeting regulatory standards and public acceptance requires transparent communication and robust treatment infrastructure.

Ultimately, effective management of these quality concerns is pivotal in realizing the full potential of wastewater reuse/recycling while upholding safety and environmental stewardship.

7.3 Designated reuse of treated sewage

The specific water quality standards are often what determine the designated use of treated water from artificial wetlands. Following are some typical applications for treated water:

- **Non-potable reuse**: Reusing treated water for non-potable purposes such as irrigation, industrial processes, firefighting, dust control, or toilet flushing some of the option. These applications do not require treated water to meet drinking water standards but still require certain quality criteria to safeguard human health and the environment.
- **Environmental discharge**: The treated water may be released into receiving bodies of water, such as rivers, lakes, or coastal areas, if it satisfies certain water quality standards. This designated use helps to support aquatic life, preserve the ecological balance, and maintain ecosystem health.
- **Groundwater recharge:** To replenish aquifers in areas where groundwater resources are crucial, treated water can be injected beneath the surface. To protect the groundwater and guarantee its appropriateness for future extraction, water must meet a water quality standard to prevent contamination.
- **Agricultural reuse:** Treated water may be used for agricultural purposes, including irrigation of crops, horticulture, or aquaculture. To safeguard soil quality, crop health, and food safety during this specified usage, strict water quality regulations must be maintained.
- **Industrial reuse**: Industries that need non-potable water, including cooling towers, production operations, or industrial cleaning, may use treated water. In order to be suitable for the particular industrial application, the water must meet certain water quality standards.
- **Recreational uses**: Treated water may be used for recreational purposes like lake or pond filling, creating opportunities for activities like boating, fishing, or swimming

8 ESSENTIAL FOR DETECTING CHANGES AND MITIGATING RISKS

The wetland should be checked periodically to observe general site conditions and to detect major adverse changes, such as erosion or growth of undesirable vegetation. Vegetation should be regularly monitored to assess its health and abundance. More frequent monitoring is also required during the first five years after the wetland is installed. Species composition and plant density are easily determined by inspecting quadrats (square plots, usually 3 ft x 3 ft) within the wetland at selected locations. A lightweight, open frame of wood or PVC pipe is laid on the wetland, and the number of stems of each species present within the frame is counted. Changes of concern include an increase in the number of aggressive nuisance species, a decrease in the density of the vegetative cover, or signs of disease. Some species may have a tendency to die out and be replaced by others.

8.1 Evaluation of Performance

The effectiveness of contaminant removal can be determined from the difference between influent loads (inflow volume x contaminant concentration) and effluent loads (discharge volume x contaminant concentration). The parameters of concern may include:

- **Domestic wastewater**: BOD, nitrogen, phosphorus, total suspended solids, heavy metals, bacteria (total or fecal coliform).
- **Agricultural wastewater**: BOD, nitrogen, phosphorus, total suspended solids, pesticides, bacteria (total or fecal coliform).
- **Mine drainage:** pH, iron, manganese, aluminum, total suspended solids, sulfate.
- **Storm-water:** total suspended solids, nitrogen, phosphorus, heavy metals, vehicle emission residues

Surface water sampling stations should be located at accessible points at the inlet and outlet and, depending on the size and complexity of the system, at points along the flow path within the wetland. Surface water quality stations should be permanently marked. The effluent should be sampled during high storms, and spring runoff flows to ensure that sediments are retained in the wetland. Groundwater should also be monitored once or twice a year to ensure that the wetland is not contaminating groundwater.

The wetland is usually measured by determining:

- Hydraulic loading rates
- Inflow and outflow volumes
- Water quality changes between inflow and outflow
- Excursions from normal operating conditions.

8.2 Quality Assurance, Quality Control, and Quality Assessment Measures

Quality assurance/quality control measures are essential to meet the desired objectives and performance criteria of the CWs system Table 26. It provides precision (how much the treatment results are reproducible). Quality Assurance generally refers to a broad plan for maintaining quality in all aspects of a CWs treatment facility. This plan should describe how you will undertake your monitoring effort Figure.18.

Table 26: Details on quality assurance of the CWs

Quality Assurance	Steps
Pre-construction planning	Define the objectives and goals of the CWs project
	Conduct a site assessment to determine the feasibility and suitability of the site
	Develop design criteria and performance standards based on the project goals and regulatory requirements
Design phase	Prepare detailed engineering designs, including hydrological, hydraulic, and structural consideration
	Conduct a comprehensive review of the design to ensure compliance with the established criteria and standards
	Obtain necessary permits and approvals from regulatory authorities
Construction phase	Implement a quality control plan to monitor the construction activities
	Ensure that construction materials meet the required specifications
	Conduct regular inspections to verify that construction is progressing according to the design plans and specifications
	Address any issues or deviations promptly and document corrective actions taken.
Commissioning and testing	Perform functional testing of key components, such as inlet and outlet structures, distribution systems, and media or substrate layers
	Conduct hydraulic and water quality tests to verify that the wetland functions as intended
	Monitor the wetland performance during the establishment period to identify any operational issues or design deficiencies
Operation and maintenance	Develop an operation and maintenance plan to ensure the ongoing performance and longevity of the CWs
	Implement regular monitoring protocols for water quality, vegetation health, and hydraulic performance
	Conduct routine maintenance activities, such as vegetation management, sediment removal, and infrastructure inspections
	Keep detailed records of maintenance activities and any modifications or repairs made to the wetland
Performance evaluation	Periodically assess the wetland's performance against the established objectives and performance criteria
	Analyze monitoring data to identify any trends or deviations from expected outcomes
	Implement corrective actions or modifications as needed to optimize performance
Compliance and reporting	Ensure compliance with relevant regulatory requirements and permit conditions
	Prepare periodic reports documenting the wetland's performance, monitoring results, and any remedial actions taken
	Communicate the findings and outcomes to stakeholders, regulatory agencies, and the public as necessary

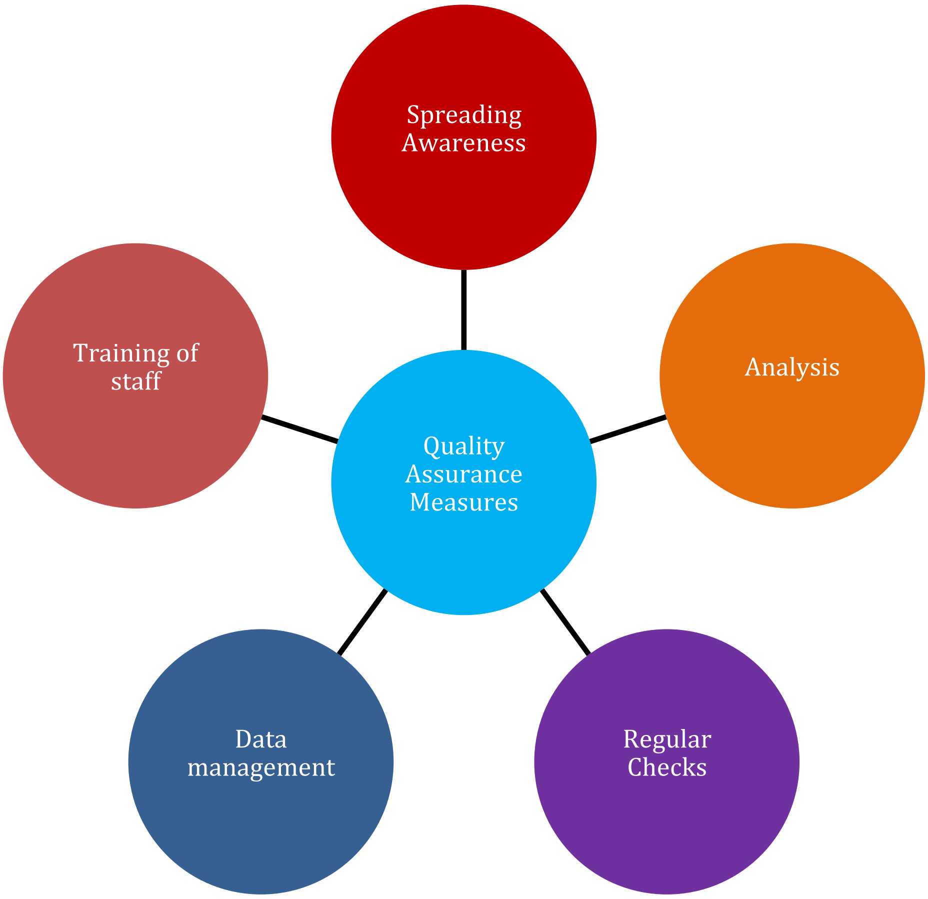

Figure 18: Basic quality assurance measures

After you've run the analyses, quality assessment is your assessment of the overall precision and accuracy of your data.

8.3 Steps to Quality Control

Following steps are recommended for quality control

1. Consult technical committee and/or advisor to help determine quality assurance/quality control measures to meet desired water quality requirements
2. Locate a quality control lab—an independent lab or tie-up with an external Institution.
3. Determine which quality checks one has the resources and capabilities to carry out.

9 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

One of the most common applications of CWs has been the treatment of primary or secondary domestic sewage effluent. A large number of wetlands have been constructed to treat drainage has been active across all across India. CWs are not commonly recommended for in-situ treatment of water. Their primary purpose is to mimic the natural wetland processes, and they are generally implemented in controlled settings rather than directly within contaminated water sites. For instance, in wastewater treatment, the wastewater is first collected at a centralized location and then channeled to the preliminary, primary, and secondary treatment stages, where CWs are integrated as part of the overall treatment process. This allows for more effective and controlled water purification while ensuring optimal performance of the CWs.

According to the survey, the design and operational circumstances are suitable for wastewater treatment. The focus is on maximization of efficiency, cost minimization, ecological sanitation, and water reuse. Key features of the survey report are listed below:

1) The treatment facility at AMU has been functioning very well from primary to tertiary treatment, providing water for multiple uses.
2) The time frame of the established wetlands and their monitoring is approximately 2 to 5 years, which gives an idea that wetlands are good enough to treat wastewater in the long run. However, still, it will be too early to conclude anything.
3) The major advantage of the wetlands is that they could even be established in a small space example, Sati Nagar wetland.
4) The wastewater must be treated sufficiently high for public health standards. A filtration and disinfection process will usually be required before the water for multiple uses of water.
5) Advancements in technologies is still required to address the problems such as foam formation, pathogens removal, etc.
6) The total area required for wastewater treatment depends on distinct parameters such as the unit’s capacity, primary treatment, secondary treatment process, total wetlands units, tertiary treatment, and storage area.
7) The structure recognized with minimum requirements should incorporate a minimum of three general compartments. The first zone is screening and sedimentation. Second zone, secondary treatment process as required, and space CWs could be constructed. Third storage and discharge unit.

9.2 Recommendations

Maintenance of CWs, based on the condition and performance of the wetland, is followed as;

- Inspect and remove rubbish and debris from inlets
- Check the area around the inlet, especially energy dissipation (rip rap) structures, for erosion and cracking, and if present, repair.
- Assuring that flows reach all parts of the wetland.

- Inspect and clear all litter, including leaves, rubbish, branches, and any other material that would block flows.
- Check racks for corrosion and replace if necessary.
- Maintaining a healthy environment for microbes
- Check the forebay for accumulated sediment. The forebay should be generally dredged if sediment fills over 50% of the design volume.
- Maintaining a vigorous growth of vegetation.
- Control structures could be overgrown with vegetation.
- A wastewater application schedule should be selected that is both convenient and relatively continuous. Short, high-flow discharges to a wetland are more likely to erode or damage established vegetation than lower velocity, more continuous flows.
- Inspect control structures, weirs, orifices, and outfall pipes for leaks and blockages. The blockage could be sediment build up, floating debris, or rubbish.
- Clear and remove all blockages to avoid local flooding. Areas around the control structure need to be clear of vegetation and rubbish to maintain storm water flow. A boat may be required to access the outlet.
- Remove any blockages to ensure the emergency overflow path remains clear of debris and blockages. Check flow path for erosion and repair as necessary. Structural repairs must be repaired immediately to avoid catastrophic failure.
- Scheduling discharges to or from the wetland, recycling/redirecting flows, or rotating between cells, if such, are part of the design.

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Appendix – I: Case Studies

<u>Case Study 1: Sewage & Wastewater at the Heartfulness World HQ, Kanha Village for SMSF & SKGL:</u>

A mega integrated township with residences, kitchens, canteens, training halls, huge congregation facilities, mega toilet blocks etc with a challenging scenario of hosting 50,000+ at times and scaling down to 20,000 or 10,000 or just residents who are in fewer thousands. The system receives varying volumes of wastewater ranging from 200 KLD to 2,400 KLD.

BlueDrop has demonstrated phenomenal success in setting up the Aerated Wetlands in a span of 60 calendar days to meet a huge worldwide congregation deadline. The Aerated Wetland System performed the work like a breeze delivering absolute clear water meeting the PCB norms. System was commissioned on January 27, 2020.

Design Capacity: 2.40 MLD
Type of water: Domestic (Apartments, Kitchen, Canteen, Group Toilet blocks)
Address: SMSF/SKGL, 13-110 Kanha Village, Ranga Reddy dist, Telangana - 509325

Treatment units:

- Manual Bar Screen chamber (10mm & 6 mm screens)
- Wet-well (400 KLD)
- Holding tank 1 (1600 KLD Newly built)
- Holding tank 2 (600 KLD pre-existing tank, repurposed)
- Aerated Wetland Cells: 2 Nos;1000 SQM Each
- Treated water collection sump

PARAMETERS	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	Sulphate (mg/L)	Chloride (mg/L)	TDS (mg/L)	pH
Inlet	187.70	232.50	133.00	165	185	1248	6.30
Treated	<5.00	21.25	10.00	83.5	171.48	906.00	7.76

Table CS3-1: Sewage & Wastewater at the Heartfulness World HQ, Kanha Village for SMSF & SKGL:

Information CWs	Description
Location of CW	Kanha Santhi Vanam Kanha Village, Hyderabad
Geographical Coordinates	17°10'46.19"N 78°13'39.31"E
Source of Wastewater	Apartments, Kitchen, Canteen, Group Toilet blocks
Type of Wastewater	Domestic wastewater
Primary Treatment	Holding tank
Type of Constructed Wetland	Aerated Constructed Wetland
Tertiary Treatment	No
Vegetation Type	*Canna indica*
Substrate Used	Coarse gravel media
Year of Operation Started	2020
Area	2 Nos;1000 SQM Each

Capacity	2.40 MLD
Capital cost Rs.	25,000,000
Uses of Harvested Plants Biomass	No
Uses of Treated Water	Treated water collection sump
Designed and Constructed By	BlueDrop Pvt. Ltd.

Figure: Actual pictures of the established CWs

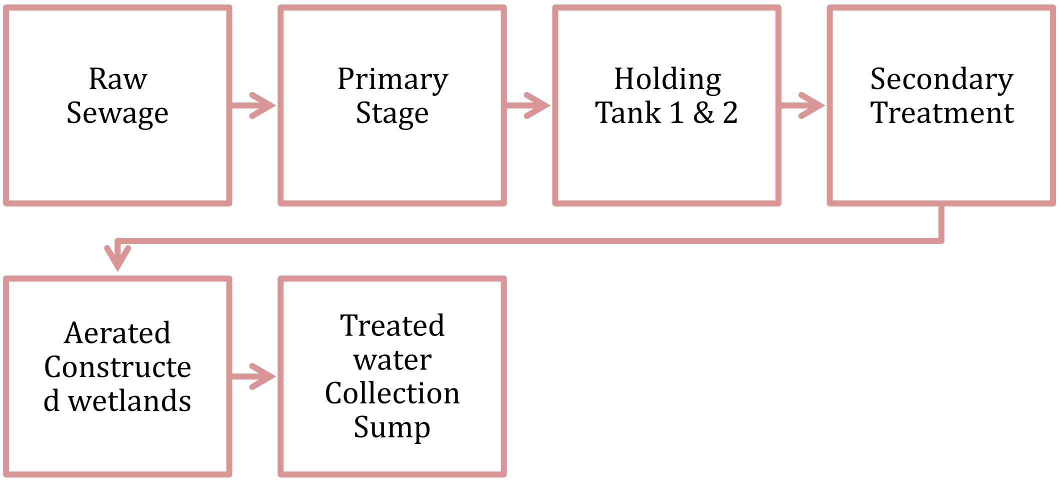


Figure: Process flow diagram

Case Study – 2: NCD Vivanta Central Court (150 KLD): ***Commissioned December 2021***

A luxury apartment community at Mokilla. The Developer having seen the complex and struggle some conventional systems in various residential apartment communities have come to a conclusion to adopt a better and environment friendly technology. BlueDrop Enviro Pvt Ltd has utilized part of their garden areas to create the Aerated Wetlands and have commissioned the system in late 2021. System has been working steadily with low maintenance and high aesthetics with zero odour. Residents enjoy being around this people friendly STP.

Design Capacity: 150 KLD
Type of water: Domestic Wastewater
Designed and constructed by: BlueDrop Enviro Pvt. Ltd.
Address: Mokila near Sankarapally

Treatment units:

- Manual Bar Screen chamber (10mm screen)
- 3 chamber Holding tank (150 KLD)
- Wetland cells 2 each 75 SQM
- Treated Water Collection Sump (2 partitions)
- Tertiary treatment (Ozonator)

PARAMETERS	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	Sulphate (mg/L)	Chloride (mg/L)	O&G (mg/L)	pH
Inlet	178	273	125	85	156	12	6.5
Treated	<10	<10	<10	<15	130	<5	7.5

Table CS3-1: NCD Vivanta Central Court (150 KLD)

Information CWs	Description
Location of CW	NCD Vivanta Central Court
Geographical Coordinates	17°43’13.00"N 78°19’64.52"E
Source of Wastewater	Communities Wastewater
Type of Wastewater	Domestic Wastewater
Primary Treatment	Holding tank
Type of Constructed Wetland	Aerated Constructed Wetlands
Tertiary Treatment	Ozonator
Vegetation Type	*Canna indica*
Substrate Used	Coarse gravel media
Year of Operation Started	2021
Area	Wetland cells 2 each 75 SQM
Capacity	150 KLD
Capital cost Rs.	3,000,000
Uses of Harvested Plants Biomass	No
Uses of Treated Water	Treated Water Collection Sump
Designed and Constructed By	BlueDrop Enviro Pvt. Ltd.

Figure: Actual Picture of Constructed Wetlands

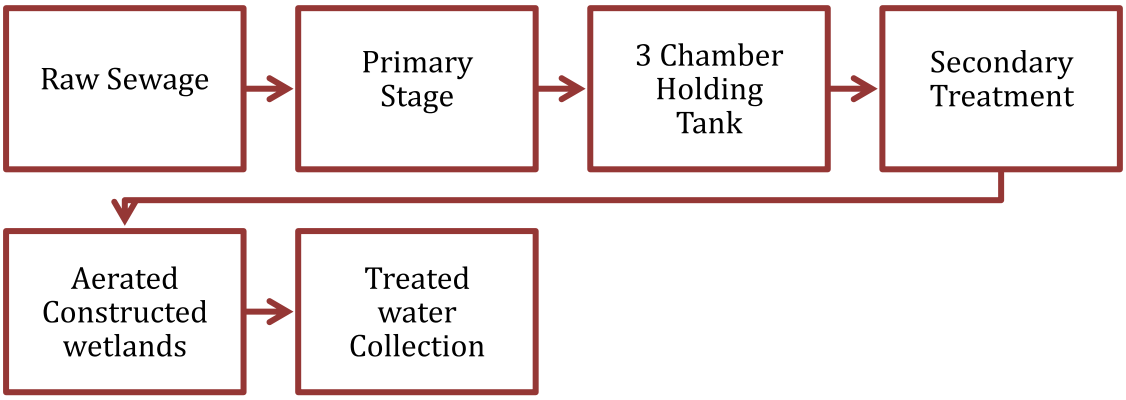


Figure: Process flow diagram

Case Study – 3: Sewage Wastewater at Hyderabad for NISA, Hakimpet:

An institutional residential set up which has a defunct Sewage Treatment Plant wanted to set up a new system. The treated water is the only source they have to water their lush green lawns of their Golf Course. BlueDrop proposed extremely optimized solution utilizing their existing tanks etc. and just adding two Aerated Wetlands.

BlueDrop demonstrated a great success with the setting up all new Aerated Wetlands system within 60 working days and has taken care of the golf course needs through the hot summer. System was commissioned on March 15, 2020.

Treatment units:

- Manual Bar Screen chamber (10mm & 6 mm screens)
- Wet-well (30 KLD)
- Holding tanks -2 No each (150 KLD pre-existing tanks, repurposed)
- Aerated Wetlands Cells: 2 Nos each 100 SQM
- Treated water collection sump

PARAMETERS	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	Sulphate (mg/L)	Chloride (mg/L)	O&G (mg/L)	pH
Inlet	186	281	48	75	147	8	7.12
Treated	8	47	12	53	126	<5	7.34

Table CS3-1: Sewage Wastewater at Hyderabad for NISA, Hakimpet

Information CWs	Description
Location of CW	NISA, Hakimpet
Geographical Coordinates	17°32'36.51"N 78°32'28.22"E
Source of Wastewater	Institutional residential
Type of Wastewater	Domestic Wastewater
Primary Treatment	Holding tanks
Type of Constructed Wetland	Aerated Wetlands
Tertiary Treatment	No
Vegetation Type	*Canna indica*
Substrate Used	Coarse gravel media
Year of Operation Started	2020
Area	2 Nos each 100 SQM
Capacity	150 KLD
Capital cost Rs.	5,600,000
Uses of Harvested Plants Biomass	No
Uses of Treated Water	Treated water collection sump
Designed and Constructed By	BlueDrop Enviro Pvt. Ltd.

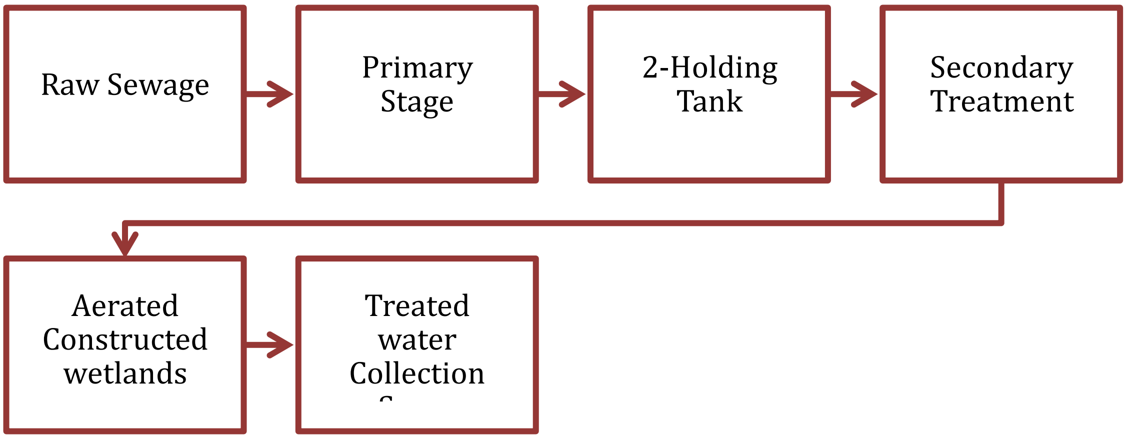


Figure: Process flow diagram

Figure: Actual Picture of Constructed Wetlands

Case Study – 4: NIH Colony, Roorkee, Uttarakhand:

The NIH Roorkee CW project serves as a promising model for sewage treatment in residential areas. Its cost-effective capital investment of Rs. 20 lakhs for a 0.04 MLD capacity and an area of 300m^2 highlights the feasibility and affordability of such treatment systems. The project's positive environmental impact and efficient pollutant removal demonstrate the potential of CWs as a sustainable and ecologically friendly solution for sewage treatment. The CW at NIH Colony, Roorkee, Uttarakhand, has demonstrated remarkable success in treating residential sewage using horizontal flow CWs with *Canna indica* vegetation and graded gravel media as substrate. Since its operation began in 2021, the CW has consistently shown effective pollutant removal. The treatment efficiency is evident from the significant reduction in various water quality parameters, such as COD (91.66%), Ammonia (94.31%), BOD (90.90%), and TSS (74.80%). Moreover, the CW has effectively improved the pH and DO levels of the treated water. The success of this site is further enhanced by the use of the harvested plant biomass, which is utilized for composting purpose. Additionally, the treated water is employed for irrigation in green areas, contributing to sustainable water reuse and environmental conservation.

Treatment units:

- Septic Tank
- Horizontal Flow CWs
- Treated water collection

PARAMETERS	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	Sulphate (mg/L)	Chloride (mg/L)	O&G (mg/L)	pH
Inlet	110	360	36.12	NA	NA	NA	7.49
Treated	10	30	9.1	NA	NA	NA	7.68

Table CS4-1: Details of the CW based STP at NIH colony Roorkee, Uttarakhand

Information CWs	Description
Location of CW	Barampur village, NIH Colony Roorkee, Uttarakhand
Geographical Coordinates	29°53'08.9"N 77°55'38.2"E
Source of Wastewater	Residential
Type of Wastewater	Sewage
Primary Treatment	Septic Tank
Type of Constructed Wetland	Horizontal Flow CWs
Vegetation Type	*Canna indica*
Substrate Used	Graded Gravel Media
Year of Operation Started	2021
Area	300m^2
Capacity	0.04 MLD
Capital cost Rs.	20 lakhs
Uses of Harvested Plants Biomass	Composting
Uses of Treated Water	Green area irrigation
Designed and Constructed By	NIH Roorkee

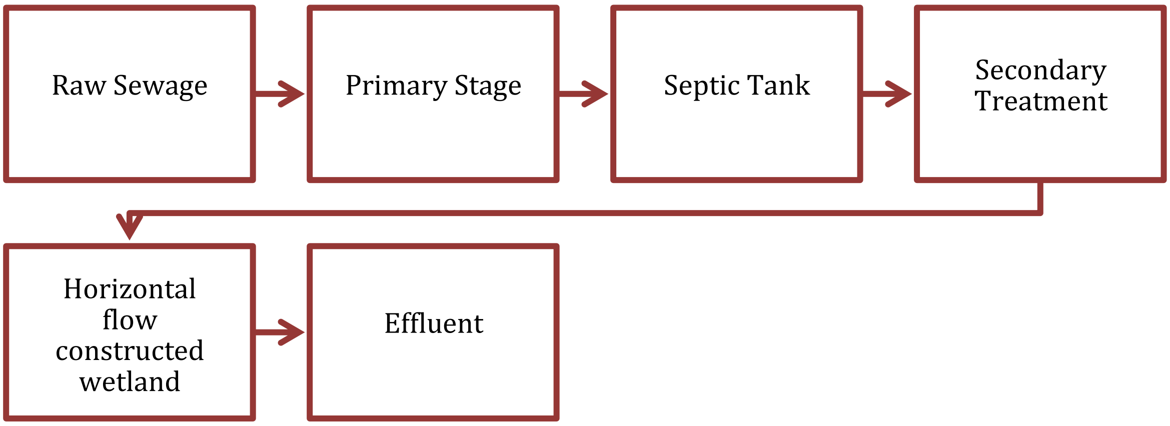
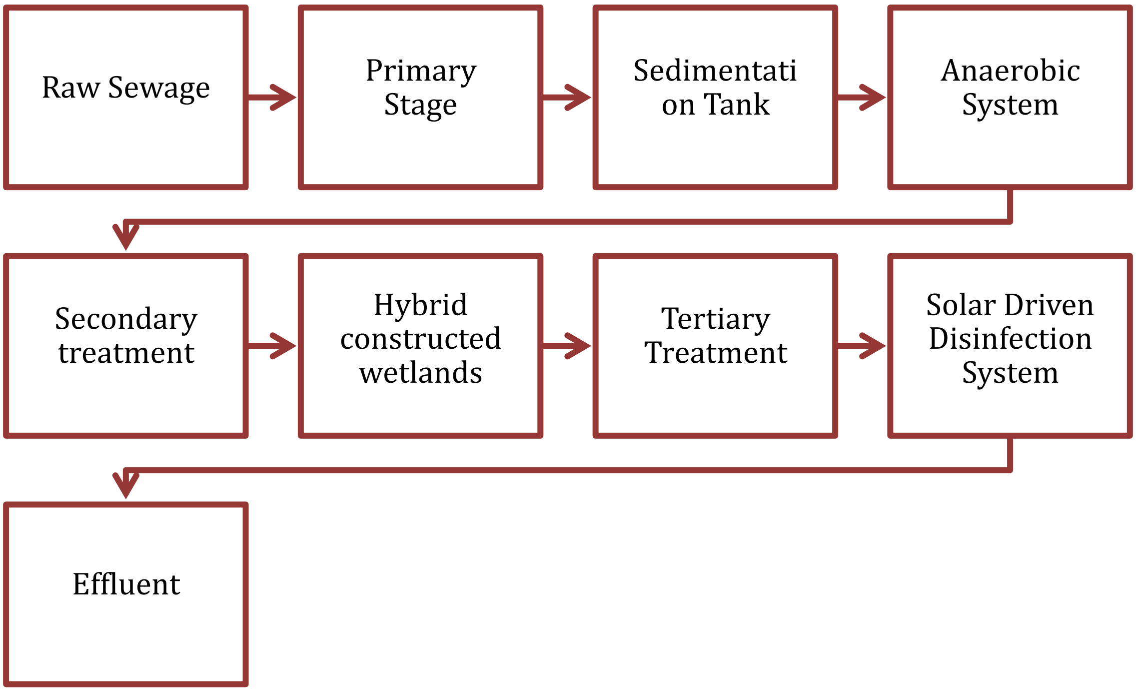


Figure: Actual view of the CWs at NIH Roorkee

Case Study – 5: Aligarh Muslim University (AMU)

The CWs at Aligarh Muslim University (AMU), Uttar Pradesh, stand as a shining example of effective and sustainable sewage treatment. The CW system, designed and constructed by AMU in 2017, utilizes a hybrid approach with Vertical Flow CW and Horizontal Flow CW, along with Upflow Anaerobic Sludge Blanket for primary treatment and Solar Driven UV Disinfection for tertiary treatment. This integrated approach ensures efficient pollutant removal and water purification. AMU's CW system effectively removes various water quality parameters, with remarkable removal rates of 93.58% for TSS, 99.31% for BOD, 85.77% for COD, and complete removal of ammonia. The CWs have significantly improved the pH and DO levels of the treated water, meeting high-quality standards. Furthermore, the treated water finds valuable application in green area irrigation, enhancing the campus environment and conserving water resources. AMU's CW project serves as a model for other institutions and municipalities, demonstrating the potential for sustainable sewage treatment solutions. The integration of natural treatment processes with advanced technologies like UV disinfection showcases the versatility and adaptability of CWs.



PARAMETERS	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	Sulphate (mg/L)	Chloride (mg/L)	O&G (mg/L)	pH
Inlet	98	487	326	NA	NA	NA	7.19
Treated	0.00	2	7	NA	NA	NA	7.11

Table CS5-1: Details of the CW based STP at AMU Aligarh, Uttar Pradesh

Information CWs	**Description**
Location of CW	AMU Aligarh, Uttar Pradesh
Geographical Coordinates	27.921463, 78.065309
Source of Wastewater	Institutional

Type of Wastewater	Sewage
Primary Treatment	Upflow Anaerobic Sludge Blanket
Type of Constructed Wetland	Hybrid CWs (VF CW and HF CW)
Tertiary Treatment	Solar Driven UV Disinfection
Vegetation Type	*Phargmites australis and Canna indica*
Substrate Used	Graded Gravel Media
Year of Operation Started	2017
Area	-
Capacity	1 MLD
Capital cost Rs.	-
Uses of Harvested Plants Biomass	-
Uses of Treated Water	Green area irrigation
Designed and Constructed By	AMU

Figure: Actual view of the CWs at AMU

Case Study -6: CW at Dharamsala Near bus stand, Himachal Pradesh

The Hybrid CW near the bus stand in Dharamsala, Himachal Pradesh, is a testament to effective community sewage treatment with a sustainable approach. Designed and constructed by Rebound Enviro Tech Pvt Ltd in 2018, this CW system utilizes a combination of natural and Multi Baffle Anaerobic Reactor.The CWs with an area of 500m^2 and with a capacity of 0.2 MLD, the CW efficiently treats sewage sourced from the community. The capital cost of Rs. 80 Lakh showcases the economic feasibility of implementing nature-based treatment solutions.

The CW employs *Canna indica* vegetation and graded gravel media as substrates, enabling the effective removal of pollutants. The system has proven highly efficient in treating wastewater, achieving remarkable removal rates of 96.66% for TSS, 96% for BOD, 88.88% for COD, and 95.96% for ammonia. Moreover, it successfully maintains the pH and DO levels within acceptable ranges, ensuring water quality compliance.

The harvested plant biomass finds a valuable purpose in composting, contributing to waste reduction and resource recovery. Furthermore, the treated water is safely discharged into water bodies, minimizing environmental impact and preserving local ecosystems.

Dharamsala's CW project serves as a sustainable sewage treatment model for communities, inspiring other regions to adopt similar environmentally friendly solutions.

PARAMETERS	**BOD** (mg/L)	**COD** (mg/L)	**TSS** (mg/L)	**Sulphate** (mg/L)	**Chloride** (mg/L)	**O&G** (mg/L)	**pH**
Inlet	140	490	491	NA	NA	NA	7.59
Treated	14	44	17	NA	NA	NA	7.41

Table CS6-1: Details of the CW based STP at Dharamsala Near bus stand, Himachal Pradesh

Information CWs	**Description**
Location of CW	Dharamsala Near bus stand, Himachal Pradesh
Geographical Coordinates	32°13'05.6"N 76°19'02.3"E
Source of Wastewater	Community
Type of Wastewater	Sewage
Primary Treatment	Multi Baffle Anaerobic Reactor
Type of Constructed Wetland	Hybrid CWs
Vegetation Type	*Canna indica*
Substrate Used	Graded Gravel Media
Year of Operation Started	2018
Area	500m^2
Capacity	0.2MLD
Capital cost Rs.	80 Lakh
Uses of Harvested Plants Biomass	Compositing
Uses of Treated Water	Discharge into water bodies

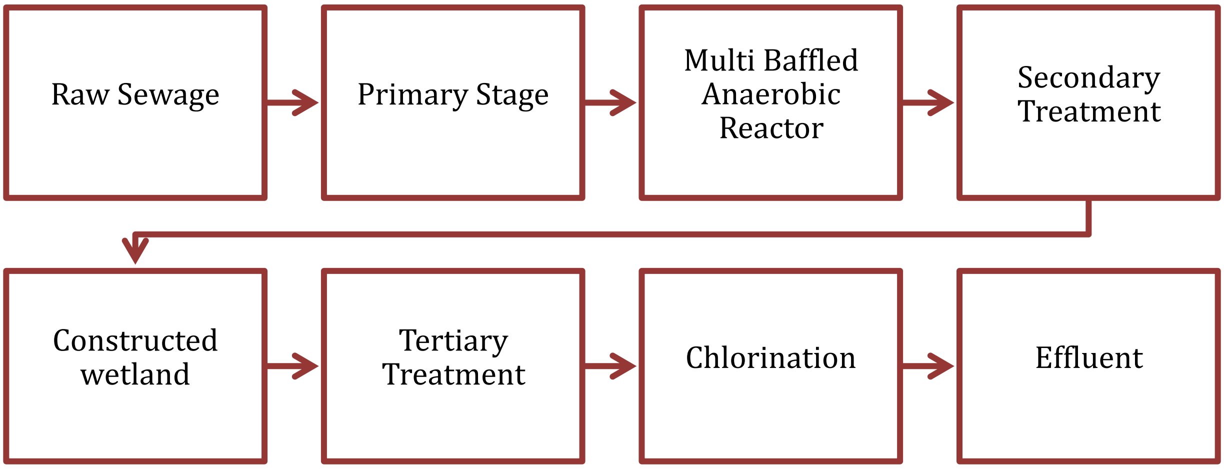


Figure: Actual view of the CWs at Dharamsala Near bus stand, Himachal Pradesh

Appendix –II: Data Collection for Constructed Wetlands Designing

General

1. **Location for the proposed CW-STP:**
2. **Geographical Coordinates (Latitude/Longitude/Altitude):**
3. **Regulatory Requirements:**
4. **Details of Location (Demography, name nearest town, District & State):**
5. **Site Characteristics:**
    a. Topography
    b. Soil type
    c. Hydrology
    d. Climatic conditions
6. **Wastewater Source:**
    a. Average Daily Flow Rate (if known):
    b. Peak Flow Rate (if known):
    c. Water Quality of the influent

Parameters	Influent
pH	
DO (mg/L)	
TSS (mg/L)	
TDS (mg/L)	
Electrical Conductivity (mS/cm)	
Ammonia (mg/L)	
Nitrite (mg/L)	
Nitrate (mg/L)	
T. Nitrogen (mg/L)	
T. Phosphate (mg/L)	
Sulfate (mg/L)	
COD (mg/L)	
BOD (mg/L)	
Coliforms	
Oil and Greases	
Heavy Metals	

7. **Treatment Specifications:**
    a. Required Capacity for Treatment:
    b. Total Land Area Available:
    c. Treatment Goals:
    d. Removal Efficiency for Pollutants
    e. Specific Water Quality Targets (e.g. washing, irrigation): As per the standard recommendations

8. **Design of Primary and Preliminary Treatment:**
9. **Design Parameters CWs:**
    a. Wetland Type:
    b. Surface Area of the Wetland:
    c. Depth of Wetland Bed:
    d. Flow Path Length:
    e. Hydraulic Retention Time:
    f. Inlet and Outlet Structure Design:

Length (m)=	Breadth (m)=	Height (m)=
Total depth of substrate layer =	height of each substrate layer=	Hydraulic Loading Rate =
Hydraulic Retention Time =	Flow Rate=	Water depth=
Treatment capacity =	Actual Treatment Area=	Population equivalent (PE) =
Total land area (m^2) =	Land area per PE (m^2/PE) =	Cost per PE (Rs/ PE) =

10. **Vegetation and Plant Species:**
    a. Source of Plant Material:
    b. List of Plant Species Locally available:
    c. Quantity of Each Plant Species Available:
11. **Construction Materials and Specifications:**
    a. Gravel Type and Size:
    b. Liners Specifications:
    c. Piping Materials and Size:
    d. Other Construction Materials:
12. **Operations and Maintenance:**
    a. Regular Maintenance Plan:
    b. Monitoring Frequency:
    c. Parameters to be Monitored:
    d. Record-Keeping System:
    e. Total Cost of O& M
13. **Budget and Resources:**
    a. Estimated Budget:
    b. Resources Available**:**

Appendix – III: List of CW service provider companies and agencies

List of some of agencies involved in the construction, operation and maintenance of constructed wetlands-based wastewater treatment facilities in India is provided for information only. The authors don't take any responsibility of their work and should not be construed as approved by any agency.

S. No.	Address of Contact Person/ Agency
1.	International Crops Research Institute for the Semi-Arid Tropics Patancheru 502324 Telangana, Hyderabad Email: icrisat@cgiar org
2.	Blue Drop Enviro Pvt. Ltd. Hyderabad Sri Krishna Homes, Plot 13/A, Masjid Banda, Kondapur, Telangana 500084, Email: projects@bluedropwetlands.com
3.	E3BIOCLEANTECH Private Ltd. Dr. Mohit Singh Rana TIDES Business Incubator, IIT Roorkee, Roorkee Uttarakhand- 247 667 Email: **info@e3cleantech.com**
4.	Tejas Kotak Sankalan (Managing director) A centre for alternative learning 13-16, Mahadev Nagar, B/H Valdas Nagar, Mirzapar Highway, Bhuj-Kutch-Gujarat. E mail : tejas@sankalan-hunnarshala.org
5.	Consortium of DEWATS Dissemination (CDD) Society 621, 5th Main Road, OMBR Layout, Banaswadi Post, Bengaluru -560043 Email:bangalore@cddindia.org; dbns.tech@cddindia.org
6.	Shrishti Eco-Research Institute Name: Sayali Joshi Country/Town: Pune, Email: seriecotech@yahoo.co.in
7.	Centre for Science and Environment 41, Tughlakabad Institutional Area New Delhi-110062 Email-gita@cseindia.org
8.	Technogreen Environmental Solution, Pune Sagar Society, Building No. 26, Scheme No. 10, Sector Number 21, Wakadewadi, Shivajinagar, Pune, Maharashtra 411003. Email: **Projects@technogreen.co.in**
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