Compendium of Green Technologies for Municipal Wastewater Treatment

A thesis submitted towards partial fulfilment of the requirements for the degree of M.E in Water Resources and Hydraulic Engineering

Submitted

by

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Dedication

"I dedicate my thesis work to my parents, Kaustav and my family. A special feeling of gratitude to my loving parents and my little brother"

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CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled **"Compendium of Green Technologies for Municipal Wastewater Treatment**" is bonafide work carried out by **RUPOSROTA KAHALI** under our supervision and guidance for partial fulfilment of the requirement of Master of Engineering (Water Resources & Hydraulic Engineering) in School of Water Resources Engineering, during the academic session 2019-2022.

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This foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented in a manner satisfactorily to warranty its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made or opinion expressed or conclusion drawn therein but approve the thesis only for purpose for which it has been submitted.

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DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as part of my Master of Engineering in Water Resources & Hydraulic Engineering degree during academic session 2019-2022.

All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by this rules and conduct, I have fully cited and referred all material and results that are not original to this work.

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Abstract

CPCB data, March 2021, states that the total volume of sewage generated by households in urban India is 72,368 MLD, of this amount, the estimated infrastructure capacity to treat sewage to secondary level is only 43% and approximately 27% of that capacity is utilized, with very limited scope of reuse. Various technologies are employed for treatment of domestic wastewater. All these technologies are dependent on automated process and consist of highly sophisticated operation techniques which may pose hurdles to implement throughout the country especially in peri-urban and rural areas. The existing centralised approach should not be considered the only method. Instead. in the rapidly urbanising cities of India, decentralised wastewater treatment systems with green technology are an attractive solution for addressing the problems of water pollution and scarcity. They may be promoted extensively due to their low operation and maintenance requirements and smaller scale investments. These treatment systems could be a feasible alternative for areas which are not connected to sewer networks as well as ones which are newly developed, so that the construction of their infrastructure is inadequate, not ready or would be executed in the future. Decentralised and low-cost wastewater treatment systems can augment limited treatment capacity. The mainstreaming of decentralised wastewater treatment systems needs a policy-level thrust from the government supported by extensive and comprehensive field level study and monitoring.

Key Words: green technology**,** natural treatment, STP, municipal wastewater, process design, decentralised,

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CHAPTER 1. Introduction

1.1. About Green Technology/ Green Engineering

Green Technology as an alternative source of technology that reduces fossil fuels and demonstrates less damage to the human, animal, and plant health, as well as damage to the world. The use of green technology is supposed to reduce the amount of waste and pollution that are created during production and consumption.

For as long as history has been recorded man has polluted and overexploited the environment in the pursuit of his own well-being. However, as everyone knows, nature itself is a source of pollution (volcanic eruption, natural burning, etc.). Nowadays, it is well understood that we must make every possible effort to protect the environment. And now more than ever engineers must provide insights leading towards a sustainable standard of living to protect human and environmental health. However, although the concept of sustainable development has been defined more than 30 years ago, to date its application to actual technological context has not been so straightforward. The main challenge that green engineering has had to face so far is the operational quest for sustainability. This means looking for strategies where water management and energy use are evaluated jointly. In order to meet this challenge, a number of considerations have to be integrated in the design of wastewater treatment plants, e.g., higher levels of removal efficiency of contaminants, and energy and nutrient recovery. To facilitate direct water reuse, research programs for wastewater treatment must be directed towards technologies that require less non-renewable energy sources, reduce the use of hazardous chemicals, and remove contaminants. Several Life Cycle Assessment studies of wastewater treatment systems have been evaluating competing technologies and consistently identifying the strong influence that energy consumption has on the overall environmental impact. Not to mention the strong influence that also sludge handling and disposal process have on the overall environmental impact.

The main purpose of green technology is **to slow down global warming and reduce the greenhouse effect**. The main idea is the creation of new technologies which do not damage the natural resources. This should result into less harm to people, species, and the general health of our planet.

Green energy offers a promising alternative to traditional energy sources. The fact that renewable energy accounts for only a modest proportion in meeting the world's (commercial) energy demand means that there is a missing link in their potential and their implementation - the barriers in their implementation. These barriers (either financial or non-financial) need to be identified and addressed to design innovative policy approaches for the international and domestic financing or renewable energy technologies. Renewable energy can play an important role in helping to meet basic energy needs using modern technologies green technologies. The Rio Declaration adopted at United Nations conference on Environment and Development in Rio emphasizes entitlement of healthy and productive human life in harmony with integration of environment protection in the development process. The Earth Summit at Rio adopted Agenda 21 on June 14, 1992, proposes various actions to be implemented from now and into the 21st century to accelerate sustainable development.

The green technology policy to provide direction and motivation to continuously enjoy good quality and a healthy environment should be based on four pillars:

- **Energy**: Seek to attain energy independence and promote efficient utilization.
- **Environment:** Conserve and minimize the impact on the environment.
- **Economy**: Enhance the national economic development using technology.
- **Social**: Improve the quality of life for all.

The principles of green engineering, coined by Anastas and Zimmerman, provide a framework for scientists and engineers for designing effective, ecologically intelligent materials, products, and systems. This approach builds on the technical excellence, scientific accuracy, and systematic thinking that have addressed in recent years the issue of science and technology for sustainability and sustainable development.

Following are the 12 principles of green engineering:

Principle 1	Designers need to strive to ensure that all material and energy inputs and outputs are as inherently non-hazardous as possible.
Principle 2	It is better to prevent waste than to treat or clean up waste after it is formed.
Principle 3	Separation and purification operations should be a component of the design framework
Principle 4	System components should be designed to maximize mass, energy and temporal efficiency
Principle 5	System components should be output pulled rather than input pushed through the use of energy and materials.
Principle 6	Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse or beneficial disposition.
Principle 7	Targeted durability, not immortality, should be a design goal.
Principle 8	Design for unnecessary capacity or capability should be considered a design flaw which includes engineering ‘‘one size fits all’’ solutions.
Principle 9	Multi component products should strive for material unification to promote disassembly and value retention (minimize material diversity).
Principle 10	Design of processes and systems must include integration of interconnectivity with available energy and materials flows.
Principle 11	Performance metrics include designing for performance in commercial ‘‘after life’’
Principle 12	Design should be based on renewable and readily available inputs throughout the life cycle

1.2. Context of Green Technology in Water Management

The world is currently dealing with multiple inter-connected crises, such as climate change, unprecedented loss of biodiversity, resource limitation, food insecurity, mass refugee displacement, and spread and control of infectious diseases, to name a few. The main causes of climate change relate to carbon dioxide equivalent (CO_2e) emissions from human activities. We use vast amounts of fossil fuels such as coal, petroleum, heavy oil, and natural gas to produce electricity, run cars and other forms of transport, and power industries, all generating greenhouse gases (GHG).

Climate change, rapid development and population growth of many nations and the consequent rapid rise in levels of water consumption and contamination have raised concerns about the unsustainability of current water use patterns and supply systems. Specifically, the world population continues to expand with a growth rate of 1.2% each year, resulting in increased pressure on water demand, water quality, safety, and health.

With the increasing demand for water, scarcity for it is prevalent. The need to find strategies on how to sustain it is becoming more urgent. Although the global amount of water is generally considered to be sufficient for the current population from the perspective of the total hydrologic cycle, world water resources are concentrated in certain areas, and severe water shortages are emerging in other places. With the advancement of technology, experts are now looking into processing wastewater. The wastewater treatment is a process that removes undesirable compounds and contaminants that pollute the water.

Green technologies are technologies creating products and facilities that can improve economic productivity, conserve natural resources and limit adverse impacts on the environment and social wellbeing (Environmental Leader 2013). The concept of green technologies can be applied to the water management field to support the growth of new industries (e.g., new end uses of recycled water), bring technological innovations (e.g., state-of-the-art water treatment approaches) to water market and position the country to capture green growth opportunities. While the application of green technology could greatly harness economic opportunities by promoting productivity, prosperity and living standards, the strategies and innovations can also balance the other environmental, social and technical aspects, which would underpin sustainable water management into the future.

With the help of green technology, it will cater to polluted waters from domestic and industrial areas to safely return it to the environment for irrigation, industrial use as well as for drinking. To achieve these, effective urban water management is needed.

To develop green technologies strategically, a comprehensive framework for managing water resources and prioritizing investment decisions is needed.

Following figure is indicative of the framework for managing water resources by applying green technologies:

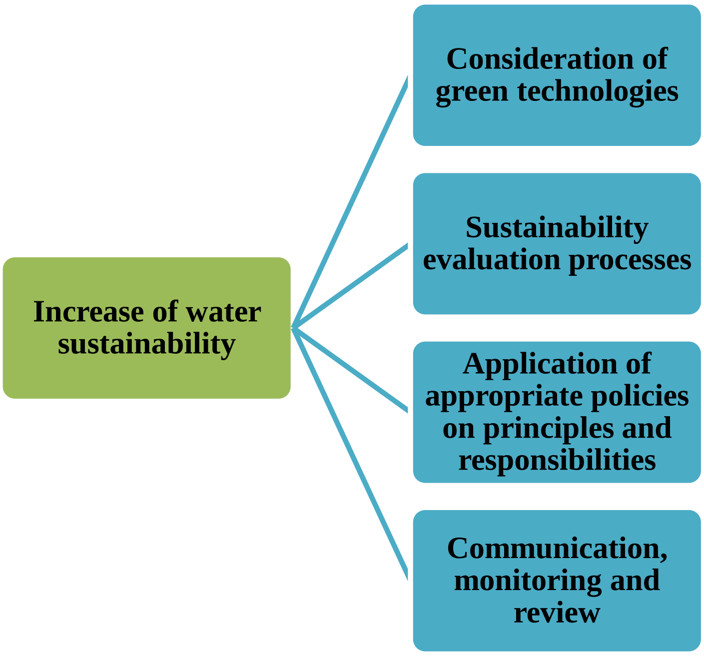


Figure 1. 1: Framework for managing water resources by applying green technologies

Water Management and adoption of Green Technologies in India

The World Resource Institute global water-stress rankings (2013) indicate that the ratio of withdrawal to supply in India is 40 to 80 per cent and the country experiences high water stress. India has witnessed a rapid increase in the urban population during the last few decades. All towns and cities currently face the problem of increasing gap between water supply and demand, which puts pressure on water resources and its supply requirements.

Water supply in most Indian cities refers to the layout of infrastructure, i.e. piped water-supply lines, sewage lines, sewage treatment plants (STPs) and layout of drainage lines. If the piped water supply is inadequate, it is supplemented by private uncontrolled groundwater extraction, which contributes to pollution of urban aquifers and fall in groundwater levels.

The current water model practised in cities focuses on water supply. This approach is unsustainable, given that more water supply leads to more wastewater generation, which in turn increases the cost of treatment. Unfortunately, most water supply and sewage treatment projects are sanctioned as infrastructure projects without giving due importance to sustainability. Furthermore, a growing built-up area in the name of 'urbanisation' leads to increased water run-off and minimal recharge.

Moreover, the high rate of urban sprawls has resulted in a loss of green spaces. A minimum availability of 8-10 sq m open space per city dweller is the proposed standard suggested by URDPFI. A more integrated land and water management system from the early stages is needed to reduce the increasing water footprint of urban centres. The land use patterns of a city are decisive pointers of its water management system.

Around 40–90 % of the total water consumption goes out as wastewater and as per CPHEEO manual, it indicates 80 %. And this sewage generated is treated in centralized sewage treatment plants before getting disposed to nearby waterbodies. With the new guidelines of effluent discharge, imposed by National Green Tribunal, and the decline in green spaces has resulted in the adoption of more advanced and mechanical based treatment plants, which require huge capital expenditure as well as has high carbon footprint due to completely mechanised system.

The current water model that primarily focuses on supply is unsustainable, given that more water supply leads to more wastewater generation, which increases the cost of treatment. In order to make a water-prudent society, a paradigm shift is needed to focus on decentralised natural systems based on reuse/recycle, prevention of leakage losses, and resource efficiency. Water resource management is also influenced by the socio-cultural fabric of an urban area.

1.3. Green Technology in Municipal Wastewater Treatment: Natural Treatment Methods

Urban Scenario: The total volume of sewage generated by households in urban India was 72,368 MLD, of this amount, the estimated infrastructure capacity to treat sewage to secondary level is only 43% and approximately 27% of that capacity is utilized, with very limited scope of reuse. Various technologies are employed for treatment of domestic wastewater. It is observed that Sequential Batch Reactor (SBR) and Activated Sludge Process (ASP) are the most prevailing technology adopted by Urban Local Bodies (ULB). All these technologies are dependent on automated process and consist of highly sophisticated operation techniques. This calls for involvement of skilled labour and high capital expenditure.

As per the CPCB data , March 2021 [3], sewage generation is estimated as 72,368 MLD and capacity utilization is only 20,235 MLD and remaining quantity of 52,133 MLD is let-out as untreated sewage.

The scenario of the municipal wastewater management in India is highlighted in the following Table 1.1 and Figure 1.2.

Table 1. 1 Status of STP as on year 2020 [3]

Sl. No.	STP Status	No. of STPs	Capacity (MLD)
1	Operational	1093	26869
2	Actual Utilization	1093	20235
3	Compliance	578	12197
4	Non-Operational	102	1406
5	Under Construction	274	3566
6	Proposed	162	4827

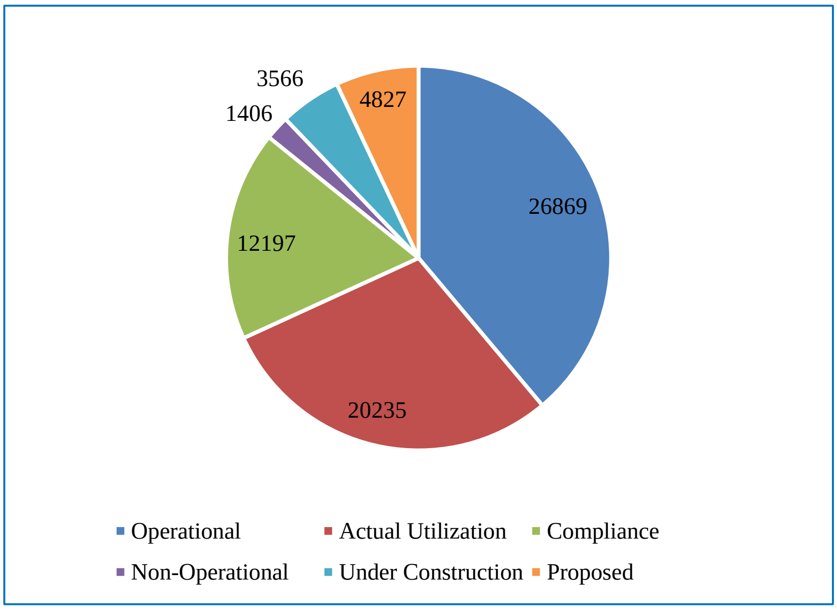


Figure 1. 2 : STP Status as per CPCB data, March 2021 [3]

The different types of treatment technologies that are currently employed for domestic wastewater treatment in India, comprises of Activated Sludge Process (ASP), Sequential Batch Reactor (SBR) etc.. These two are the most prevailing technology adopted by Urban Local Bodies (ULB) in India [3].

Technological distribution with respect to number and capacity of STPs are shown in Table 1.2 and Figure 1.3.

Table 1. 2 Technological distribution with respect to number and capacity of STPs [3]

Sl. No.	Technology	Capacity (MLD)	No. of STPs
1	ASP	9486	321
2	EA	474	30
3	SBR	10638	490
4	MBBR	2032	201
5	FAB	242	21
6	UASB	3562	76
7	WSP	789	67
8	OP	460	61
9	Any Other	8497	364

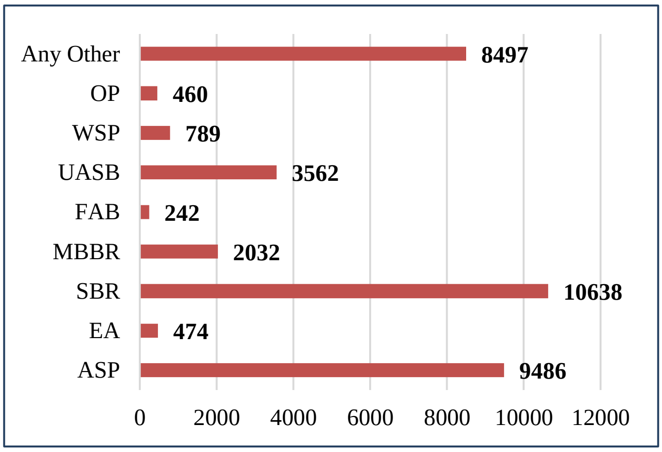


Figure 1. 3 : Technology wise Capacity (MLD) [3]

As evident that there a significant gap between sewage generation and treatment capacity which needs to be minimized urgently. Moreover, it is high time to address the matter considering sewage as a resource which can be treated as per requirement and utilized for non-potable purposes and industrial utilities. Utilization of sewage has following positive impacts:

- Re-use of treated sewage will allow to decrease the water demand from aquatic sources like river, ponds, lakes, and groundwater resources.
- Less consumption of raw water will help in conserving natural water resources.

However, in recent past, there has been a focus on reuse of treated sewage for various purposes like horticulture, irrigation, washing, community toilet flushing and utilization for different industrial activities.

CPHEEO has prescribed standards for re-use of treated sewage for different purposes like horticulture, irrigation, non-contact impoundments and washing, given in the Table 1.3.

Table 1. 3: Recommended Norms by CPHEEO For Treated Sewage Quality for Specified Activities at Point of Use [1]

Recommended norms of treated sewage quality for specified activities at point of use									
Sl. No.	Parameter	Toilet Flushing	Fire Protection	Vehicle Exterior Washing	Non-contact incompoundments	Landscaping, Horticulture & Agriculture			
						Horticulture, Golf course	Crops		
							Non-edible crops	Edible Crops	
								Raw	Cooked
1	Turbidity (NTU)	<2	<2	<2	<2	<2	AA	<2	AA
2	Suspended Solids	nil	nil	nil	nil	nil	30	nil	30
3	TDS	2100							
4	pH	6.5 to 8.3							
5	Temperature °C	Ambient							
6	Oil & Grease	10	nil	nil	nil	10	10	nil	nil
7	Minimum Residual Chlorine	1	1	1	0.5	1	nil	nil	nil
8	Total Kjeldahl Nitrogen as N	10	10	10	10	10	10	10	10
9	BOD	10	10	10	10	10	20	10	20
10	COD	AA	AA	AA	AA	AA	30	AA	30
11	Dissolved Phosphorous as P	1	1	1	1	2	5	2	5
12	Nitrate Nitrogen as N	10	10	10	5	10	10	10	10
13	Faecal Coliform in 100 ml	nil	nil	nil	nil	nil	230	nil	230
14	Helminthic Eggs/ litre	AA	AA	AA	AA	AA	<1	<1	<1
15	Colour	Colourless	Colourless	Colourless	Colourless	Colourless	AA	Colourless	Colourless
16	Odour	Aseptic which means not septic and no foul odour							
All units in mg/l unless specified; AA-as arising when other parameters are satisfied;									
A tolerance of plus 5% is allowable when yearly average values are considered.									

However, to meet the standards for different purpose of reuse and recycle of used water, green technology such as natural treatment methods can be adopted, in place of such sophisticated treatment options especially in peri-urban areas.

Rural Scenario: Wastewater generated from toilets (Blackwater) containing faecal matter with very high number of pathogens. **Swachh Bharat Mission (Grameen)** has addressed the issue of blackwater along with the drive against open defecation. Success was achieved through the installation of toilets with a twin pit system in rural areas. There are still a limited number of village households that depend on septic tanks or single pits which requires faecal sludge management.

Wastewater generated from bathing, washing, general cleaning, kitchen, maintenance of livestock, as well as from community stand posts, wells, hand pumps and other institutional areas, etc. is known as greywater. As per the guidelines issued under Jal Jeevan Mission, a flagship programme under Government of India, out of 55 LPCD water supplied in rural areas, 65 % of it is discharged as greywater, amounting to 36 LPCD of greywater [2]. Since toilet water is to be kept separate, greywater is expected to be free of faecal contamination. However, sometimes greywater does have traces of faecal matter where intermixing of septic tank effluent with greywater has occurred.

The organic content in greywater is much lower as compared to blackwater or sewage. Therefore, separate treatment of greywater is always desirable as a large quantity of water can be recovered using smaller treatment systems. Greywater contains only one-tenth of the nitrogen that blackwater does and significantly fewer pathogens. As a result, the organic content of greywater decomposes more rapidly than that of blackwater and thus, its treatment is easier. These characteristics make it reusable as a sustainable source of water for irrigation, and for other purposes, but only after treatment which allows it to meet specific quality criteria.

The community level interventions of greywater management can be brought about by adopting natural treatment methods.

Adoption of natural treatment methods at both urban and rural level has benefits in the developing countries like India because of the following reasons:

1. *Can be operated with simple technical implementation*
2. *Required lower operating costs, investment costs in comparison to mechanised treatment technologies.*
3. *Requires low energy consumption, hence, requires less carbon footprint.*
4. *Does not require skilled labour, hence can create another source of livelihood.*
5. *Treated wastewater can be recycled as a substitute for potable water for many environmentally-sound water uses.*
6. *Can be operated in decentralized manner, which is the need of the hour.*

CHAPTER 2. Objective of the Study

All wastewater treatment systems utilize natural processes. For example, gravity is used to remove particulates and bacterial decomposition reduces organics. In conventional treatment systems, these natural processes are supported by a complex array of energy-intensive mechanical equipment.

The natural technologies of wastewater treatment use natural, commonly occurring self-treatment processes that take place in the soil, water, and wetland environment. The vegetation is directly involved in the treatment process, especially by the formation of favourable conditions for the development of microorganisms involved in the treatment process, and simultaneous utilization of released plant nutrients for the biomass production.

Natural treatment systems, by contrast, utilize biological and physical/chemical processes to accomplish a wide range of treatment objectives, with minimal dependence on energy inputs and mechanical assistance. These systems can also go beyond simply providing treatment services; many provide an aesthetic benefit, and some include opportunities for wildlife viewing, environmental education, and outdoor recreation.

At first, wastewater treatment managers focused on advanced mechanical treatment methods to meet the new, more stringent water quality standards, but the high energy requirements and costs of these methods soon became apparent and the natural treatment systems were taken into consideration as more sustainable and cost-effective alternatives.

While natural treatment systems can be used to treat a variety of media, including industrial wastewater and contaminated soils, this report focuses on the use of these systems to treat domestic wastewater, either working in tandem with or taking the place of a conventional municipal wastewater treatment system.

2.1. Objective

The objective of the thesis is to prepare a State- of – Art/ Compendium of Green Technologies for Municipal Wastewater Treatment, using natural treatment methods, technically and financially suitable for Indian Conditions through extensive literature review followed by field level evaluation.

2.2. Scope of Work

- To list out the philosophies of various wastewater treatment used all over the world with special emphasizes on India and other developing countries.
- To evaluate various wastewater treatment technologies in the light of their potential of pollution control and energy efficiency
- To figure out selective green natural wastewater treatment technologies which could be

applicable in India

- ❖ To assess in detail all the feasible green natural wastewater treatment technologies for municipal wastewater treatment
- ❖ To design and make a comparative analysis of all the feasible green natural wastewater treatment technologies
- ❖ To suggest the possibilities of using green natural wastewater treatment technologies in India in future
- ❖ To prepare a State-of-Art/ Compendium of Green Technologies for Municipal Wastewater Treatment

2.3. Methodologies

Methodology is the systematic, theoretical analysis of the methods applied to a field of study. It comprises the theoretical analysis of the body of methods and principles associated with a branch of knowledge. Typically, it encompasses concepts such as paradigm, theoretical model, phases and quantitative or qualitative techniques methodology does not set out to provide solutions – it is, therefore, not the same as a method. Instead, a methodology offers the theoretical underpinning for understanding which method, set of methods, or best practices can be applied to specific case, for example, to calculate a specific result.

For this study, the following methodologies are adopted:

- ❖ At first extensive review of literatures related to various wastewater treatment technologies practiced in the world would be made.
- ❖ The technologies which are used for decades and the recently used technologies would be compared along with the criteria of effluent quality mandated over the years.
- ❖ Amongst all these technologies which are suitable for Indian cities and towns as well as mostly practiced would be identified.
- ❖ Data collection from various stakeholders, ULBs, readily available reports, master plans as well as detailed design reports.
- ❖ Detailed design criteria with respect to effluent quality, energy consumption, required footprint, reusable potential, durability and sustainability in all respects would be worked out in detail.
- ❖ Out of all these technologies identified, green technologies would be specifically studied in detail to prepare a purposeful document in the light of various urban situation.
- ❖ All the above exercise would be documented for preparation of the thesis which in turn would be a State of Arts/Compendium of Green Wastewater Treatment Technologies.

2.4. Proposed Outcome of the Thesis

Adopting water sensitivity at the stage of planning and designing new and existing developments can maintain the water cycle by managing the supply and demand for water, storm water, wastewater and groundwater as well as bring benefits such as reduction in temperature with respect to climate change and adaptation. The water sensitivity can be brought about by holistic approach in adopting green technologies in the form of natural treatment of municipal used water, integrating them with land use pattern of India**.**

The treatment technologies of the used water should not be adopted to solely advocate the effluent standards for discharge to waterbodies as proposed, but to also use the treated water to cater various other purposes other than potable use. The thesis will serve as a compendium for practitioners, various stakeholders to consult for promoting sustainable water management, as an initial approach towards Water Sensitive Urban Design and Planning (WSUDP), a need of the decade.

2.5. Thesis Outline

The thesis has been divided into 9 chapters. Chapter 3 offers the revies of the literature. Chapter 4 depicts the significance of the basic principle of natural wastewater treatment. The 5^{th} chapter is on the methodology to be adopted to select a particular treatment system. Chapter 6 describes the different natural treatment systems. Comparative statement between the different treatment systems has been draw in the 7^{th} Chapter. Details of process design has been carried out in Chapter 8. Chapter 9 describes about the future scope of adopting the treatment technologies in Indian context.

CHAPTER 3. Literature Review

The literature review has been carried out consulting various national based as well as international journals to acquire knowledge in the natural treatment technologies for municipal wastewater. A comprehensive approach has been adopted in considering international journals and papers and to replicate them in Indian context. It has been quite challenging to analysis the international based data with respect to India, however several studies are carried out in green technologies and sustainable development in water sector to form the basis of the compendium.

Prof. Nagvekar Y et. al (2022) The review summarises the types of constructed wetlands considering media, vegetation, removal efficiency, construction cost, maintenance cost and land area requirement using life cycle cost analysis. The review compares how and why constructed wetland is a better option as per treatment efficiency, their payback period and cost-effectiveness with the other wastewater treatment technologies.

Ruhma Rashid et. al (2021) The world's water supplies have been contaminated due to large effluents containing toxic pollutants such as dyes, heavy metals, surfactants, personal care products, pesticides, and pharmaceuticals from agricultural, industrial, and municipal resources into water streams. Water contamination and its treatment have emerged out as an escalating challenge globally. Extraordinary efforts have been made to overcome the challenges of wastewater treatment in recent years. Various techniques such as chemical methods like Fenton oxidation and electrochemical oxidation, physical procedures like adsorption and membrane filtration, and several biological techniques have been recognized for the treatment of wastewater. This review communicates insights into recent research developments in different treatment techniques and their applications to eradicate various water contaminants. Research gaps have also been identified regarding multiple strategies for understanding key aspects that are important to pilot-scale or large-scale systems. Based on this review, it can be determined that adsorption is a simple, sustainable, cost- effective, and environmental-friendly technique for wastewater treatment, among all other existing technologies. However, there is a need for further research and development, optimization, and practical implementation of the integrated process for a wide range of applications.

Snehal Bhaskar Thamke et. al (2021) Constructed wetlands are engineered and managed wetland systems that are increasingly receiving worldwide attention for wastewater treatment and reclamation. Compared to conventional treatment plants, constructed wetlands are cost-effective and easily operated and maintained, and they have a strong potential for application in a small community. Constructed wetlands for wastewater treatment have substantially developed in the last decades. As an eco-friendly treatment process, constructed wetlands may enable the effective, economical, and ecological treatment of agricultural, industrial, and municipal wastewater. Constructed wetlands are very effective in removing organics and suspended solids, whereas the removal of nitrogen is relatively low, but could be improved by using a combination of various types of constructed wetlands meeting the irrigation reuse standards. The removal of phosphorus is usually low, unless special media with high sorption capacity are used. Pathogen removal from wetland effluent to meet irrigation reuse standards is a challenge unless supplementary lagoons or hybrid wetland systems are used. In this paper studies various case study related to Wetlands in Indian Cities and also described include systems involving both constructed and natural wetlands, habitat creation and restoration**.**

Abou Dobara MI et. al (2020) This study aims to evaluate the performance of aerated lagoon system in Port Said city for removal efficiency of bacteriological and physicochemical contaminants. Variations of bacteriological and physicochemical parameters along the ponds system were observed and evaluated. One year (2018) analysis was done in monthly intervals from January to December. The plant consists of aerated, facultative, and maturation lagoon in series.

Fayed Abdel Hafez Al-Ajalin et. al (2020) The reed bed system is one types of phytoremediation technology for removing pollutants from the environment. This technology provides an environmentally friendly approach to treating contamination with competitive cost, compared to the physico-chemical treatment. The design of reed bed system is highly important in order to achieve the highest pollutant removal efficiency. The design of reed bed system affects the natural oxygen transfer from the environment. The reed bed system was proven to have a good efficiency in removing Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solid (TSS), Total Dissolve Solid (TDS), Total Nitrogen (TN) and a number of bacteria. In addition to the oxygen transfer from the environment, the interaction among pollutant-plants-medium-microbes also plays a vital role in the removal of pollutant using the reed bed system. It was suggested that the future related research should accommodate the importance of several environmental conditions to the interaction between pollutant, plants, medium and microbes as well as the impact of those interactions on the pollutant removal efficiency.

Xuli Meng et. al (2018) Planning for ‘water-sensitive’ infill development has become a priority for sustainable urban development in Australia. With city growth, infill development in vacant or under-used land parcels is becoming a dominant mode of development. However, the current ‘knock-down-rebuild’ approach to such development will undermine resource efficiency, liveability and urban amenity, particularly for natural water systems. There is a need to identify development options that are more water sensitive. To better analyse water efficiency and hydrological performance of Water Sensitive Urban Design (WSUD) options, we use a water mass balance evaluation framework to demonstrate the ‘whole of water cycle’ approach. The new insights gained were the extent to which the proposed WSUD options impact the water metabolism performance of the urban area through modelling the water mass balance of eight selected WSUD options within different scenarios, involving pre-development (1825), current (2016), before and after water-sensitive options in 2031. The novel contribution is the development of one new hydrological performance indicator, open space ratio and redeveloped other four water metabolism indicators to assess water performance in infill development. Results show that urbanisation dramatically altered the water flows, like stormwater runoff. Also, road space plays an important role in future solutions.

R. Kaalipushpa et. al (2017) In the developing technologies and growing environment, the usage of the water source plays a vital role and its been needed and used in large amount. Insufficient management of municipal and wastewater in immense environmental problems and increasing hygienic risks for the growing urban population thereby hampering poverty alleviation and a sustainable development of Indian society. But now days, the wastewater is converted into a source for various purposes in different aspects by the use of phytorid technology. phytorid technology is a patented technology and being very effective in water pollution treatment it leads one step forward to sustainable treatment of wastewater in safe manner using Iris Pseudacorus (Yellow Iris) plants and natural source for the treatment without affecting the ecosystem. The Chrysopogonzizanioides is to increase the pH value and to reduce the nitrogen, phosphorous content. The coagulation and flocculation process is done by alum to have a turbidity and to remove the suspended solids. This method is more advantageous of cost effective, negligible operation and maintenance with minimum electricity, smaller footprint. The main focus of the project is to avoid the scarcity of the irrigation water and to avoid the odor in the treated water and to enhance the quality of the water to prevent ground water pollution by analyzing the nominal water parameters that need to be satisfied for reusing the treated water with the references of IS 3025 code book.

C. C. Teles et. al (2017) The microorganism community that grows under duckweed shelter can play an important role on treatment processes. Therefore, the present study aimed to assess the zooplankton dynamic and microbial community in duckweed ponds (DPs) applied for domestic wastewater treatment under open field conditions. A pilot system comprised of two DPs in series (DP1 and DP2), with 10 m^2 each, received domestic wastewater through a flow rate of 200 $L \cdot day^{-1}$. Thus, the system was monitored during 314 days through samples collected and analysed weekly. Also, the zooplankton organisms were identified and quantified. DNA sequencing was performed in order to identify the bacterial populations. The findings showed a high efficiency of nutrient removal with 93% and 91% of total phosphorus and total nitrogen, respectively. A high density of microcrustaceans was observed in DP1 reaching 4,700 org.100 mL^{-1} and rotifers (over than 32,000 org.100 mL^{-1}) in DP2, that could be related to the low suspended solids concentration (<30 $mg \cdot L^{-1}$) and turbidity (<10 NTU). The bacterial community showed a strong heterogeneity between samples collected along the seasons. Through these findings, it is possible to realise that the understanding of ecology could help to enhance the operation and designs of DPs.

Wang et. al (2017) discussed the use of Constructed Wetlands which mankind had used for generation after generation for the sake of the treatment of wastewater. As wastewater treatment mostly depends on biological treatment, when mercury goes down Constructed wetlands have to face some special challenges. The main key of the study was to analyze the practice and application of the constructed wetland in cold climates. This was very much challenging to implement in a cold climate. Contamination removal was maximum in the tropical region in a constructed wetland than in a cold climate's removal variation is not affected in a cold climate, COD removal declines in winter season 75 % unplanted and 81% for planted wetlands. TKN removal was 59% below 15 degrees C and 74% above 15 degrees C, and ammonia removal was 38% below 15 degrees C and 70% above 15-degree C. Graphical variation of contamination removal between tropical and cold climate region had been shown in this paper. Constructed wetland, which is three types, which are Free water surface, subsurface flow, and hybrid wetland system.

Swapnil S. Navaghare et. al (2016) The paper emphasized on the objective of Phytorid technology concept is to produce hygienically safe and useful resource out human wastes, which can not only improve the environmental situation, but also improve living conditions in a sustainable way and lower risks on human health. The objective of this paper was also to provide a feasible solution for ever increasing sewage treatment problem and eventually conserving natural water bodies removing possibility of dumping.

Seyyedeh Cobra Azimi et. al (2016) The implementation of clean, eco-friendly, less energy and waste producing processes and technologies is realized today with an increasing interest. In order to provide a sustainable development, environmentally friendly substances, novel technologies and new green chemistry options should be utilized. In that respect, in this paper green chemistry, green engineering and their principles are reviewed in relation to green technologies for wastewater treatment.

Shrikanta et al. (2016) discussed the water coming from household's kitchen, bathroom, washing of cloths sometimes it may be industrial, commercial is called liquid waste. The practice of greywater discharge was identified unsystematic disposal in open space, unscientific kitchen garden, unscientific soakage pit and practice of black water was septic tank pipe was discharged into an open drain. There were two types of systems described i. decentralized ii. Centralized. Soak pit, leach pit, the kitchen garden was under the decentralized system and Waste stabilization pond, Duckweed, oxidation pond. Decentralized systems were low capital cost, low maintenance cost, maintenance was done by house hold level. centralized space was not required. Centralized systems were high capital cost, high maintenance cost, maintenance was done by Gram panchayat level, centralized space was required. Domestic level management like a magic pit, soak pit etc, Community-level management was done with different types of components like Transport of Grey Water preferably through pipes, Intercepting chambers at intervals and Final treatment Unit.

Maria Gratziou et. al (2015) The paper presents the effectiveness of tree waste stabilization pond (WSP) systems, operating in Northern Greece, on nutrient removal. The systems treat only domestic wastewater and consist of one facultative pond, one or two maturation ponds and a rock filter before the final discharge for algae filtration. Significant differences have been noticed among the three systems concerning their concentrations, as well as their efficiencies. During the estimation of mass efficiency, it has been observed that in most cases, mass efficiencies were almost identical to the concentration efficiencies. Yet, this was not the case during summer months, when there was a drop in mass efficiencies. The three systems were recorder to operate smoothly during the study. Moreover, the correlations between influent – effluent mass were satisfactory. The correlations between nutrient removal, pH, temperature, BOD_5, HRT, ponds, surface area, were investigated.

Pratima Singh et. al (2015) The study used a combination of fundamental mass-balance approach for energy consumption and the methodology defined by IPCC for the carbon emissions. Small-scale institutional STPs consume twelve times the energy consumed by large-scale municipal STPs, the corresponding energy intensities being 4.87 kWh/m^3 and 0.40 kWh/m^3 respectively. Embodied energy from construction material and chemicals accounted for 46% and 33% of the total energy intensity of the municipal and institutional STPs respectively. The average carbon footprint of large-scale STPs is 0.78 $kgCO_2eq/m^3$ and for small-scale STPs it is 3.04 $kgCO_2eq/m^3$. However, fugitive emissions from large-scale STPs constituted 74% of the total carbon emissions whereas the figure was only 0.05% for small-scale STPs. Average electrical energy in-tensity in STPs in India is much lower (0.14 kWh/m^3) than that in the UK (0.46 kWh/m^3). This is due to the reason that STPs in India do not have resource recovery processes and use solar heat for sludge drying.

Rahman Ekhlasur Md et. at al (2014) Constructed wetlands (CWs) are affordable and reliable green technologies for the treatment of various types of wastewaters. Compared to conventional treatment systems, CWs offer an environmentally friendly approach, are low cost, have fewer operational and maintenance requirements, and have a high potential for being applied in developing countries, particularly in small rural communities. However, the sustainable management and successful application of these systems remain a challenge. Therefore, after briefly providing basic information on wetlands and summarizing the classification and use of current CWs, this study aims to provide and inspire sustainable solutions for the performance and application of CWs by giving a comprehensive review of CWs' application and the recent development of their sustainable design, operation, and optimization for wastewater treatment. To accomplish this objective, thee design and management parameters of CWs, including macrophyte species, media types, water level, hydraulic retention time (HRT), and hydraulic loading rate (HLR), are discussed. Besides these, future research on improving the stability and sustainability of CWs are highlighted. This article provides a tool for researchers and decision-makers for using CWs to treat wastewater in a particular area. This paper presents an aid for informed analysis, decision-making, and communication. The review indicates that major advances in the design, operation, and optimization of CWs have greatly increased contaminant removal efficiencies, and the sustainable application of this treatment system has also been improved.

Martin Seidl et. al (2014) A small pilot system has been used at the university of Niamey (Niger), composed of 3 ponds with microphytes and 3 ponds covered with duckweed. The duckweed was harvested 3 times a week and fed to Tilapia in adjacent pond. The ponds were fed with 3.5 m3/day of wastewater, corresponding to a global charge of 1.1 kg-BOD_5/day or 130 kg/ha/day. The first results give a relatively good efficiency for standard parameters like DCO and DBO : (about 70 %) and for nutrients N and P (about 80 %). Excellent pathogen removal of 4 log units (>99.95%) satisfied the discharge norms for agricultural reuse. Mean duckweed productivity was about 25 103 kg/ha/month depending on the nutrient charge. The results of Tilapia farming gave a satisfactory production of 475 kgw.w./ha/month.

Shruti Ranjan et. al (2013) The disposal of untreated or partially treated wastewater into the environment has posed the several impacts on human and wild life around the world. In last many years, ample efforts have been undertaken for establishment of sewage treatment plants in order to reduce the extent of untreated effluent discharge into the natural water bodies. The appropriate O&M as well as routine performance evaluation of unit operations of any treatment unit plays an important role in meeting the design standards. Currently at most of the sewage treatment plants, the physico-chemical parameters are being considered as the basis of performance evaluation of biological treatment unit operations. In this paper, the studies of the impact of aeration in aerated lagoons were studied with the help of fluorescein diacetate (FDA) hydrolysis assay. Also, the impact of aeration was also studied in terms of removal efficiencies in terms of physico-chemical and biological parameters.

R. P. Borkar et. al (2013) The study had been undertaken by fabricating the lab scale model of constructed wetland. The effluent of Amba Nala Amravati is treated with this system and wastewater characteristic like pH, DO, TS, BOD, COD with & without plant species studied. Using sandy soil as substrate, it was found that BOD, COD removal 61 % and 51 % for unplanted constructed wetland whereas for planted constructed wetland it was 74% and 61%.

Mahmood et.at al (2013) The purpose of natural treatment systems is the re-establishment of disturbed ecosystems and their sustainability for benefits to human and nature. The working of natural treatment systems on ecological principles and their sustainability in terms of low cost, low energy consumption, and low mechanical technology is highly desirable. The current review presents pros and cons of the natural treatment systems, their performance, and recent developments to use them in the treatment of various types of wastewaters. Fast population growth and economic pressure in some developing countries compel the implementation of principles of natural treatment to protect natural environment. The employment of these principles for waste treatment not only helps in environmental cleanup but also conserves biological communities. The systems particularly suit developing countries of the world. Economic cost and energy requirements to operate various kinds of natural treatment systems were also reviewed.

Ghimire et. al (2012) Constructed Wetlands are an engineered wastewater treatment system that tries to mimic the natural biological, physical and chemical processes to treat wastewater. It is emerging as a cost-effective decentralized wastewater treatment solution in the communities where there is availability of inexpensive lands and lack of skilled operators. Different design approaches have been followed and design parameters based on different literatures have been chosen to design a Sub-surface Flow Constructed Wetlands. A simplified design approach well suited to climatic needs to be developed to maintain the cost effectiveness of the system.

Giusy Lafrano et. al (2012) In order to analyse the challenges posed by the quest for sustainability, Green Technologies for Wastewater treatment: Energy Recovery and Emerging Compounds Removal evaluates water management together with energy use. The strong effects that the release of emerging pollutants such as endocrine disruptors (EDCs), pharmaceuticals and personal care products (PPCPs) have in wastewater reuse applications are examined, as well as the need to optimize the energy consumption in wastewater treatment.

Sumate Chaiprapat et. al (2003) A mathematical model was developed to describe nitrogen transport in duckweed-covered static ponds for nutrient recovery from swine lagoon water. A finite difference technique was used to solve the partial differential equations describing the ammonia transport and concentration in the pond. The key parameters in the model include the diffusion coefficient of ammonium in the medium (D) and kinetic constant of nitrogen uptake by duckweed (k). Using one order of magnitude parameter variations, the simulations showed that the model was clearly much more sensitive to D than to k, indicating the process of nitrogen removal in a static pond by duckweed is diffusion limited. Laboratory testing was conducted with Spirodela punctata 7776, a duckweed strain, to calibrate the model. The calibration of the model with experimental data yielded a new ammonium transport coefficient (T) that is 85 times of D value. Model results showed good agreement with depth-wise experimental ammonium concentration and the model also demonstrates that intermittent mixing every 3 h can enhance ammonium uptake. Additionally, an apparent drop in pH near the duckweed mat at the surface was observed that may explain low rates of ammonia emission from duckweed ponds.

Innocent Nhapi et. al (2003) Duckweed systems are a form of natural wastewater treatment method that is ideal for developing countries. They demand less in terms of financial resources for construction and maintenance, manpower sophistication, electricity requirements, and machinery. This paper looks at the duckweed technology as a new phenomenon in Zimbabwe, reviews its requirements and problems, and finally explores its potential in the Zimbabwean environment. A simple spreadsheet model was developed to assess a water and nutrient balance of an ideal duckweed system. It was concluded that under ideal or optimum operating conditions, duckweed systems could achieve the required Zimbabwean nutrient standards of 10 mg·l-1 total nitrogen and 1 mg·l-1 total phosphorus. Duckweed systems would suit areas of moderate to high water consumption to avoid toxicity problems and also to increase the surface area available for duckweed growth. It was recommended that further experiments be carried out locally to improve and validate the model developed and used in this paper.

Ibrahim et.at al Wastewater Management (WWM) is one of the major developments challenging issues in developing countries, which need more innovative solutions to meet future sustainability goals. This paper aims to analyse and discuss different WWM sustainable options for Khartoum State. Three WWM approaches were investigated, centralized and decentralized wastewater management approaches, using Multi Criteria Decision Analysis to evaluate their suitability and sustainability for fast-expanding cities like Khartoum State – in Sudan. The results revealed that centralized wastewater approach is costly to build and operate, especially with horizontally expanding cities with low population densities. Future expansions can be problematic in terms of design and finance aspects. Decentralized wastewater management approach (onsite and cluster) was regarded as more sustainable, where such an approach is more flexible for planning, and simple as well as complex technologies are available. The decentralized system is not only a long-term solution but is more reliable and cost effective for future development purposes and sustainability assurance.

Baserba.M et. al Stricter regulations in the field of sanitation are driving new dimensions of analysis, in which socio-economic criteria combined with associated environmental issues are in turn increasing the complexity of wastewater management. In this environment, the development of innovative wastewater treatment technologies provides decision-makers with many efficient alternatives to face these new challenges. In this paper, it was demonstrated that these requirements have been successfully met in an environmental decision support system (EDSS). The EDSS was built according to a knowledge-based methodology, whose main objective is the identification and assessment of the most appropriate wastewater treatment technologies for the design of new facilities or the upgrading of obsolete plants. Because removal of nutrients is essential to this approach, this study explores the use of the EDSS to address the selection of biological treatment technologies for different scenarios characterized by wastewater composition (C/ N ratio) and other relevant criteria such as environmental and economic factors, population size, discharge in sensitive areas, reuse, cost-benefit analysis, life-cycle analysis, and technical aspects (use of innovative technologies, space availability, reliability, and simplicity of operation).

Marcos von Sperling et. al The paper presents a series of tables, figures and charts which can be used for the preliminary selection of wastewater treatment systems, especially in developing countries. The systems analysed are: stabilization ponds, activated sludge, trickling filters, anaerobic systems and land disposal. Within each system, the main process variants are covered.

CHAPTER 4. : Basic Principle of Natural Wastewater (Green) Treatment Systems

All wastewater management processes depend on natural responses, such as gravity forces for sedimentation, or on natural components, such as biological organisms. In the conventional case, however, these natural components are supported by an often-complex array of energy-intensive mechanical equipment.

The term natural system is intended to describe those processes that depend primarily on their natural components to achieve the desired purpose. A natural system might typically include pumps and piping for wastewater conveyance and distribution but would not depend on external energy sources exclusively to maintain the major treatment responses.

In theory, any specified level of water quality could be achieved via a combination of mechanical operations; however, the energy requirements and high costs of this approach soon became an obstacle, and a search for alternatives commenced.

Land application of wastewater was the first "natural" technology to be rediscovered. In the 1840s in England, it was recognized as avoiding water pollution as well as returning nutrients in wastewater back to the land. In the 19th century it was the only acceptable method for waste treatment, but it gradually slipped from use with the invention of modern devices. Studies and research quickly established that land treatment could be very effective to achieve many goals while at the same time obtaining significant benefit from the reuse of the nutrients, other minerals, and organic matter in the wastes. Land treatment of wastewater became recognized and accepted by the engineering profession as a viable treatment concept and it is now considered routinely in project planning and design.

Other "natural" concepts that have never been dropped from use include ***lagoon systems and land application of sludges***. Wastewater lagoons model the physical and biochemical interactions that occur in natural ponds, while land application of sludges model conventional farming practices with animal manures.

Aquatic and wetland concepts are relatively new developments with respect to utilization of wastewaters and sludges. Some of these concepts provide other cost-effective wastewater treatment options.

4.1. Wastewater Treatment Concepts and Performance Expectations [11]

systems for effective wastewater treatment are available in three major categories:

- Aquatic
- Wetland
- Terrestrial.

All depend on natural physical and chemical responses as well as the unique biological components in each process.

4.1.1. Aquatic Treatment Units

The design features and performance expectations for natural aquatic treatment units are summarized in ***Table 4.1***. In all cases, the major treatment responses are due to the biological components. In most of the pond systems listed in Table 4.1, both performance and final water quality are dependent on the algae present in the system. Algae are functionally beneficial, providing oxygen to support other biological responses, and the algal–carbonate reactions are the basis for effective nitrogen removal in ponds; however, algae can be difficult to remove. When stringent limits for suspended solids are required, alternatives to facultative ponds must be considered. For this purpose, controlled discharge systems were developed in which the treated wastewater is retained until the water quality in the pond and conditions in the receiving water are mutually compatible.

Table 4. 1 Design Features and Expected Performance for Aquatic Treatment Units [11]

Concepts	Typical Criteria					
	Treatment Goals	Climate Needs	Detention Time (days)	Depth (m)	Organic Loading (Kg/ha-d)	Effluent Characteristics (mg/L)
Oxidation Pond	Secondary	Warm	10 to 40	1 to 1.5	40 to 120	BOD: 20 -40 TSS: 80 -140
Facultative Pond	Secondary	None	25 to 180	5 to 8	22 to 67	BOD: 30 -40 TSS: 40 -100
Partial- mix aerated pond	Secondary	None	7 to 20	2 to 6	50 to 200	BOD: 30 -40 TSS: 30 -60

4.1.2. Wetland Treatment Units

Wetlands are defined as land where the water table is at (or above) the ground surface long enough to maintain saturated soil conditions and the growth of related vegetation. The capability for wastewater renovation in wetlands has been verified in numerous studies in a variety of geographical settings. Wetlands used in this manner have included pre-existing natural marshes, swamps, strands, bogs, peat lands, cypress domes, and systems specially constructed for wastewater treatment. The design features and expected performance for the three basic wetland categories are summarized in ***Table 4.2***. A major constraint on the use of many natural marshes is the fact that they are considered part of the receiving water by most regulatory authorities. As a result, the wastewater discharged to the wetland has to meet discharge standards prior to application to the wetland. In these cases, the renovative potential of the wetland is not fully utilized.

Table 4. 2 Design Features and Expected Performance for Four Types of Wetlands [11]

Concepts	Typical Criteria					
	Treatment Goals	Climate Needs	Detention Time (days)	Depth (m)	Organic Loading (Kg/ha-d)	Effluent Characteristics (mg/L)
Free Water Surface	Secondary	None	7 to 15	0.1 to 0.6	100	BOD: 5 -10 TSS: 5 -15 TN: 5 - 20
Sub Surface Flow	Secondary	3 to 14	25 to 180	0.3 to 0.6	90	BOD: 5 -40 TSS: 5 -20 TN: 5 - 20
Vertical Flow	Primary	1 to 12	7 to 20	0.6 to 0.9	200	BOD: 5 -10 TSS: 5 -10 TN: 10 - 20

Constructed wetland units avoid the special requirements on influent quality and can also ensure much more reliable control over the hydraulic regime in the system; therefore, they perform more reliably than natural marshes. The three types of constructed wetlands in general use, they are:

- the ***free water surface (FWS) wetland***, which is similar to a natural marsh because the water surface is exposed to the atmosphere,
- the ***subsurface flow (SSF) wetland***, where a permeable medium is used and the water level is maintained below the top of the bed, and
- the ***vertical flow (VF) wetlands***, where the distribution system is on the surface and the distributed flow moves vertically through sand and gravel media as shown in ***Figure 4.1.***

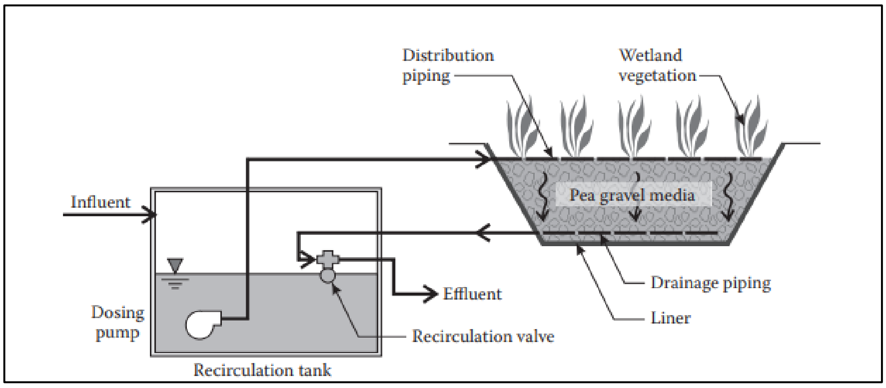


Figure 4. 1: Vertical flow constructed wetlands with recycle.

4.1.3. Terrestrial Treatment Methods

Typical design features and performance expectations for the three basic terrestrial concepts are presented in ***Table 4.3***. All three are dependent on the physical, chemical, and biological reactions on and within the soil matrix. In addition, the ***slow rate (SR)*** and ***overland flow (OF)*** methods require the presence of vegetation as a major treatment component. The slow rate process can utilize a wide range of vegetation, from trees to pastures to row-crop vegetables (shown in ***Figure 4.2***). The overland flow process depends on perennial grasses to ensure a continuous vegetated cover. The hydraulic loading rates on rapid infiltration (RI) systems, with some exceptions, are typically too high to support beneficial vegetation. All three concepts can produce high-quality effluent. In the typical case, the SR process can be designed to produce drinking water quality in the percolate. Reuse of the treated water is possible with all three concepts. Recovery is easiest with OF because it is a surface system that discharges to ditches at the toe of the treatment slopes. Most SR systems require underdrains or wells for water recovery.

Another type of terrestrial concept is on-site systems that serve single-family dwellings, schools, public facilities, and commercial operations. These typically include a preliminary treatment step followed by in-ground disposal.

Table 4. 3 Terrestrial Treatment Units, Design Features, and Performance [11]

Concepts	Typical Criteria					
	Treatment Goals	Climate Needs	Vegetation	Area (ha)	Hydraulic Loading (m/yr)	Effluent Characteristics (mg/L)
Slow Rate	Secondary	Warmer seasons	Yes	23 to 280	0.5 to 6	BOD: <2 TSS: < 2 TN: <3 TP: <0.1 FC: 0/100 ml
Overland Flow	Secondary	Warmer seasons	Yes	6 to 40	3 to 20	BOD: 10 TSS: 10 TN: <10

Figure 4. 2: Fresh vegetables irrigated with recycled water

4.2. Basic Process Responses and Interaction

Many of the responses and interactions between the wastewater constituents and process components are common to more than one of the treatment concepts. Water is the major constituent of all the wastes of concern, as even a “dewatered” sludge can contain more than 50% water. The presence of water is a volumetric concern for all treatment methods, but it has even greater significance for many of the natural treatment concepts because the flow path and the flow rate control the successful performance of the system. Other wastewater constituents of major concern include the simple carbonaceous organics (dissolved and suspended), toxic and hazardous organics, pathogens, trace metals, nutrients (nitrogen, phosphorus, potassium), and other micronutrients. The natural system components that provide the critical reactions and responses include bacteria, protozoa (e.g., algae), vegetation (aquatic and terrestrial), and the soil. The responses involved include a range of physical, chemical, and biological reactions.

4.3. Important Design Considerations

There are significant factors that are essential for the design of wastewater treatment processes and plant units. The essential design factors include the following:

- Strength and characteristics of wastewater
- Flow rates and their fluctuations
- Mass Loading
- Design Criteria

4.3.1. Strength and Characteristics of Wastewater

The foremost important factor that is required to be known for designing of the wastewater is its strength and characteristics. The strength of the wastewater is generally termed as pollution load-determined from the concentrations of significant physical, chemical, and biological contents present in the wastewater.

Table 4. 4: Significant Parameters for Physical, Chemical and Biological Characteristics [9]

Physical characteristics	Chemical characteristics	Biological characteristics
Solids *Total, Suspended and Dissolved,* *Volatile and Fixed Solids*	Organic Contents *BOD, COD, fats, phenols, surfactants, oil, grease etc.*	Animals
Colour	Inorganic contents *Alkalinity, Chlorides, nitrogen, phosphorus, sulphur, heavy metals, pH etc.*	Plants
Odour	Gases *Oxygen, methane, hydrogen sulphide*	Protista
Temperature	-	Pathogens

4.3.2. Flow Rates and Fluctuations

The next important parameter is the quantum of wastewater generated in terms of flow rates. It is the total quantity of the wastewater needed to be treated every day. This quantity of wastewater is never uniform all throughout the day, nor is it uniform all throughout the year for 365 days.
Hence fluctuations in flow rate occurs as:

- Daily variation
- Seasonal variation

Definitions of different types of Flow Rates is as follows:

Q_d = Daily flow rate (m^3/d, MLD)

Q_{avg} = Daily average flow rate based on yearly data (m^3/d, MLD)

Q_{peak} = Peak/ Maximum daily flow based on yearly data (m^3/d, MLD)

<u>Some useful ratios:</u>

Peak factor = Maximum Flow/ Average Flow = 1.5 - 3.0 (usually)

Minimum factor = Minimum Flow/ Average Flow = 0.1 - 0.3 (usually)

4.3.3. Concept of Mass Load

The mass pollution in terms of any particular parameter, say, biochemical oxygen demand or suspended solids, is usually defined as product of volume (flow rate) and the strength of the wastewater expressed as mass load per unit time.

<u>For example</u>: Wastewater having 1000 m^3/day flow and 200 mg/l (g/m^3) Bod has the mass pollution load of BOD of 200 Kg/day (1000 m^3/day x 200 mg/l)

4.3.4. Concept of Design Criteria

The most frequently used criteria for designing wastewater treatment plants are as follows:

- *Detention period/ time (Hydraulic Retention Time, HRT; t/ Θ)*
- *Flow through velocity (Horizontal velocity of flow, v_h)*
- *Settling Velocity (v_s)*
- *Surface Loading Rate/ Over Flow Rate (SLR/ OFR)*
- *Weir Loading Rate (WLR)*
- *Organic Loading (BOD/ COD/ VSS loading)*
- *Food to Microorganisms Ratio (F/M)*
- *Mean Cell Residence Time (MCRT)/ Solids Retention Time (SRT, Θ_c)*
- *Hydraulic Loading*
- *Volumetric Loading*
- *Basin Geometry- Length: Breadth: Depth (Rectangular tanks) & Diameter and Side Water Depth (Circular tank)*

As designing of the wastewater treatment units depend on the above-mentioned criteria, a clear understanding of the terms is necessary.

I. *<u>Detention period/ time (Hydraulic Retention Time, HRT; t/ Θ)</u>*

It is the time in which a particle or a unit volume of wastewater remains in the reactor. It is a very important parameter which is used to determine the sizing of the treatment plant units.

Mathematically, $t = V/Q$ ………………………….. Equation 4. 1

Where,

t = Detention time in days

V = Volume of the basin (m^3)

Q = Flow of wastewater (m^3/day)

II. *Flow through velocity (Horizontal velocity of flow, v_h)*

In any tank having continuous flow, the solid particles experience two types of velocity, one along the horizontal direction due to drag force, and another along the vertical direction due to gravitational force. The horizontal velocity component is called the flow through velocity (v_h), while the vertical component is called settling velocity (v_s).

Mathematically, v_h = L/t……………………………Equation 4. 2

Where,

v_h = Flow through velocity (m/d)
L = Length of the rectangular basin (m)
t = Detention time in days

III. *Settling Velocity (v_s)*

Settling velocity is used to determine the depth of treatment unit to separate the suspended solids by gravity settling and for checking the adequacy of the length/diameter of the tank to remove the particles before the effluent flows out of the basin.

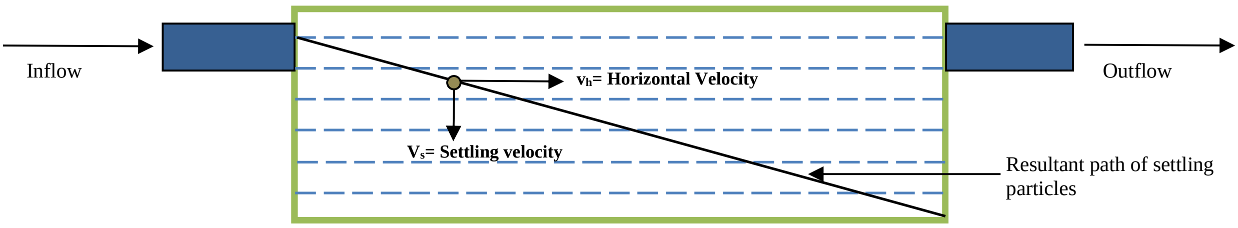


Figure 4. 3 : Settling path of a solid in a tank

IV. *Surface Loading Rate (SLR) / Over Flow Rate (OFR)*

It is the volume of wastewater (flow rate) applied per unit surface area of the treatment basin. This is used to determine the surface area of the tank.

Mathematically, SLR= Flow/ Surface area……………………………Equation 4. 3

V. *Organic Loading*

The concept of organic loading is more significant in the design of secondary treatment units, particularly in the case of designing reactors for biological processes. Organic loading conceptually means the total quantity of organic matter (in terms of BOD/ COD) that is applied per day over the unit surface area or per unit volume of the treatment tank or basin.

This is significant in determining either the surface area or the volume of the treatment unit when the total quantity of organic load is known.

VI. ***Mean Cell Residence Time/ Solids Retention Time (SRT, Θc)***

It is the average time in days for which the biomass or biological solids are retained or remains in the biological reactor or system. It is also termed as sludge age.

VII. ***Food to Microorganism Ratio***

It is the relationship between the food (F) available and the microorganisms (M) present in a biological reactor.
It is a process parameter which is used to measure or control the performance of treatment process. The food available to the microorganisms is measured in terms of the BOD/ COD of the influent (Kg/d) and the MLVSS (Mixed Liquor Volatile Suspended Solids) is the measure of mass of the organisms (biomass) in the reactor unit in Kg. If biomass M is measured as MLSS, then normally MLVSS is computed assuming MLVSS as 55% - 80 % of MLSS.
Mathematically,

$F/M = (Q \times S_o)/ (V \times X)$…………………………Equation 4. 4

$F/M = S_o/ (\Theta \times X)$,……………………………Equation 4. 5

where,

S_o = Influent Substrate (mg/L)
X = Concentration of biomass in reactor as MLSS/ MLVSS (mg/L)

VIII. ***Hydraulic Loading***

The hydraulic loading refers to the daily quantity of wastewater applied to each unit surface area of the treatment basin. It helps in determining the surface area of the treatment unit when the flow of wastewater is known.

IX. ***Volumetric Loading***

It refers to the daily quantity of wastewater applied to each unit volume of the treatment basin. It helps in determining the volume of the treatment unit when the flow of wastewater is known.

X. ***Length : Breadth : Depth Ratio***

It has been found that the ratio of the length, breadth and depth of the rectangular tank affects the hydraulic performance of the rectangular treatment units. If the ratio is not maintained, then it can result in hydraulic short-circuiting between the inlet and outlet channels, with formation of dead pockets at the corners of the tank

However, such phenomenon is more significant in waste stabilization ponds as proper L:B ratio is not followed while designing the large surface area of the ponds.

4.3.5. Design Essentials

The rates at which wastewater constituents will be removed or converted to produce new cells in the reactor, the type of the reactor, and the kind of reactions occurring in the treatment units are very significant in the designing of wastewater treatment systems.

➢ **Reaction Rates**

The rate of many reactions is proportional to the concentration of the reactants raised to a small integral power.
The three commonly occurring reaction rates in wastewater treatment have been classified as:

I. Zero Order
II. First Order
III. Second Order

➢ **Concept of Reactors**

The units or vessels that hold the wastewater to undergo treatment by various methods are called reactors. The reactors may be of any shape, but mostly rectangular or circular reactors are adopted.

➢ **Type of Reactors**

Depending on the flow and operating conditions and the method of mixing of the wastewater therin, the reactors have been classified as-

I. Continuous- Flow Stirred Tank Reactor (CFSTR)
II. Plug-Flow Reactor (PFR)
III. Completely Mixed Batch Reactor (CMBR)

In some specific cases, the treatment system may be designed to achieve desired degree of treatment by adopting same type of reactor or any combination of above reactors in series.
A brief description of the different types of reactor:

I. Continuous- Flow Stirred Tank Reactor (CFSTR)

As the flow of wastewater is continuous in such types of reactors, the reactants entering the reactor and the products flowing out from the reactor are considered as continuous. It is assumed that the contents are distributed throughout the tank as soon as the wastewater enters the reactor and their uniform concentrations are maintained in the reactor operating under steady state conditions.

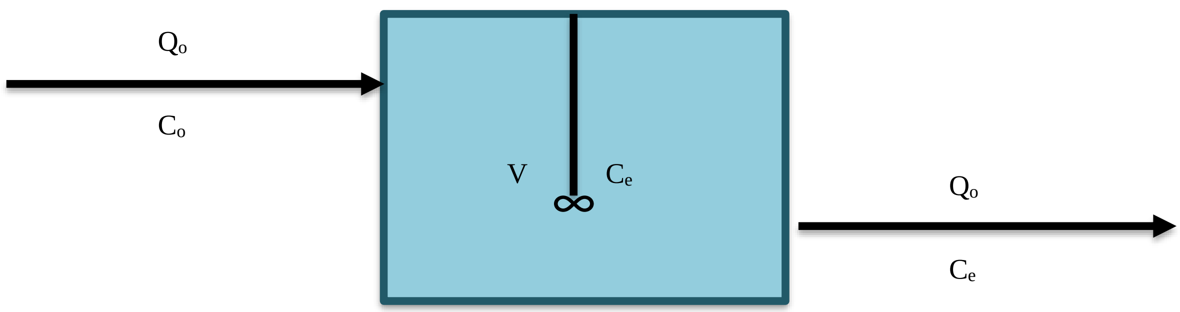


Figure 4. 4 : Schematic Diagram of CFSTR

Here, the notations are:

V	=	Reactor Volume
Q_o	=	Wastewater Flow rate
C_o	=	Reactant concentration in the influent
C_e	=	Final reactant concentration in the effluent

II. Plug-Flow Reactor (PFR)

In a plug flow reactor, the contents of the wastewater follow the principle of "First-in-first-out". So, the particles pass through the tank in the same sequence they enter the tank. The longitudinal mixing is assumed to be almost negligible. The concentration of a reactant varies with time and along the length of the reactor.

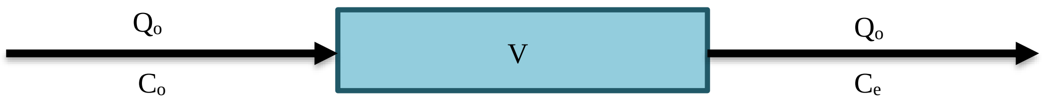


Figure 4. 5 : Schematic Diagram of PFR

III. Completely Mixed Batch Reactor (CMBR)

A completely mixed batch reactor is a closed system where no flow is added or allowed to leave during the detention period/ reaction time. The reactants are added to the reactor when it gets empty, and the reactants are allowed to leave once the reaction time is over. The reaction kinetics is assumed to be first order, and at a given time , the reactant concentration is uniform throughout the reactor.

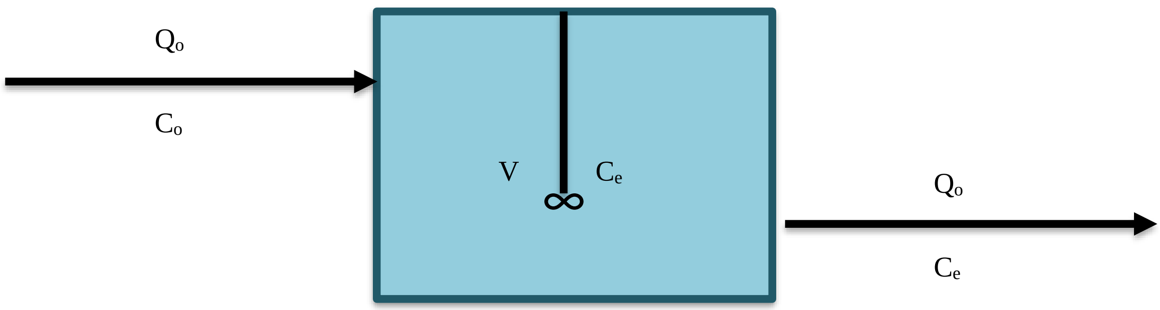


Figure 4. 6 : Schematic Diagram of CMBR

CHAPTER 5. : Methodology: Planning, Feasibility Assessment, and Site Selection

When conducting a wastewater treatment and reuse planning study, it is important to evaluate as many alternatives as possible to ensure that the most cost-effective and appropriate system is selected. For new or unsewered communities, decentralized options should also be included in the mix of alternatives. The feasibility of the natural treatment processes depends significantly on-site conditions, climate, regulatory requirements, and related factors. It is neither practical nor economical, however, to conduct extensive field investigations for every process, at every potential site, during planning. A sequential approach needs to be adopted which first determines potential feasibility and the necessary land requirements and site conditions of each alternative. The second step evaluates each site coupled with a natural treatment process based on technical and economic factors and selects one or more for detailed investigation. The final step involves detailed field investigations, identification of the most cost-effective alternative, and development of the criteria necessary for the final design.

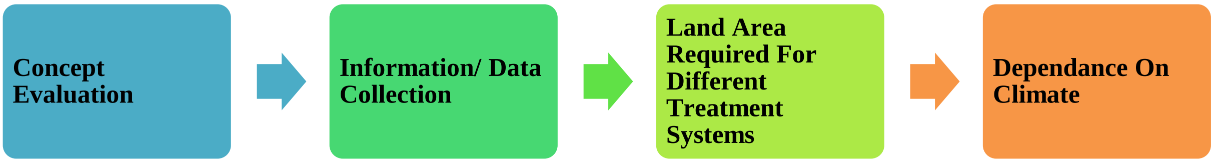


Figure 5. 1 : A Schematic Diagram Indicating the Approach Methodology

5.1. Concept Evaluation

One way of categorizing the natural systems is to divide them between discharging and non-discharging systems. Discharging systems would include those with a surface water discharge, such as treatment ponds, constructed wetlands, and overland flow land treatment. Under drained SR systems may also have a surface water discharge that would be permitted under the National Regulation. Non-discharging systems would include reuse wetlands, slow rate land treatment, onsite methods, and biosolids treatment and reuse methods. Site topography, soils, geology, and groundwater conditions are important factors for the construction of discharging systems but are often critical components of the treatment process itself for non-discharging systems. Design features and performance expectations for both types of systems are presented in Tables 5.1. Special site requirements are summarized in Tables 5.1 and 5.2 for each type of system for planning purposes. It is presumed that the percolate from a non-discharging system mingles with any groundwater that may be present. The typical regulatory requirement for compliance is the quality measured in the percolate/ groundwater as it reaches the project boundary.

Table 5. 1 Special Site Requirements for Discharge Systems [11]

Concept	Requirement
Treatment Ponds	• Proximity to a surface water for discharge, • impermeable soils or liner to minimize seepage, • no steep slopes, • no groundwater within the excavation depth
Constructed Wetlands	• Proximity to a surface water for discharge, • impermeable soils or liner to minimize seepage, • 0%-6% slopes, • no groundwater within the excavation depth
Overflow Rate	• Relatively impermeable soils, clay and clay loam, • slopes 0%-12%, • depth to groundwater is not critical, however 0.5-1 m is desirable, • must have access to surface water for discharge

Table 5. 2 Special Site Requirements for Non-discharging System [11]

Concept	Requirement
Slow Rate	• Sand loams to clay loams: >0.15 to <15cm/hr permeability, • slope <20%, • groundwater >1.5m
Rapid Infiltration	• Sand loams to clay loams: 5 to 50cm/hr permeability, • slope <10%, • groundwater >5m

5.2. Information Needs and Sources/ Data Collection

A preliminary determination of process feasibility and identification of potential sites are based on the analysis of maps and other information. The requirements shown in Tables 5.1 and 5.2, along with an estimate of the land area required for each of the methods, are considered during this procedure. The type of information needed are summarized below-

- Elevations, slope, water and drainage features, building and road locations (Through Topographic survey)
- Soil type, depth and permeability, depth to bedrock, slope (Through Geo-technical Investigation)
- Flood hazard (Through Concerned Department/s)
- Land use, water supply, sewerage systems (Through Concerned Department/s)
- Climatic data (Through Concerned Department/s)
- Geologic data, water quality data (Through Concerned Department/s)

5.3. Land Area Required

The land area estimates derived to determine, with a study of the maps, whether suitable sites exist for the process under consideration. These preliminary area estimates are very conservative and are intended only for this preliminary evaluation. These estimates should not be used for the final design.

Treatment Ponds The types of treatment ponds include oxidation ponds, facultative ponds, controlled-discharge ponds, partial-mix aerated ponds, complete-mix ponds, proprietary approaches, and modifications to conventional.

5.3.1. Treatment Ponds

The types of treatment ponds include oxidation ponds, facultative ponds, controlled-discharge ponds, partial-mix aerated ponds, complete-mix ponds, proprietary approaches, and modifications to conventional approaches. The area estimate for pond systems will depend on the effluent quality required (as defined by biochemical oxygen demand [BOD] and total suspended solids [TSS]), on the type of pond system proposed, and on the climate in the particular geographic location. The equations given below are for total project area and include an allowance for roads, levees, and unusable portions of the site.

i. Facultative Ponds in Cold Climates

The area calculation in Equation 4.1 assumes an 80-day detention time, a pond 1.5 m deep, an organic loading of 16.8 kg/ha·d, (15 lb/ac·d) an effluent BOD of 30 mg/L, and TSS > 30 mg/L. The area required is:

A_{fw}= (k)(Q) …………………………Equation 5. 1

Where,

A_{fw} = facultative pond site area, warm climate in ha

k = factor 1.6×10^{-2},

Q = design flow in m^3/d

ii. Facultative Ponds in Warm Climates

Assume more than 60 days of detention in a pond 1.5 m deep and an organic loading of 56 kg/ha·d (50 lb/ac·d); the expected effluent quality is BOD = 30 mg/L and TSS > 30 mg/L. The area required is:

A_{fw} = (k)(Q)…………………………Equation 5. 2

Where,

A_{fw} = facultative pond site area, warm climate in ha

k = factor 5.0×10^{-3},

Q = design flow in m^3/d

iii. Controlled-Discharge Ponds

Controlled-discharge ponds are used to avoid winter discharges and in warm climates to match effluent quality to acceptable stream flow conditions. The typical depth is 1.5 m, maximum detention time is 180 days, and the expected effluent quality is BOD < 30 mg/L and TSS < 30 mg/L. The required site area is:

A_{cd} = (k)(Q) …………………………Equation 5. 3

where

A_{cd} = controlled-discharge pond site area in ha

k = factor -1.63 × 10^{-2}

Q = design flow in m^3/d

iv. Partial-Mix Aerated Pond

The size of the partial-mix aerated pond site will vary with the climate; for example, shorter detention times are used in warm climates. Assumed detention time is 50 days, depth of 2.5 m, and an organic loading of 100 kg/ha·d. Expected effluent quality is BOD = 30 mg/L and TSS > 30 mg/L. The site area can be calculated using Equation 5.4:

A_{pm} = (k)(Q) ………………………………..Equation 5. 4

Where,

A_{pm} = aerated pond site area in ha

k = factor - 2.9 × 10^{-3}

Q = design flow in m^3/d

5.3.2. Free Water Surface Constructed Wetlands

Constructed wetlands are typically designed to receive primary or secondary effluent, to produce an advanced secondary effluent, and to operate year-round in moderately cold climates. The detention time is assumed to be 7 days, the depth is 0.3 m, and the organic loading is <100 kg/ha·d. The expected effluent quality is BOD = 10 mg/L, TSS = 10 mg/L, total N < 10 mg/L (during warm weather), and P > 5 mg/L. The estimated site area given in Equation 5.5 does not include the area required for a preliminary treatment system before the wetland:

A_{fws} = (k)(Q) ……………………………….Equation 5. 5

Where,
A_{fws} = site area for free water surface constructed wetland in ha
k = factor - 4.31 × 10^{-3}
Q = design flow in m^3/d

5.3.3. Subsurface Flow Constructed Wetlands

Subsurface flow constructed wetlands generally require less site area for the same flow than do free water surface wetlands. The assumed detention time is 3 days, the water depth is 0.3 m, with a media depth of 0.45 m; the organic loading rate is <80 kg/ha·d; and the expected effluent quality is similar to the free water surface wetlands above:

$A_{ssf} = (k)(Q)$ ……………………………Equation 5. 6

Where,
A_{ssf} = site area for subsurface flow constructed wetland in ha
k = factor - 1.85×10^{-3}
Q = design flow in m^3/d

5.3.4. Vertical Flow Wetlands

The area needed for a vertical flow wetland depends on the hydraulic loading rate selected and the average design flow. The area needed can be calculated using Equation 5.7.
$A_{vf} = (k)(Q)$ …………………………………Equation 5. 7

Where,

A_{vf} = site area for vertical flow wetlands in m^2

K = factor - 0.041

Q = design flow in m^3/d

5.3.5. Overland Flow Systems

The area required for an OF site depends on the length of the operating season. The recommended storage days for an overland flow system for planning purposes can be estimated. The effective flow to the OF site can then be estimated using Equation 5.8:
$Q_m = q + (t_s)(q)/t_a$ ………………………………...Equation 5. 8

Where,

Q_m = average monthly design flow to the overland flow site in m^3/mo

q = average monthly flow from pre-treatment in m^3/mo
ts = number of months storage is required
ta = number of months in the operating season

The OF process can produce advanced secondary effluent from a primary effluent or equivalent. The expected effluent quality is BOD = 10 mg/L, TSS = 10 mg/L, total N < 10 mg/L, and total P < 6 mg/L. The site area given by Equation 2.10 includes an allowance for a 1-day aeration cell and for winter wastewater storage (if needed), as well as the actual treatment area, with an assumed hydraulic loading of 15-cm/wk:

$$A_{of} = (3.9 \times 10^{-4})\,(Q_m + 0.05qt_s)$$ ……………………..**Equation 5. 9**

Where,

A_{of} = overland flow project area in ha

Q_m = average monthly design flow to the overland flow site, m^3/mo

q = average monthly flow from pre-treatment, m^3/mo

t_s = number of months storage is required

5.3.6. Slow-Rate (SR) Systems

SR systems are typically non-discharging systems. The size of the project site will depend on the operating season, the application rate, and the crop. The number of months of possible wastewater application can be estimated based on the geographical location. The design flow to the SR system can be calculated from Equation 4.10. The land area will be based on either the hydraulic capacity of the soil or the nitrogen loading rate. The expected effluent (percolate) quality is BOD < 2 mg/L, TSS < 1 mg/L, total N < 10 mg/L (or lower if required), and total P < 0.1 mg/L:

$$A_{sr} = (6.0 \times 10^{-4})\,(Q_m + 0.03qt_s)$$ …………………….**Equation 5. 10**

Where,

A_{sr} = slow rate land treatment project area in ha

Q_m = average monthly design flow to the SR site, m^3/mo

q = average monthly flow from pre-treatment, m^3/mo

t_s = number of months storage is required

5.4. Site Identification

It is possible that a community or industry may not have suitable sites for all the natural system options. However, whichever sites are suitable, should be located on the maps. Some options may be dropped from consideration because no suitable sites are located within a reasonable proximity from the wastewater source. In the next step, local knowledge regarding land use commitments, costs, and the technical ranking procedure are considered to determine which processes and sites are technically feasible. A complex screening procedure is not usually required for pond and wetland systems, because close proximity and access to the point of discharge are usually most important in site selection for these systems. For land application systems for wastewater and biosolids, the economics of conveyance to the potential site may compete with the physical and land use factors described in the following section.

5.5. Climate

The regional climate has a direct effect on the potential biosolids management options. Climatic factors are not included in the rating procedure for wastewater systems, because seasonal constraints on operations are already included as a factor in the land area determinations. Seasonal constraints and the local climate are important factors in determining the design hydraulic loading rates and cycles for wastewater systems, as well as the length of the operating season and stormwater runoff conditions for all concepts. The pertinent climatic data required for the design of both wastewater and biosolids systems are listed in Table 5.3.

Table 5. 3: Climatic Data Required for Land Application Designs

Condition	Required Data	Types of Analysis
Precipitation	• Rainfall, • Snowfall (annual average, maximum, minimum)	• Frequency, • Annual Distribution
Storm Events	• Intensity, • Duration	Frequency
Temperature	• Variation all throughout the year	Frequency
Wind	• Direction, • Velocity	-
Evapotranspiration	• Annual average, • Monthly average	Annual distribution

CHAPTER 6. : Treatment Options

6.1. Waste Stabilization Ponds

6.1.1. Introduction

Figure 6. 1 : Waste Stabilization Pond

Waste Stabilization Ponds (WSPs) are large, shallow basins in which raw sewage is treated entirely by natural processes involving both algae and bacteria. They are used for sewage treatment in temperate and tropical climates, and represent one of the most cost-effective, reliable and easily operated methods for treating domestic and industrial wastewater. Waste stabilization ponds are very effective in the removal of faecal coliform bacteria. Sunlight energy is the only requirement for its operation. Further, it requires minimum supervision for daily operation, by simply cleaning the outlets and inlet works. The temperature and duration of sunlight in tropical countries offer an excellent opportunity for high efficiency and satisfactory performance for this type of water-cleaning system. They are well-suited for low-income tropical countries where conventional wastewater treatment cannot be achieved due to the lack of a reliable energy source. Further, the advantage of these systems, in terms of removal of pathogens, is one of the most important reasons for its use.

WSP systems comprise a single string of anaerobic, facultative and maturation ponds in series, or several such series in parallel. In essence, anaerobic and facultative ponds are designed for removal of Biochemical Oxygen Demand (BOD), and maturation ponds for pathogen removal, although some BOD removal also occurs in maturation ponds and some pathogen removal in anaerobic and facultative ponds (UNEP). In most cases, only anaerobic and facultative ponds will be needed for BOD removal when the effluent is to be used for restricted crop irrigation and fishpond fertilization, as well as when weak sewage is to be treated prior to its discharge to surface waters. Maturation ponds are only required when the effluent is to be used for unrestricted irrigation, thereby having to comply with the WHO guideline of >1000 faecal coli form bacteria/100 ml. The WSP does not require mechanical mixing, needing only sunlight to supply most of its oxygenation. Its performance may be measured in terms of its removal of BOD and faecal coli form bacteria.

6.1.2. Processes in Waste Stabilization Ponds

a. Anaerobic Ponds

Anaerobic ponds are commonly 2 - 5 m deep and receive wastewater with high organic loads (i.e., usually greater than 100 g BOD/m^3.day, equivalent to more than 3000 kg/ha.day for a depth of 3 m). They normally do not contain dissolved oxygen or algae. In anaerobic ponds, BOD removal is achieved by sedimentation of solids, and subsequent anaerobic digestion in the resulting sludge. The process of anaerobic digestion is more intense at temperatures above 15^o C. The anaerobic bacteria are usually sensitive to pH <6.2. Thus, acidic wastewater must be neutralized prior to its treatment in anaerobic ponds. A properly designed anaerobic pond will achieve about a 40% removal of BOD at 10^o C, and more than 60% at 20^o C. A shorter retention time of 1.0 - 1.5 days is commonly used.

b. Facultative Ponds

Facultative ponds (1-2 m deep) are of two types: Primary facultative ponds that receive raw wastewater, and secondary facultative ponds that receive particle-free wastewater (usually from anaerobic ponds, septic tanks, primary facultative ponds, and shallow sewerage systems). The process of oxidation of organic matter by aerobic bacteria is usually dominant in primary facultative ponds or secondary facultative ponds.

The processes in anaerobic and secondary facultative ponds occur simultaneously in primary facultative ponds. It is estimated that about 30% of the influent BOD leaves the primary facultative pond in the form of methane (UNEP). A high proportion of the BOD that does not leave the pond

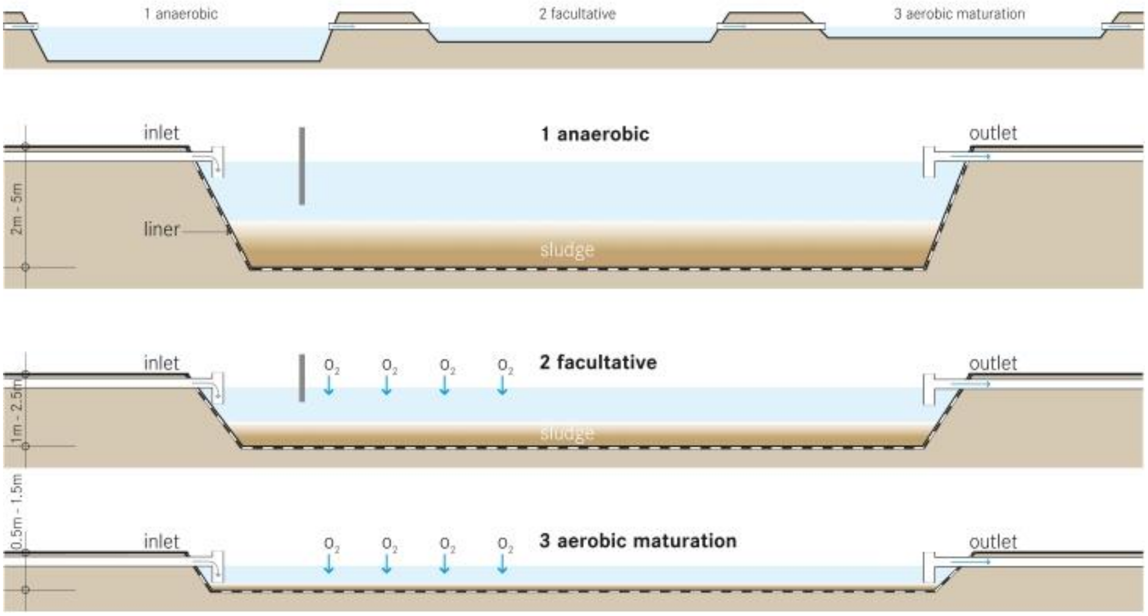


Figure 6. 2 : A Typical Schematic Diagram of Waste Stabilisation Ponds (WSP)

as methane ends up in algae. This process requires more time, more land area, and possibly 2 -3 weeks water retention time, rather than 2 -3 days in the anaerobic pond. In the secondary facultative pond (and the upper layers of primary facultative ponds), sewage BOD is converted into "Algal BOD", and has implications for effluent quality requirements. About 70 - 90% of the BOD of the final effluent from a series of well-designed WSPs is related to the algae they contain.

c. *Maturation Ponds*

Maturation ponds (low-cost polishing ponds), which generally follow either the primary or secondary facultative pond, are primarily designed for tertiary treatment, i.e., the removal of pathogens, nutrients and possibly algae. They are very shallow (usually 0.9 – 1 m depth), to allow light penetration to the bottom and aerobic conditions throughout the whole depth. The loading on the maturation pond is calculated on the assumption that 80% of the BOD has been removed in the preceding treatment. Maturation pond is the third pond in the multi- cell series of WSP system and is designed for faecal coliform removal.

6.1.3. Basic Design Guidelines

The basic design criteria for waste stabilization pond are: -

1. Sewage flow rate
2. Temperature and Net Evapotranspiration
3. BOD

When these criteria are properly established the size types and number of ponds required can be determined.

A brief description on how these parameters influence the process design of the WSP are as follows:

1. *Sewage Flow Rate*:
   The size of the ponds, and hence their cost, is directly proportional to the flow. A suitable design value is 80 percent of the in-house water consumption.
   In CPHEEO Manual, the sewage generated per household is advised to be calculated as 80% of water consumption per capita.
   The mean daily flow or the average flow of wastewater is considered for designing of the system.
2. *Temperature & Net Evapotranspiration*:
   The usual design temperature is the mean air temperature in the coolest month (or quarter). This provides a small margin of safety as pond temperatures are 2-3^{o} C warmer than air temperatures in the cool season (the reverse is true in the hot season).
   Net evaporation (= evaporation – rainfall) has to be considered in the design of facultative and maturation ponds (Shaw, 1962), but not in that of anaerobic ponds, as these generally have a scum layer which effectively prevents significant evaporation. The net evaporation rates in the months used for selection of the design temperatures are used.

3. *BOD:*

BOD may be measured using 24-hour flow-weighted composite samples for proper. If it does not, it may be estimated from the following equation:

Li = 1000 B/q ………..Equation 6. 1

Where, Li = wastewater BOD, mg/l

B = BOD contribution, g/caput d

q = wastewater flow, l/caput d

6.1.4. Design of Waste Stabilization Ponds

Design of Anaerobic Pond

Anaerobic Pond can be satisfactorily designed on the basis of the volumetric BOD loading (λ_V, g/m^3d), which is given by:

$$\lambda_V = LiQ/V_a \text{ ………..Equation 6. 2}$$

Where, Li = influent BOD, mg/l (= g/m3)

Q = flow, m3/d

V_a = anaerobic pond volume, m3

The permissible design value of λ_V increases with temperature. The recommended design values (Mara and Pearson (1986)), given in the following table which may be safely used for design purposes in India.

Once a value of λ_V has been selected, the anaerobic pond volume is then calculated from Equation 6.2. The mean hydraulic retention time in the pond (θ_a, d) is determined from:

$$\theta_a = V_a/Q \text{ …………Equation 6. 3}$$

Retention times in anaerobic ponds <1 day should not be used. If Equation 6.3 gives a value of θ_a <1 day, a value of 1 day should be used and the corresponding value of V_a recalculated from Equation 6.2.

Table 6. 1: Design values of permissible volumetric BOD loadings on and percentage BOD removal in anaerobic ponds at various temperatures [6]

Temperature(T) (ºC)	Volumetric loading (g/m^3d)	BOD removal (%)
<10	100	40
10-20	20T-100	20T+20
20-25	10T+100	20T+20
>25	350	70

Source: Mara and Pearson (1986) and Mara et al. (1997)

The performance of anaerobic ponds increases significantly with temperature.

Design of Facultative Pond

Facultative Pond can be designed on the basis of surface BOD loading (λ_S, kg/ha d), which is given by:

$$\lambda_S = 10\, L_i Q / A_f \text{ ....Equation 6. 4}$$

where, A_f = facultative pond area, m^2

There are two methods of selecting the permissible design value of λ_S:

1. based on latitude
2. based on temperature

Based on Latitude:

The variation of permissible design value for λ_S with latitude in India is given in Table 6.2 (Source: Arceivala et al., 1970). This relationship can be expressed mathematically as:

$$\lambda_S = 375 - 6.25\, L \text{ ....Equation 6. 5}$$

where, L = latitude, ^oN (range considered for India : 8 – 36^oN).

Latitude Design BOD loading

Table 6. 2: Variation of design BOD loading on facultative ponds in India with latitude [6]

Latitude (^oN)	Design BOD Loading (kg/ha day)
36	150
32	175
28	200
24	225
20	250
16	275
12	300
8	325

Table 6.1 and Equation 6.2 are to be consulted for the designing of facultative ponds, which are located at sea level in the areas which have sky clearance for at least 75% of the year (approximately 274 days).

If it is less than 75%, then Equation 6.5 should be decreased by 3% for every 10% reduction in the sky clearance factor below 75%; and, to allow for elevations above sea level, the value given by Equation 6.5 should be divided by the following factor:

$$[1 + (3 \times 10^{-4})\, E] \text{ ....Equation 6. 6}$$

Where, E = elevation above mean sea level, m

Based on Temperature:

The permissible design value of λ_S increases with temperature (T, °C). An appropriate global design equation(relationship) was given by Mara (1987):

$$\lambda_S = 350\ (1.107-0.002T)^{T-25}$$ **…………Equation 6. 7**

Once a suitable value of λS has been selected, the pond area is calculated from equation 4.4 and its retention time (θ_f, d) from:

$$\theta_f = A_f D/Q_m$$ **…………Equation 6. 8**

where, D = pond depth, m (usually 1.5 m)
Q_m = mean flow, m^3/day

Design of Maturation Pond

The main objective of the design of the maturation pond is to remove faecal coliform. The method of Marais (1974) is generally used to design a pond series for faecal coliform removal. This assumes that faecal coliform removal can be modelled by first order kinetics in a completely mixed reactor. The resulting equation for a single pond is thus:

$$N_e = N_i/(1 + k_T\theta)$$ **………Equation 6. 9**

Where, N_e = number of FC per 100 ml of effluent
N_i = number of FC per 100 ml of influent
k_T = first order rate constant for FC removal, d^{-1}
θ= retention time, d

For a series of anaerobic, facultative and maturation ponds, Equation- 8 becomes:

$$N_e = N_i/[(1+k_T\theta_a)(1+k_T\theta_f)(1+k_T\theta_m)^n]$$ **……. Equation 6. 10**

Where,

N_e and N_i refer to the numbers of FC per 100 ml of the final effluent and raw wastewater respectively;
the sub-scripts a, f, and m refer to the anaerobic, facultative and maturation ponds; and
n is the number of maturation ponds.
The value of k_T is highly temperature dependent. Marais (1974) found that:

$$k_T = 2.6\ (1.19)^{T-20}$$ **………Equation 6. 11**

Thus, k_T changes by 19 percent for every change in temperature of 1°C.

Discussion:

From various literature review, it is understood that WSP can operate satisfactorily at any level of BOD, although it is worth noting the following three points:

- ***Anaerobic ponds should have a minimum retention time of 1 day; however, if the resulting volumetric BOD loading is <30 g/m³d, then anaerobic ponds should not be used as there is essentially no experience of their satisfactory performance at lower loadings.***

- ***Facultative ponds should have a minimum retention time of 4 days at design temperatures above 20˚C and 5 days at lower temperatures. If the wastewater BOD is very low, but this does not matter – the algal population will adjust accordingly and the nominally facultative pond will function algologically more as a maturation pond, but treatment efficiency will not be seriously impeded.***

6.2. Constructed Wetlands

6.2.1. Introduction

Figure 6. 3 : Constructed Wetlands

Constructed wetlands are artificial wastewater treatment systems consisting of shallow ponds or channels which have been planted with aquatic plants and which rely upon natural microbial, biological, physical and chemical processes to treat wastewater. They have impervious clay or synthetic liners and engineered structures to control the flow direction, liquid detention time and water level. Depending on the type of system, they contain an inert porous media such as rock, gravel or sand [US EPA 2000].

Constructed wetlands have been used for-

- Treating septic tank and Imhoff tank effluents from housing complexes,
- Providing tertiary treatment to effluents from aerated lagoons and conventional sewage treatment plants to meet more stringent BOD and suspended solids (SS) standards.
- Additionally, they are also used to treat urban runoff and agricultural drainage.

A constructed wetland comprises of the following five major components:

a) Basin
b) Substrate
c) Vegetation
d) Liner
e) Inlet/Outlet arrangement system.

The system can be divided into two types:

- Free-Water Surface type (FWS) -> The water level is over the surface,
- Sub Surface type (SF) -> The water level is maintained below the surface.

Free-Water Surface type is quite similar to pond systems incorporating with the emergent macrophytes (aquatic plants). They look like ponds containing aquatic plants that are rooted in the soil layer on the bottom. The water flows through the leaves and stems of the plants. Their design and operation is very close to pond systems.

For SF system, the water is maintained below the surface of the wetland bodies, usually made up of gravel planted with the emergent macrophytes. They can be further categorized into two types based on the pattern of flow, one with horizontal subsurface (HSF) and one with vertical subsurface flow (VSF).

The SF type can also be called **"reed bed"**.

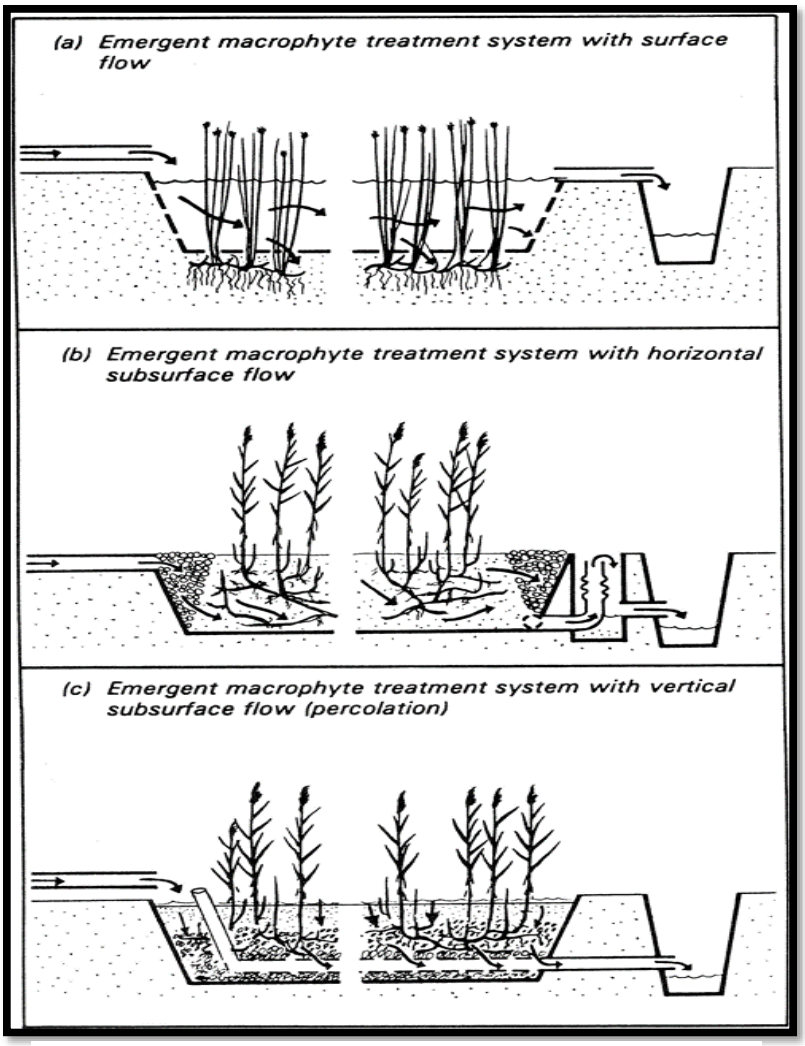


Figure 6. 4 : Schematic presenting each type of constructed wetlands which a: FWS, b: HSF, and c: VSF (Brix, 1993)

6.2.2. Wetland Components

The major system components that may influence the treatment process in constructed wetlands include the plants, detritus, soils, bacteria, protozoa, and higher animals. Their functions and the system performance are, in turn, influenced by water depth, temperature, pH, redox potential, and dissolved oxygen concentration.

- **Types of Plants**

a. Emergent Macrophytes:

Emergent macrophytes are the dominant life form in wetlands and marshes, growing within a water table range from 0.5 m below the soil surface to a water depth of 1.5 m or more. In general, they produce aerial stems and leaves and an extensive root and rhizome system. The root and rhizome systems of these plants exist in permanently anaerobic sediments and must obtain oxygen from the aerial organs for sustained development. These plants are morphologically adapted to growing in a waterlogged or submerged substrate by virtue of large internal air spaces for transportation of oxygen to roots and rhizomes. Part of the oxygen may leak into the surrounding rhizosphere, creating oxidized conditions in an otherwise anoxic environment and stimulating both decomposition of organic matter and growth of nitrifying bacteria. nutrient pumps and play a key role in seasonal changes in available N, P and K. As occurs among terrestrial plants, much (often >90%) of the nutrients used, recycled during growth, and stored in aboveground tissues of wetland macrophytes is translocated back to and stored within rooting tissues belowground. The release of ions during senescence and decay may be into the water or to the sediment but in both cases the vigorously growing attached microbial community sequesters most of the nutrients being released.

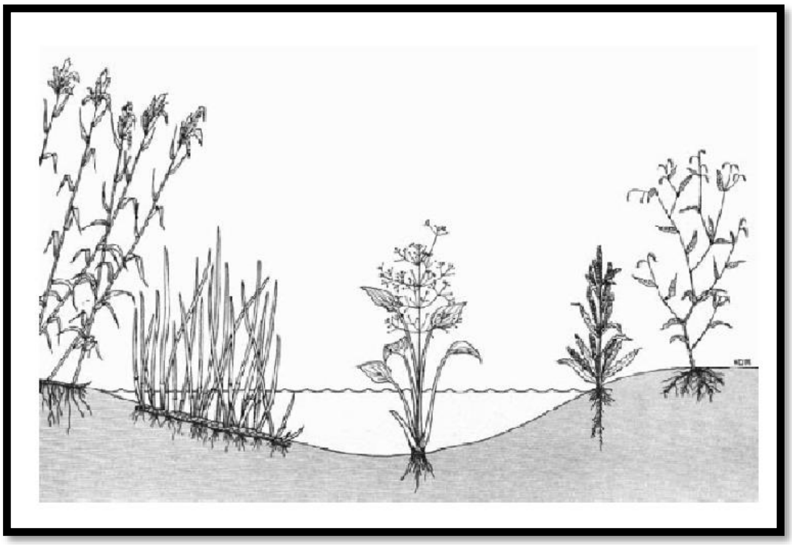


Figure 6. 5 : Emergent macrophytes (from Sainty and Jacobs, 1981, drawing by David Mackay)

The net effect of rooted emergent vegetation is to transfer nutrients from the soil to the surface water via leaching and litterfall, especially at the end of the growing season. Atmospheric carbon dioxide is clearly a significant source of inorganic carbon among emergent macrophytes.

Examples of emergent macrophytes include: *Acorus calamus* (Sweet flag),*Phalaris arundinacea* (Reed canarygrass) *Phragmites australis* (Common reed), *Panicum hemitomon* (Maidencane), *Pontederia cordata* (Pickerelweed), *Sagittaria* spp. (Arrowheads), *Scirpus* spp. (Bulrushes), *Sparganium* spp. (Bur-reeds), *Zizania aquatica* (Wild rice)

b. Submerged Macrophytes

Submerged macrophytes occur at all depths within the photic zone, but vascular angiosperms occur only to about 10 m (1 atm hydrostatic pressure). Among the vascular submerged macrophytes, numerous morphological and physiological modifications are found that allow existence in a totally aqueous environment. Rooted submerged macrophytes can obtain their phosphorus requirements by direct uptake from the sediments. However, the adsorption of phosphorus from water occurs as well. Among most submerged macrophytes, phosphorus absorption rates by foliage are proportional to and dependent on the concentrations in the water. Very large quantities of several mg/l are rapidly assimilated in excess of requirements until concentrations in the water are reduced to about 10 μg/l.

Likewise for nitrogen, studies have shown significant uptake from the sediments. Rates of nitrate assimilation by foliage of several submerged macrophytes are considerably less than are rates of ammonia assimilation, especially at high pH values. Many submerged macrophytes utilize primarily or only CO2 as a carbon source, however utilization of HCO_3^- under natural conditions has been reported for a number of submerged species.

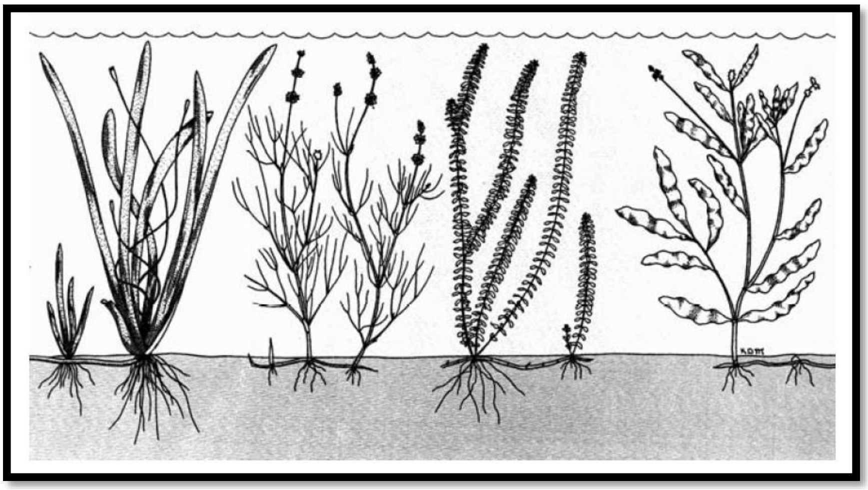


Figure 6. 6 : Submerged macrophytes (from Sainty and Jacobs, 1981, drawing by David Mackay)

Examples of submerged macrophytes include *Cacomba caroliniana* (Fanwort), *Hydrilla verticillata* (Hydrilla), *Myriophyllum* spp. (Watermilfoils), *Najas* spp. (Water nymphs, Naiads), *Potamogeton* spp. (Pondweeds), *Utricularia* spp. (Bladderworts).

c. Floating-leaved Macrophytes

I. Free floating:

The freely floating macrophytes which occur submerged or on the surface, exhibit great diversity in form and habit, ranging from large plants with rosettes of aerial and/or floating leaves and well-developed submerged roots, e.g., Water hyacinth or Water lettuce to minute surface-floating plants with few or no roots such as Duckweeds. Several of these plants develop so profusely in some waterways and lakes that they inhibit the commercial use of these systems. Water hyacinth is one of the fastest growing plants in the world.

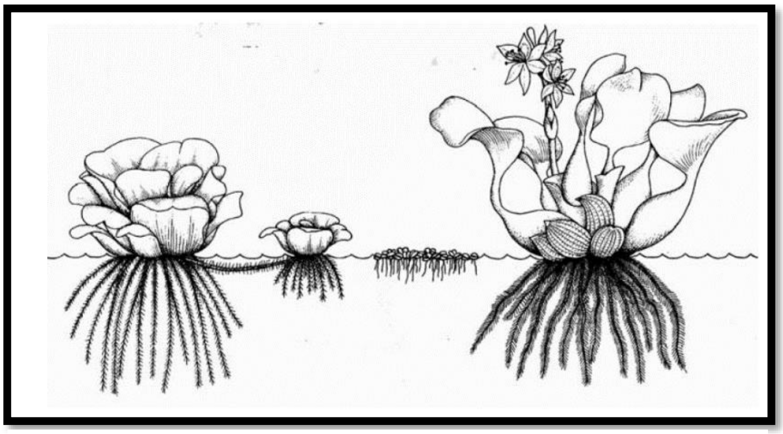


Figure 6. 7 : Free floating macrophytes (from Sainty and Jacobs, 1981, drawing by David Mackay)

Freely floating macrophytes are generally restricted to sheltered habitats and slow-flowing waters. Their nutrient absorption is completely from the water, and most of these macrophytes are found in water bodies rich in dissolved salts. A few species of freely floating angiosperms, such as some duckweeds, utilize both atmospheric and aqueous carbon sources.

II. Rooted

The rooted floating-leaved macrophytes are primarily angiosperms that occur attached to submerged sediments at water depth from about 0.5 to 3.0 m. Floating-leaved rooted macrophytes, particularly the water lilies, exhibit very short leaf longevity averaging about 30 days (50 days during the cooler seasons). Senescence and sinking of leaves are essentially continuous throughout the growing season with an average turnover rate of aboveground foliage of 4-8 times a year.

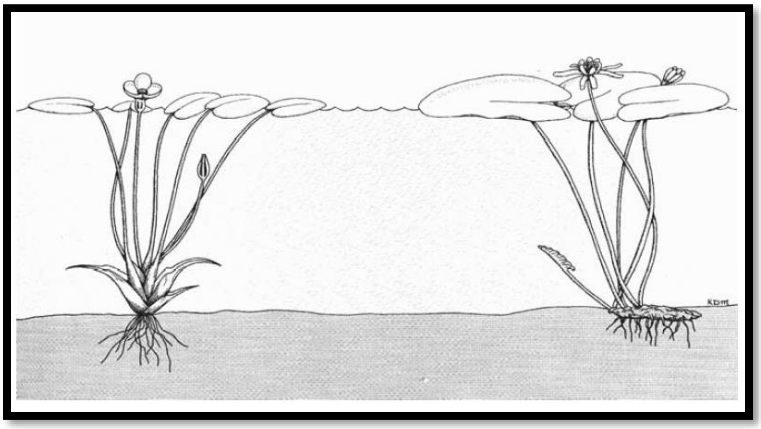


Figure 6. 8 : Floating-leaved rooted macrophytes (from Sainty and Jacobs, 1981, drawing by David Mackay)

- **Role of Macrophytes in Constructed Wetlands:**

The presence of macrophytes is one of the most conspicuous features of wetlands and their presence distinguish constructed wetlands from unplanted soil filters or lagoons. The macrophytes growing in constructed wetlands have several properties in relation to the treatment process that make them an essential component of the design (Brix, 1996).

Table 6. 3: Summary of the role of macrophytes in constructed treatment wetlands. From Brix (1996)

Macrophyte Property	Role in Treatment Process
Aerial plant tissue	*Light attenuation → reduced growth of phytoplankton* *Influence of microclimate → insulation during winter* *Reduced wind velocity → reduced risk of resuspension* *Aesthetic pleasing appearance of the system* *Storage of nutrients*
Plant tissue in water	*Filtering effect → filter out large debris* *Reduced current velocity → increased rate of sedimentation, reduced risk of resuspension* *Provides surface area for attached biofilms* *Excretion of photosynthetic oxygen → increases aerobic degradation* *Uptake of nutrients*
Roots and rhizomes	*Stabilizing the sediment surface → less erosion* *Prevent the medium from clogging in vertical flow systems* *Release of oxygen increase degradation (and nitrification)* *Uptake of nutrients* *Release of antibiotics*

The presence of vegetation in constructed wetlands distributes and reduces the current velocities of the water. This creates better conditions for sedimentation of suspended solids and reduces the risk of resuspension. Stands of emergent macrophytes substantially reduce the wind velocities near the soil or water surface as compared to velocities above the vegetation. This creates suitable conditions for settlement of suspended solids, prevents resuspension, thus improving the removal of suspended solids in constructed wetlands with free water surface. On the other hand, lower wind speed reduces aeration of the water column.

Macrophytes attenuate the light penetration into the water column thus limiting the algal growth. Macrophyte shading on phytoplankton is expected to be particularly important in shallow habitats where macrophyte cover is extensive. In the case of free-floating macrophytes, such as Water hyacinth or Duckweed, which can cover completely the surface of the wetlands, algal growth is limited to minimum due to lack of light. This is desirable as in constructed wetlands, phytoplankton growth is not appreciated because of increase of suspended solids in the outflow.

In vertical flow constructed wetlands, where wastewater is fed onto the bed surface, the presence of macrophytes helps to prevent clogging of the medium. The movement of plants as a consequence of wind, etc., keep the surface open for water percolation by creating annular holes in the surface around the stems.

The stems and leaves of macrophytes that are submerged in the water column provide a huge surface area for biofilms. The submerged plant tissues are colonized by dense communities of photosynthetic algae as well as bacteria and protozoa. The algae oxygenate the water and take up nutrients, bacteria degrade organics.

Biological activity becomes the dominant mechanism in constructed wetlands as compared to land treatment systems, partially due to the significantly longer HRT in the former systems. When water is applied to the soil surface in most land treatment systems, the residence time for water as it passes from the surface through the active root zone is measured in minutes or hours; in contrast, the residence time in most constructed wetlands is usually measured in terms of at least several days.

In some cases, these emergent aquatic plants are known to take up and transform organic compounds, so harvesting is not required for removal of these pollutants. In the case of nutrients, metals, and other conservative substances, harvesting and removal of the plants are necessary if plant uptake is the design pathway for permanent removal. Plant uptake and harvest are not usually a design consideration for constructed wetlands used for domestic, municipal, and most industrial wastewaters.

Even though the system may be designed as a biological reactor and the potential for plant uptake is neglected, the presence of the plants in these wetland systems is still essential. Their root systems are the major source of oxygen in the SSF concept, and the physical presence of the leaves, stems, roots, rhizomes, and detritus regulates water flow and provides numerous contact opportunities between the flowing water and the biological community. These submerged plant parts provide the substrate for development and support of the attached microbial organisms that are responsible for much of the treatment.

- **Soil**

In wetlands, most of the nutrients required for plant growth are obtained from the soil by emergent aquatic plants. Cattails, reeds, and bulrushes will grow in a wide variety of soils and in relatively fine gravels. The void spaces in the media serve as the flow channels in SSF constructed wetlands. Treatment in these cases is provided by microbial organisms attached to the roots, rhizomes, and media surfaces. However, in case of FWS constructed wetlands, the major flow path is above the soil surface, and the most active microbial activity occurs on the surfaces of the detrital layer and the submerged plant parts.

Soils with some clay content can be very effective for phosphorus removal. Phosphorus removal in the soil matrix of a land treatment system can be a major pathway for almost complete phosphorus removal for many decades. In FWS wetlands, the only contact opportunities are at the soil surface; during the first year of system operation, phosphorus removal can be excellent due to this soil activity and plant development. These pathways tend to come to equilibrium after the first year or so, and phosphorus removal will drop off significantly. Phosphorus removal in SSF wetlands has not been successful in most cases, as the limited hydraulic capacity of soils results in most of the applied flow moving across the top of the bed rather than through the subsurface voids so the anticipated contact opportunities are not realized. The gravels used in most SSF wetlands have a negligible capacity for phosphorus removal.

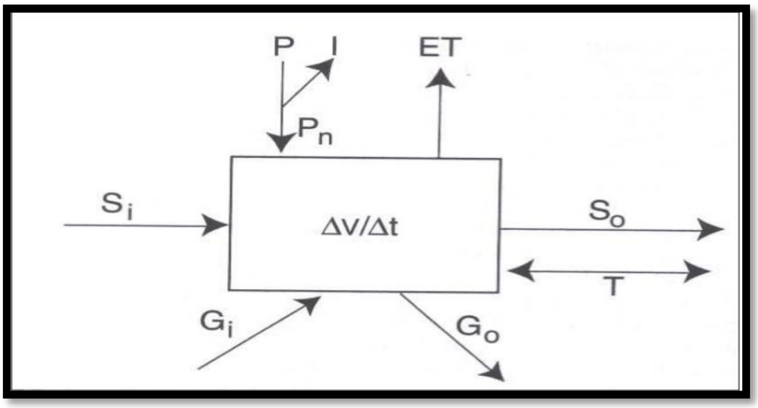
Soils, again with some clay content, or granular media containing some clay minerals also have some ion exchange capacity. This ion exchange capability may contribute, at least temporarily, to removal of ammonium (NH4) that exists in wastewater in ionic form. This capacity is rapidly exhausted in most SSF and FWS wetlands as the contact surfaces are continuously under water and continuously anaerobic. In VF beds, aerobic conditions are periodically restored, and the adsorbed ammonium is released via biological nitrification, which then releases the ion exchange sites for further ammonium adsorption.

- **Organisms**

A wide variety of beneficial organisms, ranging from bacteria to protozoa to higher animals, can exist in wetland systems. The range of species present is similar to that of pond systems. In the case of emergent aquatic vegetation in wetlands, this microbial growth occurs on the submerged portions of the plants, on the litter, and directly on the media in the SSF wetland case. All of these systems require a substrate for the development of the biological growth; their performance is dependent on the detention time in the system and on the contact opportunities provided and is regulated by the availability of oxygen and by the temperature.

- **Wetland Hydrology**

"Hydrology is probably the single most important determinant of the establishment and maintenance of specific types of wetlands and wetland process (Mitsch & Gosselink, 2007, p. 108)." Wetland design is affected by the volume of water, its reliability and extremes, and its movement through the site (U.S. EPA, 1999). Wetland hydrology describes the input and output of water in wetland systems. It affects the composition of vegetation and species communities by acting as the main pathway via which energy and nutrients are transported. Water enters wetlands via surface flow, precipitation, and groundwater discharge, while it flows out via surface flow, ground water recharge, and evapotranspiration (ET) (Note: Tide is not considered in this study).



Abbreviations:

- *P → precipitation;*
- *I → interception;*
- *P_n → net precipitation;*
- *ET → evapotranspiration;*
- *S_i → surface inflow;*
- *S_o → surface outflow;*
- *G_i → groundwater inflow;*
- *G_o → groundwater outflow;*
- *T → tide;*
- *$\Delta V/\Delta t$ → change in storage per unit time.*

Figure 6. 9 : Wetland hydrology

The wetland water budget is the total of inflows and outflows of water through a wetland. The overall water balance in a wetland is affected by climate and weather, hydro period, hydraulic residence time, hydraulic loading rate, groundwater exchange, and ET (U.S. EPA, 1999).
The wetland hydrology is critical in wastewater treatment processes because it determines the duration of water-biota interactions, and the transport of waterborne substances to the sites of biological and physical activity (Kadlec & Wallace, 2009). The longer water remains in the wetland the greater is the chance of sedimentation, adsorption, biotic processing and retention of nutrients (William, 1995). Wetland systems installed in cold climates require larger and deeper structures with a longer detention time for better pollutant removal.

6.2.3. Performance Expectations

Wetland systems can effectively treat high levels of BOD, TSS, and nitrogen, as well as significant levels of metals, trace organics, and pathogens. Phosphorus removal is minimal due to the limited contact opportunities with the soil. The basic treatment mechanisms include sedimentation, chemical precipitation and adsorption, and microbial interactions with BOD and nitrogen, as well as some uptake by the vegetation. Even if harvesting is not practiced, a fraction of the decomposing vegetation remains as refractory organics and results in the development of peat in wetland systems. The nutrients and other substances associated with this refractory fraction are considered to be permanently removed.

Wastewater treatment in wetlands include removal of pollutants like organic material, suspended solids, pathogens, toxic waste, etc and nutrients like nitrogen and phosphorous. Processes of removal of pollutants and nutrients in wetlands can be broadly classified in to physical, chemical and biological processes. (Sundaravadivel 2001)

- ***Physical processes***: Physical processes include filtration and sedimentation. Vegetation in the wetland acts as hindrance for the flowing water, thereby reducing velocity and helping in sedimentation of suspended solids. The substrate in the wetland acts as a medium for filtration process.
- ***Chemical processes***: Some chemical processes that occur in constructed wetlands are precipitation of heavy metals, destruction of pathogens due to photochemical reactions.
- ***Biological processes***: The main biological processes occurring in wetlands that results in removal of pollutants and nutrients are: photosynthesis, respiration. Fermentation, nitrification, denitrification and phosphorus removal. Photosynthesis helps in maintaining the oxygen supply for plants. Respiration helps in maintaining dissolved oxygen content in the water. Fermentation leads to decomposition of organic carbon. Nitrification and denitrification are processes of nitrogen cycle that results in removal of nitrogen. Phosphorus removal process results in removal of phosphorous from the wetland.

Removal of BOD (biochemical oxygen demand), which is a measure of rate of oxygen consumption of organic matter by microorganisms), is removed by processes of biological degradation and sedimentation. Biological degradation of organic carbon in the organic matter takes place in the wetland in aerobic conditions to produce CO2 and in anaerobic conditions to produce methane. Suspended solids are removed by sedimentation, filtration. Suspended solids are removed by adsorption on the substrate (gravel). Pathogens trace metals are removed by sedimentation, filtration, adsorption and exposure to sunlight. Trace metals are reduced by processes like plant uptake, soil or substrate adsorption and precipitation of the compounds of the metals.

- **Removal of Nitrogen and Phosphorus**

Both nitrogen and phosphorus can be present in many forms (particulate, dissolved, organic, inorganic, etc.), and these forms are acted upon differently by the various processes within the wetland compartments. For example, some forms are volatile and released into the atmosphere, others fall to the bottom of the wetland, and other forms are used by plants and microorganisms. These wetland processes are affected by the presence or absence of oxygen, season, temperature, water inflow rate, nutrient loading rate, and retention or holding time of the water within the wetland. So, while a wetland is always working to remove nutrients, the rate of this removal depends on a great variety of factors.

While the dominant removal processes for nitrogen and phosphorus are different, both nutrients are utilized by wetland biota. Wetland plants uptake inorganic nitrogen and phosphorus forms (i.e., nitrate, ammonia, and soluble reactive phosphate) through their roots and/or foliage during the spring and summer and convert them into organic compounds for growth. However, this only provides temporary storage of the nutrients. The majority of these assimilated nutrients are released back into the water and soils when plants grow old and decompose during the fall and winter. A small amount of the nutrients (10–20%) does remain stored in hard-to-decompose plant litter and becomes incorporated in wetland soils, but this is relatively minor compared to other removal processes.

Removal of nitrogen

The process of nitrogen removal by bacterial conversions in wetlands follows a series of reactions as in a nitrogen cycle. The nitrogen cycle has 3 main processes. Ammonification is the conversion of organic N to NH_4^+. Nitrification is a two-step process – **conversion of NH_4^+ to Nitrite** and **conversion of nitrite to nitrate.** The third process is denitrification – where nitrates convert to nitrites and conversion of nitrites to organic N.

In wetlands, the nitrogen removal process starts with the nitrification. It is a two-step process, where the nitrogen fixing bacteria takes energy from the process of ammonification and carbon source to convert nitrogen to different forms. Ammonia ion is oxidized in the presence of oxygen by Nitrosomonas bacteria.

$$NH_4^+ + O2 \rightarrow NO_2^- + 2H^+ + H_2$$

The nitrite is then oxidized to nitrate in the absence of oxygen by the Nitrobacter bacteria.

$$2NO_2^- + O_2 \rightarrow 2\ NO_3^-$$

The next step is denitrification, where nitrates are reduced to organic N. Denitrification occurs under anaerobic conditions and in the presence of organic matter – which is the carbon source. This reaction is catalyzed by *Pseudomonas* sp. bacteria. The N formed from denitrification is released in to the atmosphere in the form of nitrous oxide, thereby removing nitrogen from the wetland system.

$$NO_3^- + C\ (organic) \rightarrow N_2 + CO_2 + H_2O$$

Nitrification is affected by factors like availability of dissolved oxygen, temperature and pH of the wastewater. Denitrification is affected by factors like absence of oxygen, temperature, pH, availability of carbon source, nitrate availability, hydraulic load and HRT. (Bastviken 2006) Nitrogen is wetlands can also be removed by nutrient uptake of plants. The plants uptake nitrogen in the form of ammonium or nitrate, which is then stored in the plant in the organic form. The uptake capacity of emergent plant species in constructed wetlands can vary from 200 to 2500 Kg ha-1year-1. Factors effecting nutrient uptake of plants is growth rate of plants, concentration of nutrients in the plant tissues and climatic conditions. The major portion of the nitrogen removal is through bacterial conversion as compared to nutrient uptake by plants.

Removal of Phosphorus

Phosphorus is present in the water in the form of orthophosphate and organic phosphorus. It is found in the wetlands as part of sediments.

Adsorption of is the most important phosphorus removal process in the wetlands. Adsorption of phosphorus occurs due to reactions with iron, calcium and magnesium present in sediments. Adsorption of phosphorus to iron ions takes places under aerobic and neutral to acidic conditions to form stable complexes. If the conditions are anaerobic, adsorption to iron ions is less strong. Adsorption to calcium ions takes place under basic to neutral pH conditions. Thus, adsorption of phosphorus to the ions removes it from the wastewater. Adsorption is reversible process and each substrate has a particular capacity until it cannot adsorb any more phosphorus. (Verhoeven 1999)

Phosphorus can also get precipitated with iron or aluminum ions. Under this process, phosphate from the water is fixed in the matrix of phosphates and metals. Decomposition of litter (dead plants) and organic matter in the wetland also takes up phosphorus. This process results in storage of phosphorus in the organic matter which will be released eventually. Growing plants take up nutrients like phosphorus, thereby reducing levels in the wetland. The plant uptake of phosphates varies from 30 to 150 Kg ha-1year-1. (Sundaravadivel 2001).

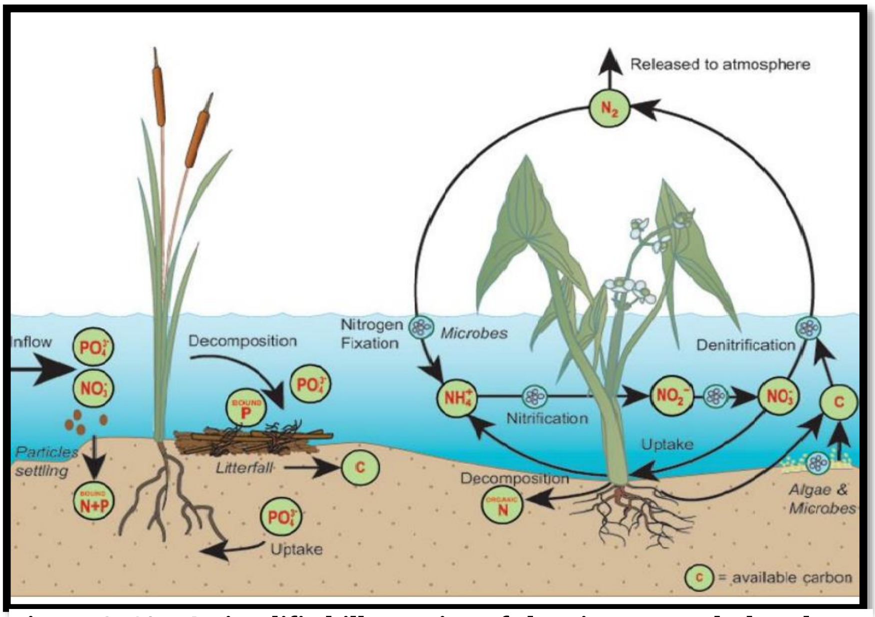


Figure 6. 10 : A simplified illustration of the nitrogen and phosphorus cycles in a wetland

As compared to nitrogen, removal of phosphorus does not result in its complete removal from the wetland system. Nitrogen is eliminated from the system, in the form for N2 gas, but phosphorus is only removed from the water and is either adsorbed to the metals ions, or taken up by plants or fixed in the clay minerals.

- **Wetland Performance**

The performance of a constructed treatment wetland is defined as the efficiency of the wetland in removing pollutants and nutrient from the wastewater. The performance of wetland depends upon the following factors: inflow rate, outflow rate, pollutant loading rate, hydraulic retention time (HRT), hydraulic loading rate, climatic conditions, temperature, pH, oxygen availability, wetland design components – substrate, vegetation and living organisms. (DeBusk 1999). The wetland design factors, that include influent and effluent concentrations, inflow and outflow rates, HRT, loading rate, etc., should be selected accurately to meet the objectives of the constructed wetland.

The wetland performance tends to decrease if the influent concentration becomes close to the background concentration of the wetland, while the effluent concentration is in its desired range. But the wetland performance will increase if the loading rate increases while the outflow concentration may or may not change.

Presence of oxygen concentration of the sediments in the wetland, increase the rate of processes in the nitrogen cycle. In phosphorus removal, oxygen content of the sediment increases the binding capacity of phosphorus to metal ions. The two important factors effecting nutrient reduction in the wetland are temperature and the type of vegetation used in wetlands. According to the study by Sakadevan 1999, Constructed wetlands are capable of removing N and P and thereby treating wastewater. The wetland performance also depends on the design of wetland. Low hydraulic loading and higher retention times increase the P and N removal.

Table 6. 4: Pollutant Removal Mechanisms in Constructed Wetlands (Cooper et al., 1996)

Wastewater Characteristics	Removal Mechanism
Suspended Solids	Sedimentation Filtration
Soluble Organics	Aerobic Microbial Degradation Anaerobic Microbial degradation
Phosphorus	Matrix sorption Plant uptake
Nitrogen	Ammonification followed by microbial nitrification Denitrification Plant uptake Matrix adsorption Ammonia volatilization (mostly in SF system)
Pathogens	Sedimentation Filtration Natural die-off Predation UV irradiation (SF system) Excretion of antibiotics from roots of macrophytes

6.2.4. Design of Different Types of Wetlands

Process Design of Constructed Wetlands (Horizontal Flow Type)

1. ***Reaction Rate and Hydraulic Residence Time***

The following assumptions are typically made for wetlands design:

- The temperature of water can be assumed to be approximately equal to the mean ambient temperature. This is a reasonable assumption for tropical environments (Kadlec and Knight, 1996) and the shallow depths of constructed wetlands.

- The removal rates for BOD and nitrogen in FWS constructed wetland systems can be based on first-order kinetics and plug-flow models proposed by the USEPA (1988) and Reed et al. (1995), which have been used in the design of most constructed wetland systems in the USA and Europe (Chen et al., 1999; Economopoulou and Tsihrintzis, 2003; Economopoulou and Tsihrintzis, 2004). These can be applied in tropics but with suitable modifications to account for different climatic conditions.

The removal rates of BOD and nitrogen in FWS constructed wetlands can be estimated with Equation 6.12 (Reed et al., 1995).

The removals of **c**oliforms and phosphorus can be estimated with Equation 6.13 (Kadlec and Knight, 1996; Economopoulou and Tsihrintzis, 2004).

$$C_e/C_i = e^{-K_T} \text{ (for BOD and N)} \quad \textbf{…… Equation 6. 12}$$

$K_T = k_{20}\theta_{20}^{(T-20)}$

For BOD, $K_T = 0.678\ (1.06)^{T-20}\ (d^{-1})$.
For nitrification, $K_T = 0.2187\ (1.0648)^{T-20}\ (d^{-1})$.
For denitrification, $K_T = 1.15^{T-20}\ (d^{-1})$.

$$C_e/C_i = e^{K_1/h_1} \text{ (for Coliforms and P)} \quad \textbf{…… Equation 6. 13}$$

For fecal coliforms, $K_1 = 0.3\ (md^{-1})$.

For P, $K_1 = 0.0273\ (md^{-1})$.

$h_1 = Q/A$,

where

C_e	-	Pollutant effluent concentration
C_i	-	Pollutant influent concentration *(mg/L for BOD, N, and P)* *(coliform count/100mL for fecal coliform)*
K_T	-	Reaction rate parameter *(d^{-1})*
K_1	-	Reaction rate constant *($m\ d^{-1}$)*
h_1	-	Hydraulic loading rate *($m\ d^{-1}$)*
t	-	Hydraulic residence time (HRT) *(d)*
Q	-	Design flow rate *(m^3d^{-1})*
A	-	Mean surface area *(m^2)*
T	-	Water temperature or ambient temperature in °C

Table 6. 5: Temperature coefficients and rate constants (Sundaravadivel and Vigneswaran, 2001)

Pollutant	*Free Surface Flow System*		*Subsurface Flow System*	
	θ_{20}	k_{20}	θ_{20}	k_{20}
BOD	1.060	0.678	1.060	1.104
Nitrification	1.048	0.218	1.048	0.411
Denitrification	1.150	1.000	1.150	1.000
Pathogen Removal	1.190	2.600	1.190	2.600

The hydraulic residence time in the wetland can be calculated with Equation 6.14:

$$t = LWyn/Q$$ **…….. Equation 6. 14**

where

L	-	Length of the wetland cell (m)
W	-	Width of the wetland cell (m)
y	-	Depth of water in the wetland cell (m)
n	-	Porosity, or the space available for water to flow through the wetland. Vegetation and litter occupy some space in the FWS wetland, and the media, roots, and other solids do the same in the SSF case. Porosity is a percent (expressed as a decimal).
Q	-	The average flow through the wetland *(m^3d^{-1})*

$$Q = (Q_{in} + Q_{out})/2$$ **…….. Equation 6. 15**

It is necessary to determine the average flow with ***Equation 6.15*** to compensate for water losses or gains via seepage or precipitation as the wastewater flows through the wetland.

A conservative design might assume no seepage and adopt reasonable estimates for evapotranspiration losses and rainfall gains from local records for each month of concern. This requires a preliminary assumption regarding the surface area of the wetland so the volume of water lost or added can be calculated. It is usually reasonable for a preliminary design estimate to assume that Q_{out} equals Q_{in}.

Discussion:

For the effective removal of ammonium, it is recommended to have a minimum of 6–8 days of retention (Economopoulou and Tsihrintzis, 2004).

2. ***Sizing of constructed wetland (FWS and SSF)***

Deciding the areal requirements is an iterative process and is an estimate because the structure and functions of wetland ecosystems are very complex.

The surface area of the wetland can be obtained by combining **Equation 6.16** and **Equation 6.17**:

$$A_s = L.W$$ ………**Equation 6. 16**

$$A_s = [Q. \ln (C_o/C_e)] / (K_T . y.n)$$ …….**Equation 6. 17**

Where, A_s is the surface area of wetland (m^2)

3. ***Water Depth in FWS and Bed Depth in SSF***

Water depth is a critical factor, and for effective *free water surface constructed wetlands* this is typically kept at less than 0.1 m during warm periods and less than 0.45 m during cool periods (Reed et al., 1995).

Bed depth for SSF wetlands is generally less than 0.6 m (Kadlec and Knight, 1996). Typical flow depths vary from 0.49 m to 0.79 m (Cooper et al., 1998). This has been influenced by how far roots penetrate into the soil (and therefore different bed depths for different emergent plants). Deeper beds require less horizontal linear distance in construction.

Hydraulic Design Procedures

The hydraulic design of constructed wetland systems is critical to their successful performance. All of the design models in current use assume uniform and unrestricted flow conditions.

However, in reality flow through wetland systems is hindered by the frictional resistance in the system which is imposed by the vegetation and litter layer in the FWS type and the media, plant roots, and accumulated solids in the SSF type.

The energy to overcome this resistance is provided by the head differential between the inlet and the outlet of the wetland.

Some of this differential can be provided by constructing the wetland with a sloping bottom to ensure complete drainage when necessary and to provide an outlet that permits adjustment of the water level at the end of the wetland. This adjustment can then be used to set whatever water surface slope is required and in the lowest position used to drain the wetland.

The aspect ratio (length-to-width) selected for the wetland strongly influences the hydraulic regime and the resistance to flow in the system. Aspect ratios from less than 1:1 up to about 3:1 or 4:1 are acceptable.

1. *Hydraulic Design Procedures in FWS System*

Manning's equation is generally accepted as a model for the flow of water through FWS wetland systems. The flow velocity, as described by **Equation 6.18**, is dependent on the depth of water, the hydraulic gradient (i.e., slope of the water surface), and the resistance to flow:

$$\mathbf{v = (1/n)(y^{2/3})(s^{1/2})} \text{……… } \textbf{Equation 6. 18}$$

where,

v = Flow velocity (m/s).

n = Manning's coefficient ($s/m^{1/3}$).

y = Water depth (m).

s = Hydraulic gradient (m/m).

In FWS wetlands, the resistance to flow extends through the entire depth of water due to the presence of the emergent vegetation and litter. The relationship between the Manning number (n) and the resistance factor (a) is defined by Equation 6.19:

$$\mathbf{n = a/y1/2} \text{ …….. } \textbf{Equation 6. 19}$$

where

a is the resistance factor ($s{\cdot}m^{1/6}$).

Reed et al. (1995) presented the following values for resistance factor a in FWS wetlands:

- Sparse, low-standing vegetation — $y > 0.4$ m, $a = 0.4\ s{\cdot}m^{1/6}$
- Moderately dense vegetation — $y \geq 0.3$ m, $a = 1.6\ s{\cdot}m^{1/6}$
- Very dense vegetation and litter — $y < 10.3$ m, $a = 6.4\ s{\cdot}m^{1/6}$

Reed et al. (1995) developed a model that can be used to estimate the maximum desirable length of a FWS wetland channel:

$$\mathbf{L = [(A_s \,.\, y^{2.667} .\, m^{0.5} \,.86{,}400) / (a \,.Q_A)]^{0.667}}$$ **………..Equation 6. 20**

where

- L = Maximum length of wetland cell (m).
- A_s = Design surface area of wetland (m^2).
- y = Depth of water in the wetland (m).
- m = Portion of available hydraulic gradient used to provide the necessary head (% as a decimal).
- a = Resistance factor ($s \cdot m^{1/6}$).
- Q_A = Average flow through the wetland (m^3/d) = $(Q_{IN} + Q_{OUT})/2$.

An initial m value between 10 to 20% is suggested for design to ensure a future reserve as a safety factor. In the general case, this model will produce an aspect ratio of 3:1 or less.

2. ***Hydraulic Design Procedures in SSF System***

Darcy's law describes the laminar flow regime in a porous media, however for turbulent flow Ergun's equation is more accurate.

Generally, Darcy's law is accepted for the design of SSF wetlands using soils and gravels as the bed media, but in practical scenario, flow is neither nor uniform. Flow may change depending on the evapotranspiration, precipitation, seepage local short-circuiting of flow may occur due to unequal porosity or poor construction. A higher level of turbulent flow may occur in beds using very coarse rock, in which case Ergun's equation is more appropriate. Darcy's law is not strictly applicable to subsurface flow wetlands because of physical limitations in the actual system.

However, if small- to moderate-sized gravel is used as the media, if the system is properly constructed to minimize short-circuiting, if the system is designed to depend on a minimal hydraulic gradient, and if the gains and losses of water are recognized, then Darcy's law can provide a reasonable approximation of the hydraulic conditions in a SSF wetland:

$$v = k_s \,.s$$

Because

$$v = Q/Wy$$

then

$$\mathbf{Q = k_s\, A_c \,.s}$$ **……….Equation 6. 21**

where

v = Darcy's velocity, the apparent flow velocity through the entire cross-sectional area of the bed(m/d).

k_s = Hydraulic conductivity of a unit area of the wetland perpendicular to the flow direction ($m^3/m^2 \cdot d$).

s = Hydraulic gradient, or slope, of the water surface in the flow system (m/m).

Q = Average flow through the wetland (m^3/d) = $[Q_{in} + Q_{out}]/2$.

W = Width of the SSF wetland cell (m).

y = Average depth of water in the wetland (m).

A_c = Total cross-sectional area perpendicular to the flow (m^2).

It is possible by substitution and rearrangement of terms to develop an equation for determining the acceptable minimum width of the SSF wetland cell that is compatible with the hydraulic gradient selected for design:

$$W = (1/y)[(Q_A .A_s)/(m .k_s)]^{0.5} \quad \text{.........Equation 6. 22}$$

where

W = Width of the SSF wetland cell (m).
y = Average depth of water in the wetland (m).
Q_A = Average flow through the wetland (m^3/d).
A_s = Design surface area of the wetland (m^2).
m = Portion of available hydraulic gradient used to provide the necessary head, as a decimal.
k_s = Hydraulic conductivity of the media used ($m^3/m^2/d$).

The m value typically ranges from 5 to 20% of the potential head available. However, it is recommended that not more than one third of the effective hydraulic conductivity (k_s) be used in the calculation and that the m value not exceed 20% to provide a large safety factor against potential clogging and other contingencies not defined at the time of design.

6.2.5. Vertical Flow Constructed Wetlands

Vertical Flow constructed wetland comprises a flat bed of sand/gravel topped with sand/gravel and vegetation. Wastewater is fed from the top and then gradually percolates down through the bed and is collected by a drainage network at the base.

VF wetlands are fed intermittently in a large batch flooding the surface. The liquid gradually drains down through the bed and is collected by a drainage network at the base. The bed drains completely free, and it allows air to refill the bed. The next dose of liquid traps this air and this together with aeration caused by the rapid dosing onto the bed leads to good oxygen transfer and hence the ability to nitrify. Th e oxygen diffusion from the air created by the intermittent dosing system contributes much more to the filtration bed oxygenation as compared to oxygen transfer through plant. Platzer (1998) showed that the intermittent dosing system has a potential oxygen transfer of 23 to 64 g $O_2.m^{-2}.d^{-1}$ whereas Brix (1997) showed that the oxygen transfer through plant (common reed species) has a potential oxygen transfer of 2 g $O_2.m^{-2}. d^{-1}$ to the root zone, which mainly is utilized by the roots and rhizomes themselves.

The latest generation of constructed wetlands has been developed as vertical flow system with intermittent loading. The reason for growing interest in using vertical flow systems are:

- They have much greater oxygen transfer capacity resulting in good nitrification.
- They are considerably smaller than HF system,
- They can efficiently remove BOD5, COD and pathogens

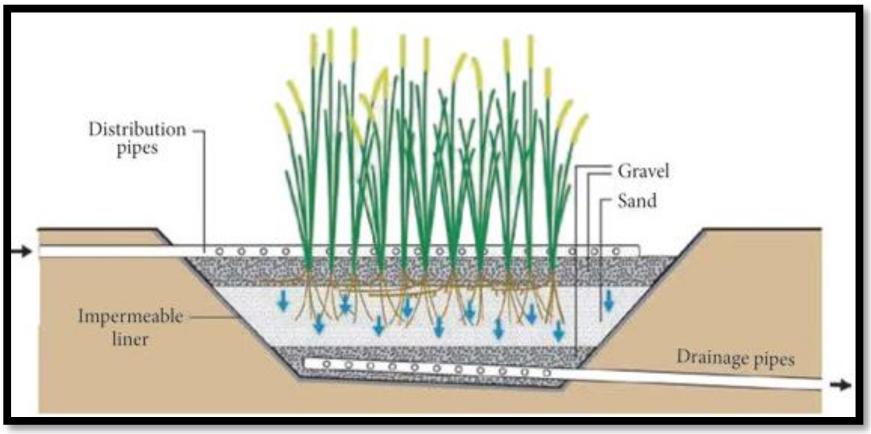


Figure 6. 11 : Schematic cross- section of a vertical flow constructed wetland (Morel & Diener, 2006)

- **Salient features of VF Constructed Wetlands**

Salient Features

- Requires less area for operation (1 -3 m^2/ PE) in compariosn to HF CW.
- Vertical CWs are considered as aerobic filters which in turn enhance the nitrification process in the wastewater.
- VF CW provides a good removal of suspended solids (SS), organics and ammonia.
- Slight denitrification takes place.
- Elimination of phosphorus in Vertical CW is generally low.

- **Design Recommendations for Vertical Flow Wetland treating domestic wastewater**

In VF CW wastewater is intermittently pumped onto the surface and then drains vertically down through the filter layer towards a drainage system at the bottom. In VF CW treatment process is characterized by intermittent short-term loading intervals (4 to 12 doses per day) and long resting periods during which the wastewater percolates through the unsaturated substrate and the surface dries out. By means of intermittent loading it provides aerobic condition and facilitates high microbial degradation activities. The top surface of the filter has to be kept levelled and the distribution pipes are often covered with gravel to prevent open water accumulation during the pumping periods. The piping of the system should be design in such manner that they achieve an even distribution of the pre-treated wastewater on the entire constructed wetland bed.

a. Bed Slope

The top surface of the media should be level or nearly level for easier planting and routine maintenance. Theoretically, the bottom slope should match the slope of the water level to maintain a uniform water depth throughout the bed. A practical approach is to uniformly slope the bottom along the direction of flow from inlet to outlet to allow for easy draining when maintenance in required. No research has been done to determine an optimum slope, but **a slope of 0.5 to 1%** is recommended for ease of construction and proper draining.

b. Media Selection

The substrate properties, d_{10} (effective grain size), d_{60} and the uniformity coefficient (the quotient between d_{60} and d_{10}) are the important characteristics in the selection of the substrate. Th ere is not one uniform standard substrate design for the construction of VF wetland. Various literatures reports effective grain size should be **$0.2 < d_{10} < 1.2$ mm**, uniformity coefficient **$3 < d_{60}/d_{10} < 6$** and hydraulic conductivity **$K_f = 10^{-3}$ to 10^{-4} m/s** (Reed et al., 1990, Vymazal et al., 1998, GFA, 1998, Liénard et al., 2000, Brix, H., 2004, Korkusuz, E.A., 2005). The filter media used at Dhulikhel Hospital had **$d_{10} = 0.4$ mm** and **$d_{60}/d_{10} = 1.5$** (Shrestha R.R., 1999). The rate of decrease in permeability for similar SS influent characteristics is highest for porous media with smaller pore sizes. Compared to the gravel, the sands show a relatively more rapid reduction in their permeability due to effects of sediment accumulation at the surface of the sands. However, the depth of clogging is higher for larger particle sizes (Walker, 2006).

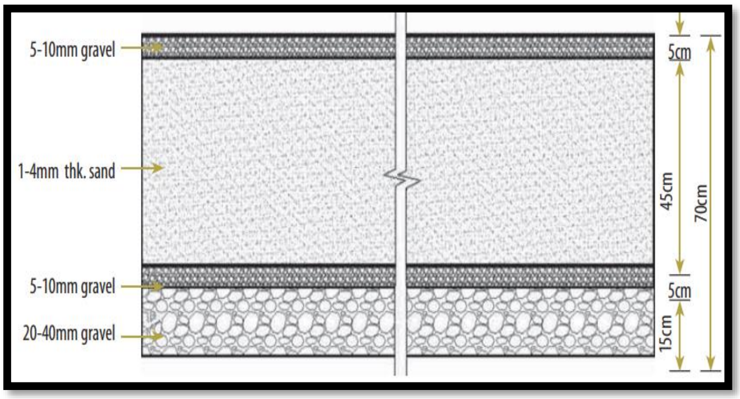


Figure 6. 12 : Substrate arrangement in a VF wetland

It is recommended to use sand (0 – 4 mm) as main substrate with **$d10 > 0.3$ mm**, **$d_{60}/d_{10} < 4$** and having permeability of **10^{-3} to 10^{-4} m/s**.

c. Sizing of VF Constructed Wetlands

For VF systems, the required bed surface area depends on the organic load and is expressed as unit area per population equivalent (m^2/p.e.). The surface area required for each stage of the system depends on the climate, the required level of pollutant removal, and the hydraulic load.

The typical values are given below:

- 1 m^2/p.e - without nitrification
- 2 m^2/p.e – with nitrification

For the VS CW, there are other tools similar to rules of thumb, but they require a few thematical operations. O'Hogain calculated the area of two consecutive VSSF CWs with the following equations:

$$A_1 = 3.5 \times PE^{0.35} + 0.6 \times PE \quad \text{...........Equation 6. 23}$$

$$A_2 = 0.5 \times A_1 \quad \text{.............Equation 6. 24}$$

Where,

A1 = Area of the first VF CW
A2 = Area of the second VF CW
PE = Population Equivalent

Noorvee et al. [18] calculated the area (A) of a single VSSF CW attending to the need for oxygen, using the following equation

$$\mathbf{A = OD/VA} \text{ ……….}\textbf{Equation 6. 25}$$

Where,

VA = Aeration Potential
Estimated: 30g O_2 $m^{-2}d^{-1}$

OD = Oxygen Demand
$[(BOD_{in} – BOD_{out})+(NH_4\text{-}N_{in} – NH_4\text{-}N_{out}) \times 4.3] \times Q$,
Here, Q = mean flow rate (L/day)

Area is also calculated by using the first order kinetics model, that is

$$\mathbf{A= Q_d (\ln C_{in} – \ln C_{out}) / K_{BOD}} \text{ ………..}\textbf{Equation 6. 26}$$

Where,

A = the surface flow of bed (m^2)
Q_d = the average flow rate (m^3/d)
C_{in} = the influent BOD5 (mg/L)
C_{out} = the effluent BOD5 (mg/L)
K_{BOD} = the rate constant (d^{-1})

$$\mathbf{K_{BOD}= K_T \times d \times n} \text{ …………}\textbf{Equation 6. 27}$$

$$\mathbf{K_T = K_{20} (1.06)^{(T-20)}} \text{ ……………..}\textbf{Equation 6. 28}$$

K_{20} = rate constant at 20°C (d^{-1})
T = operational temperature of system (°C)
d = depth of water column (m)
n = porosity of the substrate medium (percentage expressed as fraction)

d. Depth

As per UN Habitat CW manual, it is recommended by to use **substrate depth of 0.7 m**, which can provide adequate nitrification in addition to the organic pollutant's removal.

6.3. Land Treatment of Wastewater

6.3.1. Introduction

Figure 6. 13 : Land Treatment System

By the mid nineteenth century land application of wastes was considered to be the safest and most reliable method for waste disposal by the technical experts and regulatory officials of the time. The connection between contaminated water and disease was recognized, although the causative agents were not identified, so waste discharges to water supplies were avoided wherever possible. The first comprehensive reviews of wastewater disposal in were done in USA by George Rafter of the U.S. Geological Survey. He reviewed the status of wastewater treatment in the United States and Europe. Most of the 143 sewage treatment facilities in the United States and Canada as of 1899 were land treatment systems.

Rafter drew the following conclusions from his studies (direct quotations):

- *The most efficient purification method of sewage can be obtained by its application to land.*
- *On properly managed sewage farms the utilization of sewage is not prejudicial to health.*
- *Sewage may be purified by broad irrigation in all seasons of the year at any place where the mean annual temperature of the coldest month is not lower than about 20 to 25°F.*
- *From the experience gained abroad it is clear that we may successfully cultivate almost any of the ordinary agricultural productions of the United States on sewage farms, due regard being had in every case to the special conditions for each particular crop.*
- *Sewage utilization should go hand in hand with purification. When operated with reference to all the necessary conditions, a proper degree of purification may be obtained as well as satisfactory utilization.*
- *The proper method of utilizing sewage is, for purposes of irrigation, by means which do not differ, except in matters of detail, from those of ordinary irrigation as practiced abroad for centuries.*

The use of land treatment began to decline soon after Rafter published his reports, and by the 1960s the concepts were almost forgotten. By the time discussion again began in the early 1970s many of his conclusions were the subject of bitter debate and controversy. Among the factors identified for the decline were pressures for alternative land uses, overloading due to incomplete technical understanding, and probably most important, the development of the germ theory for disease transmission, with the use of chlorine as a disinfectant which made it "safe" to discharge partially treated sewage to waterways. By the early 1920s the focus had shifted to “modern methods of sewage treatment,” and design criteria for trickling filters, activated sludge, and other technologies were all available.

A considerable effort has been expended during the past 60 years to improve the efficiency of these “modern methods,” but the basic design criteria remain about the same. It was recognized that there was more to pollution than BOD and TSS, and it was decided that a strong norms and funds would be needed to clean up the nations’ waterways. Gradually “zero discharge “concept has been developed and propagated. To achieve the goal a reuse and recovery philosophy needs to be encouraged. Land application of wastewater is the only economical way to achieve all of these goals, and so the concept was reborn. However, it was not accepted at the time by much of the engineering profession and the regulatory community, and so a very significant research and development effort was undertaken to reconfirm the conclusions that were obvious to Rafter and to develop criteria for reliable and cost-effective design, construction, and operation. As a result of these efforts, land treatment has been re-established as an acceptable waste management technology and is now routinely considered by planners and engineers.

In Rafter’s time sewage treatment systems were typically found only at the larger, more sophisticated metropolitan centres that could not discharge to an ocean. Except in special cases, it is unlikely that land treatment would be the sole method of treatment for the very large metropolitan centres that exist today. The costs and the jurisdictional problems in developing a single very large system would be difficult to resolve. However, there are no technical constraints on the size of a land treatment system. Land treatment can be a viable and cost-effective choice for industries and commercial activities, small towns, moderately large cities, and for portions of large metropolitan areas.

The design approach for land treatment systems is essentially empirical, based on observation of successful performance followed by derivation of criteria and mathematical expressions predicting performance expectations.

6.3.2. Definition

Land treatment is defined as the controlled application of wastes onto the land surface to achieve a specified level of treatment through natural physical, chemical, and biological processes within the plant-soil-water matrix. The basic concepts include slow rate (SR), rapid infiltration (RI), and overland flow (OF). These titles were selected to reflect the rate of water (wastewater) movement and the flow path within the process.

6.3.3. Requirements of Land Treatment

Basically, there are two types of requirements for land treatment of municipal and agricultural wastewaters: pre-application treatment and site requirements. Pre-application treatment requirements pertain to the quantity and quality of the effluent or treated wastewater that is to be applied to the land. The wastewater constituents of most importance to land treatment are BOD (biochemical oxygen demand), SS (suspended solids), pH, total and faecal coliforms, dissolved salts, and nitrogen compounds. Generally, these constituents, more than any others, determine how effective land treatment will be in renovating wastewater and what effect the wastewater will have on the soils and ultimately the groundwaters.

Site requirements are expressed in terms of geologic, soil, and hydrologic characteristics that have a direct or indirect influence on the ability of a site to renovate and recycle wastewater. All three characteristics are interrelated and are at least as important as effluent requirements in affecting the success or failure of a land-treatment system. For each type of land treatment, there exists an optimum geology-soils-hydrology scheme or combination. A scheme that works well for one type of land treatment may not work at all for another type.

6.3.4. Type of Land Treatment

There are broadly three types of land treatment of wastewater.

I. Slow Rate Process
II. Overland Flow Process
III. Rapid Infiltration Process

The desirable site characteristics for the three Land Treatment processes are given in Table 6.6. These are not limits to be adhered to rigorously, but rather typical ranges based on successful experience.

Table 6. 6: Site Characteristics for Land Treatment Processes [11]

Parameter	Slow rate (SR)	Rapid infiltration (RI)	Overland flow (OF)
Grade	20%, cultivated site 40%, uncultivated	Not critical	2 to 8% for final slopes
Soil permeability	Moderate	Rapid	Slow to none
Groundwater depth	0.7–3 m	0.9 m during application 1.5-3 m during drying	Not critical
Climate	Winter storage in cold climates	Not critical	Winter storage in cold climates

Typical design features of the three land treatment processes are given in Table 6.7 and the Expected Effluent Water Quality from Land Treatment Processes is given in Table 6.8.

Table 6. 7: Typical Design Features for Land Treatment Processes [11]

Parameter	Slow rate (SR)	Rapid infiltration (RI)	Overland flow (OF)
Application method	Sprinkler or surface	Surface (usually)	Sprinkler or surface
Annual loading, (m)	0.7–6	6–125	3–20
Treatment area for 1 mld (hectares)	6-60	0.6-6	1.3-10
Weekly application (cm)	1.5–10	10–240	6.5–40
Minimum preliminary treatment	Primary	Primary	Grit removal and comminution
Need for vegetation	Required	Grass sometimes used	Water-tolerant grasses

Table 6. 8: Expected Effluent Water Quality from Land Treatment Processes (mg/L Unless Otherwise Noted) [11]

Parameter	Slow rate (SR)	Rapid infiltration (RI)	Overland flow (OF)
BOD_5	**<2**	**5**	**10**
TSS	**<1**	**2**	**10**
NH_3/NH_4 (as N)	**<0.5**	**0.5**	**<4**
Total N	**3**	**10**	**5**
Total P	**<0.1**	**1**	**4**
Faecal coli (number/100 mL)	**0**	**10**	**200+**

The expected effluent quality from the three basic land treatment processes is shown in Table 6.8 for the most common wastewater parameters. The average values in Table 6.8 result from the treatment that will occur within the immediate plant-soil matrix with no credit for mixing, dispersion, or dilution with the groundwater or further travel in the subsoil. Phosphorus, for example, can be reduced at least another order of magnitude for RI systems with additional travel through the soil.

6.3.5. Slow Rate Process

Slow rate (SR) land treatment is the controlled application of wastewater to vegetated land surface at a rate typically measured in terms of a few centimetres of liquid per week. The design flow path depends on infiltration, percolation, and usually lateral flow within the boundaries of the treatment site. Treatment occurs at the soil surface and as the wastewater percolates through the plant root-soil matrix. Depending on the specific system design, some to most of the water may be used by the vegetation, some may reach the groundwater, and some may be recovered for other beneficial uses. Off-site runoff of any of the applied wastewater is specifically avoided by the system design. The hydraulic pathways of the applied water can include:

- *Vegetation irrigation with incremental percolation for salt leaching*
- *Some vegetative uptake with percolation the major pathway*
- *Percolation to underdrains or wells for water recovery and reuse*
- *Percolation to groundwater and/or lateral subsurface flow to adjacent surface waters*

Wastewater applications can be via ridge and furrow or border strip flood irrigation or with sprinklers using fixed nozzles or moving sprinkler systems. The selection of the application method is dependent on site-conditions and process objectives.

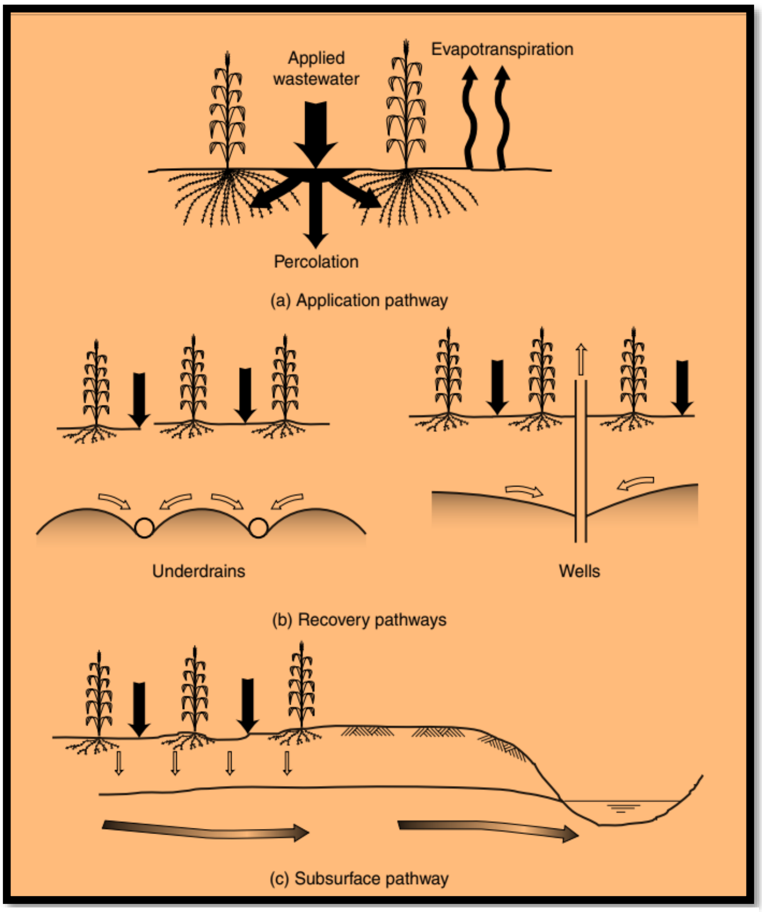


Figure 6. 14 : Hydraulic pathways for slow rate (SR) land treatment.

Slow rate land treatment can be operated to achieve a number of objectives including:

- *Treatment of the applied wastewater*
- *Economic return from the use of water and nutrients to produce marketable crops*
- *Exchange of wastewater for potable water for irrigation purposes in arid climates to achieve overall water conservation*
- *Development and preservation of open space and green belts.*

These goals are not mutually exclusive, but it is unlikely that all can be brought to an optimum level within the same system. In general, maximum cost-effectiveness for both municipal and industrial systems will be achieved by applying the maximum possible amount of wastewater to the smallest possible land area. That will in turn limit the choice of suitable vegetation and possibly the market value of the harvested crop. In the more humid parts of the World optimization of treatment is usually the major objective for land treatment systems. Optimization of agricultural potential or water conservation goals are generally more important in the more arid areas.

Optimization of a system for wastewater treatment usually results in the selection of perennial grasses because a longer application season, higher hydraulic loadings, and greater nitrogen removals are possible compared to other agricultural crops. Annual planting and cultivation can also be avoided with perennial grasses. However, corn and other crops with higher market values are also grown on systems where treatment is a major objective.

Forested systems also offer the advantage of a longer application season and higher hydraulic loadings than typical agricultural crops but may be less efficient than perennial grasses for nitrogen removal depending on the type of tree, stage of growth, and general site conditions.

6.3.6. Rapid Infiltration Process

Rapid infiltration (RI) land treatment is the controlled application of wastewater to earthen basins in permeable soils at a rate typically measured in terms of metre of liquid per week. As shown in Table 6.7, the hydraulic loading rates for RI are usually at least an order of magnitude higher than for SR systems. Any surface vegetation that is present has a marginal role for treatment owing to the high hydraulic loadings. However, vegetation is sometimes critical for stabilization of surface soils and the maintenance of acceptable infiltration rates. In these cases, water-tolerant grasses are typically used. Treatment in the RI process is accomplished by biological, chemical, and physical interactions in the soil matrix, with the near surface layers being the most active zone.

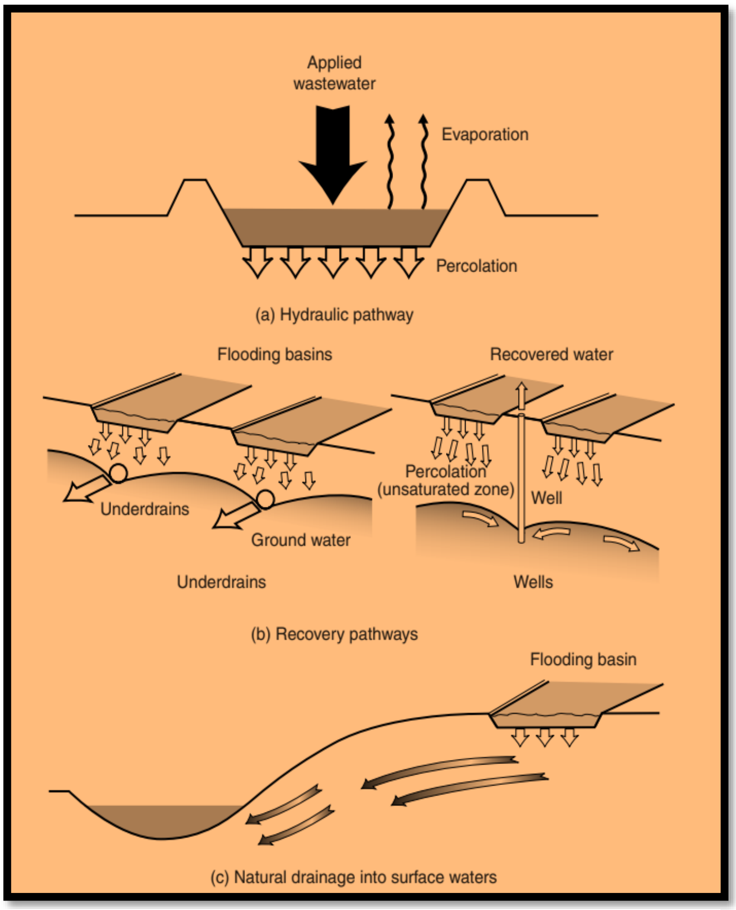


Figure 6. 15 :Hydraulic pathways for rapid infiltration (RI)

The design flow path involves surface infiltration, subsurface percolation, and lateral flow away from the application site (Fig. 6.15). A cyclic application is the typical operational mode with a flooding period followed by days or weeks of drying. This allows aerobic restoration of the infiltration surface and drainage of the applied percolate. The geo-hydrological aspects of the RI site are more critical than for the other processes, and a proper definition of subsurface conditions and the local groundwater system is essential for design.

The purpose of a rapid infiltration system is wastewater treatment, so the system design and operating criteria are developed to achieve that goal. However, there are several alternatives with respect to the utilization or final disposal of the treated water:

- *Groundwater recharge*
- *Recovery of treated water for subsequent reuse or discharge*
- *Recharge of adjacent surface streams*
- *Seasonal storage of treated water beneath the site with seasonal recovery for agriculture*

The recovery and reuse of the treated RI effluent is particularly attractive in arid regions, and studies in Arizona, California, and Israel have demonstrated that the recovery of the treated water is suitable for unrestricted irrigation on any type of crop. Groundwater recharge may also be attractive, but special attention is required for nitrogen if drinking water aquifers are involved. Unless special measures are employed, it is unlikely that drinking water levels for nitrate nitrogen (10 mg/L as N) can be routinely attained immediately beneath the application zone with typical municipal wastewaters. If special measures are not employed, there must then be sufficient mixing and dispersion with the native groundwater prior to the downgradient extraction points. In the more humid regions neither recovery nor reuse is typically considered. In these cases, groundwater impacts can often be avoided by locating the RI site adjacent to a surface water body. The quality of the sub flow entering the surface water will generally exceed that which could be produced by an advanced wastewater treatment plant.

6.3.7. Overland Flow Process

Overland flow (OF) is the controlled application of wastewater to relatively impermeable soils on gentle grass covered slopes. The hydraulic loading is typically several centimetres of liquid per week and is usually higher than for most SR systems. Since costs tend to be directly related to hydraulic loading, OF systems are usually more cost-effective than SR systems for equivalent water quality requirements. Vegetation, consisting of perennial grasses, is an essential component in the OF system, for its contribution both to slope stability and erosion protection and to its function as a treatment component.

The design flow path is essentially sheet flow down the carefully prepared vegetated surface with runoff collected in ditches or drains at the toe of each slope (Fig. 6.16). Treatment occurs as the applied wastewater

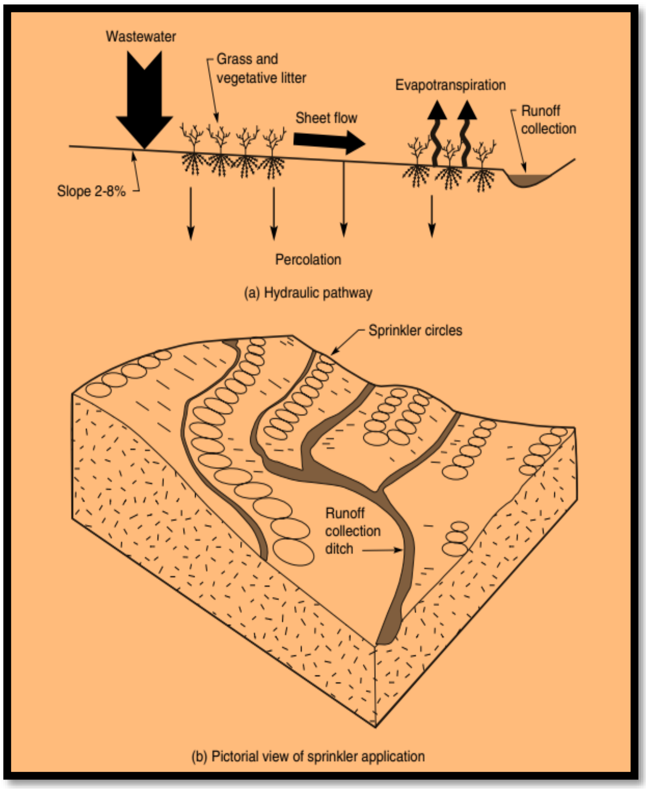


Figure 6. 16 : Hydraulic pathways for overland flow (OF)

interacts with the soil, the vegetation, and the biological surface growths. Many of the treatment responses are similar to those occurring in trickling filters and other attached growth processes. Wastewater is typically applied from gated pipe or nozzles at the top of the slope or from sprinklers located on the slope surface. Industrial wastewaters and those with higher solids content typically use the latter approach. A small portion of the applied water may be lost to deep percolation and a larger fraction to evapotranspiration, but the major portion is collected in the toe ditches and discharged, typically to an adjacent surface water. The SR and RI concepts may include percolate recovery and discharge but the OF process almost always includes a surface discharge, and the necessary permits are required. The purpose of overland flow is cost-effective wastewater treatment. The harvest and sale of the cover crop may provide some secondary benefit and help offset operational costs, but the primary objective is treatment of the wastewater.

6.3.8. Vegetation in Land Treatment

Vegetation plays different roles in each land treatment process. In slow rate (SR) the vegetation is essential and is generally used for nitrogen removal and, in some cases, for economic return. In overland flow (OF) vegetation is the support medium for biological activity and is needed for erosion protection. The grass in OF systems also removes nutrients and slows the flow of wastewater so that suspended solids can be filtered and settled out of the flow stream. Vegetation is not always part of rapid infiltration (RI) systems. It can play a role in stabilization of the soil matrix and can maintain long-term infiltration rates but does not appear to have a major impact on treatment performance for RI systems.

I. Slow rate systems

The crop is an essential component of the SR process for municipal wastewater treatment. In some industrial wastewater SR systems, bare land can be used, particularly if nitrogen removal is unnecessary. The function of the crop in the SR process is to remove nutrients by crop uptake, reduce erosion, and maintain or increase infiltration rates. Crops can also be grown for revenue where local markets are available, and the crops are compatible with the wastewater treatment objectives.

Important crop characteristics for SR systems include potential as revenue producer, potential as water user, potential as nitrogen user, and moisture tolerance. Some crops, such as alfalfa, are high water users but cannot tolerate prolonged soil saturation. Most SR systems are designed to minimise land area by using maximum hydraulic loading rates. Crops that are compatible with high hydraulic loading rates are those having high nitrogen uptake capacity, high consumptive water use, and high tolerance to moist soil conditions. Other desirable crop characteristics for this situation are low sensitivity to wastewater constituents, and minimum management requirements.

Forage and turf crops are most compatible with the SR objective of maximum hydraulic loading. Turfgrasses are excellent choices for SR systems because they use large amounts of nitrogen and water and use it over much of the year. Golf courses also make good land use candidates for SR systems, being long-term users of irrigation water in most areas. The Tifway (hybrid warm-season bermudagrass) is one major choice for irrigation with wastewater.

Corn is an attractive crop because of its potentially high rate of economic return as grain or fodder. The limited root biomass early in the season and the limited period of rapid nutrient uptake, however, can present problems for nitrogen removal. Prior to the fourth week, root biomass is too low to renovate the wastewater effectively, and after the ninth week, plant uptake slows. During the rapid uptake period, however, corn removes nitrogen efficiently from percolating wastewater. Intercropping is a method of expanding the nutrient and hydraulic capacity of a field corn crop system. A dual system of rye intercropped with corn to maximize the period of nutrient uptake was studied. For such dual corn-ryegrass cropping systems, rye can be seeded in the standing corn in August or after the harvest in September. The growth of rye in the spring, before the corn is planted, allows the early application of high-nitrogen wastewater. While planting the corn, an herbicide can be applied in strips to kill some rye so that the corn can be seeded in the killed rows. With the remaining rye absorbing nitrogen, less is leached during the early growth of the corn. Alternatively, forage grasses can be intercropped with corn. This “no-till” corn management consists of planting grass in the fall and then applying an herbicide in the spring before planting the corn. When the corn completes its growth cycle, grass is reseeded. Thus, cultivation is reduced, water use is maximised, nutrient uptake is enhanced, and revenue potential is increased.

The most common agricultural crops grown for revenue using wastewater are corn (silage), alfalfa (silage, hay, or pasture), forage grass (silage, hay, or pasture), grain sorghum, cotton, and grains. However, any crop, including food crops, may be grown with reclaimed wastewater after suitable preapplication treatment.

II. Overland flow systems

A perennial close-growing grass crop is required for overland flow systems. The OF grass crop must have high moisture tolerance and long growing season and be suited to the local climate. A mixture of grasses is generally preferred over a single species. The mixture should contain grasses whose growth characteristics complement each other, such as sod formers and bunch grasses and species that are dormant at different times of the year. Another advantage of using a mixture of grasses is that, owing to natural selection, one or two grasses will often predominate. A successful combination of grasses has been Reed canary grass, tall fescue, and ryegrass. Being an annual grass, when the barnyard grass died, it left bare areas that were subject to erosion. Grasses to be avoided include those sensitive to salt (like clover) and those that have long slender seed stalks (Johnson grass and yellow foxtail). In the early stages of development grasses Johnson grass will provide an effective cover, however, with maturity the bottom leaves die off and the habitat for microorganisms becomes reduced.

III. Rapid infiltration systems

Vegetation is generally not used in rapid infiltration systems, but when it is, the use is to maintain high infiltration rates or to stabilize the soils. At some places bermudagrass was used in the early research, showing a 25 percent increase in infiltration rates over bare sand. At some places, natural vegetation is used to maintain long-term infiltration. Equipment is kept off these RI sites to avoid soil compaction. Vegetation for RI systems must be water-tolerant and in most cases must be able to withstand several days to a week of inundation. Bermudagrass, Kentucky bluegrass, and Reed canary grass have been shown to survive inundation for up to 10 days. Silty clay loam and clayey sands are marginal soils for RI systems, and use of vegetation with these soils should be investigated. The effect of different crops on infiltration is shown in Fig. 6.17

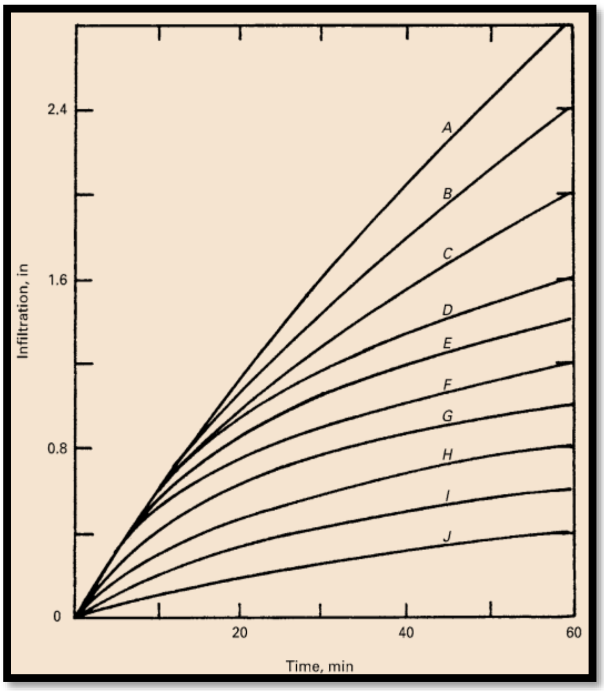


Figure 6. 17 : Effect of crop cover on infiltration rates for various conditions.

Symbols A to J represent the following conditions: A—old permanent pasture or heavy mulch; B—4- to 8-year-old permanent pasture; C—3- to 4-year-old permanent pasture, light grazing; D—permanent pasture, moderate grazing; E—pasture cut for hay; F—permanent pasture, heavily grazed; G—strip cropped or mixed cover; H—weeds or grain; I—clean soil, tilled; and J—bare ground, crusted.

Ref: Hart, R. H., "Crop Selection and Management," Factors Involved in Land Application of Agricultural and Municipal Wastes, U.S. Department of Agriculture, Agricultural Research Service, Beltsville, Maryland, 1974.)

6.4. Facultative Aerated Lagoon

6.4.1. Introduction

An aerated lagoon or aerated basin is a holding and/or treatment pond provided with artificial aerated to promote the biological oxidation of wastewater. In contrast of waste stabilization ponds where the oxygen required for stabilizing the organic matter is furnished by algae, the oxygenation is provided in aerated lagoon by mechanical surface aerators

Figure 6. 18 : Aerated Lagoon System

installed on floats or rates or fixed platforms, or by diffused air units. The wastewater in this lagoon system is treated either on a flow through basis or by solids recycle.

Amongst aerated lagoons, the facultative type is most commonly used since their power requirements are relatively less and operation is simple. Facultative lagoon can be termed as a partial green technology as the power requirement is quite less, which ensures the reduction in land area required for construction, which is also an essential aspect considering India and its density of population.

In facultative aerated lagoons, the power input per power unit volume serves only for the diffusion of oxygen into the wastewater liquid, but it is not sufficient to keep the solids in suspension. As a result, some of the solids entering the lagoon as well as the solids which are produced within it, due to substrate removal, tend to settle down at the bottom of the lagoon. This settled solids then undergo anaerobic decomposition.

Table 6. 9: Characteristics of Facultative Aerated Lagoon (From *Soli J. Arceivala*)

SL. No.	Characteristics	Facultative Aerated Lagoon
1.	Suspended Solids concentration in lagoon (mg/l)	50-150
2.	Mean Cell residence time (days)	High (because of settlement)
3.	Overall BOD removal rate (per day) at 20^{O} C	0.6-0.8
4.	Detention time (days)	3-12
5.	BOD removal efficiency (%)	70-90
6.	Nitrification	None
7.	Coliform removal (%)	60-99
8.	Lagoon depth (metre)	2.5-5.0
9.	Land requirement (m^2/person) Warm: Temperate	 0.30-0.40 0.45-0.90
10.	Power requirement (kW/person-year)	12-15
11.	Sludge	Accumulates in the lagoon, requires manual removal after some years
12.	Outlet arrangement	Effluent flows over a weir
13.	Temperature coefficient	1.035

6.4.2. Design Variables in Facultative Aerated Lagoons

For facultative aerated lagoons, the dispersed flow model gives the relation between influent and effluent substrate concentrations, S_0 and S, respectively and other variables such as the nature of the waste, the detention period and the mixing conditions, as shown in the Wehner-Wilhem equation given below-

$S/S_0 = (4ae^{1/2d}) / (1+a)^2 . e^{a/2d} - (1-a)^2 . e^{-a/2d}$ ……….Equation 6. 29

Where $a = \sqrt{(1 + 4Ktd)}$, in which,

d = Dispersion number (Dimensionless)

$= (D/UL)$
$= (Dt/L^2)$

D = Axial dispersion coefficient (length^2/time)
L = Length of axial travel path
t = Theoretical detention period (Volume/ Flow rate)
U = Velocity of flow through lagoon (length/time)
K = Substrate removal rate in lagoon (time^{-1})
S_0 = Initial Substrate Concentrations
S = Final Substrate Concentrations

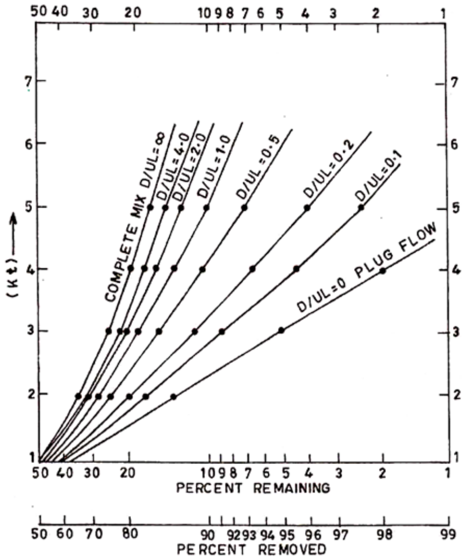


Figure 6. 19 : Graphical plot showing Wehner-Wilhem equation for substrate removal efficiency based on the dispersed flow model

A graphical solution of equation 1 is shown in the figure given below. From this it is evident that a prior knowledge of the substrate removal rate K and the mixing conditions (likely to prevail) in a lagoon is necessary to determine the efficiency of BOD removal at selected detention period.

- **Mixing Conditions**

The mixing conditions in a lagoon are reflected by the term d which is known as the dispersion number and equals (D/UL) or (Dt/L^2). It is affected by various factors. Observed results have shown the (D/UL) values to be in the approximate range given in the Table 6.10 for different length-width ratios of lagoons.

Table 6. 10: Probable Values of Dispersion Numbers (D/UL) at different ratios of Length-Width

Length: Width	Approximate Range of D/UL	Typical mixing condition
1:1 to 4:1	3.0 to 4.0 and over	Well mixed
8:1 or more	0.2 to 0.6	Approaching plug flow
2 or 3 units in series	0.2 to 0.6 (overall)	Approaching plug flow

In order to estimate the efficiency of the substrate removal rate in the lagoon, the ideal complete mixing model has been generally used by Eckenfelder and others.

However, in practice, either due to process considerations or land availability, a relatively long and narrow path flow is preferred which results in plug flow condition. Rather in most cases, substrate removal and oxygenation requirement can be better approximated by using dispersed flow model since aerated lagoons can neither be complete mix type nor plug flow type.

It is desirable to adopt a low D/UL value because of the following reasons-

- Removal follows first order or higher order kinetics
- Higher coliform removal efficiency is required

For municipal or domestic sewage, relatively plug flow type conditions (i.e., low values of DU/L) are preferred.

- **Substrate Removal Rate**

For facultative aerated lagoons the overall substrate removal rate constant K for sewage at 20°C, i.e., K_{20} varies from 0.6 to 0.8 per day (soluble BOD basis). The removal rate generally follows first order kinetics and can be recapitulated as-

dS/dt = k. S

dS/dt = K_L. S ……..**Equation 6. 30,** **in which**

S	=	Substrate concentration (mass/volume)
k	=	Specific substrate removal rate
	=	0.17 – 0.03 $(mg/l)^{-1}(day)^{-1}$ for domestic sewage
K_L	=	Overall substrate removal rate $(time)^{-1}$
	=	0.6 – 0.8 per day (filtered effluent basis)

At any other temperature T°C in lagoon the value of K, i.e., K_L may be obtained from the following formula-

K_L (T^O C) = K_L (20^O C) . $\Theta^{(T-20)}$ ………Equation 6. 31

where, Θ for municipal sewage is 1.035

The temperature in the lagoon (T_L) can be estimated by the following equation:

t/h = (T_i -T_L)/ f(T_L -T_a) ………..Equation 6. 32, in which

t	=	Detention time (days)
h	=	Depth of lagoon (metre)
T_i	=	Temperature of influent sewage (^{O}C)
T_a	=	Temperature of ambient air (^{O}C)
f	=	Heat transfer coefficient (m/day)
		For aerated lagoon, f = 0.49 m/day

- **Lagoon Depth**

The depth of the facultative aerated lagoons is generally kept between 2.5 and 5.0 metres. Deeper lagoons are preferred to ensure an anaerobic zone at the bottom of the lagoon so that the growth of the methane fermenters can occur if the temperature is optimum for the growth.

- **Suspended Solid, Oxygenation and Power Level**

For facultative lagoon, a minimum aeration power input of 0.75 KW/1000 m^3 lagoon volume is recommended. This power will ensure at least 30- 50 mg/l of solids in suspension, though when treating domestic sewage, the concentration may be well around 40 -60 mg/l. At higher power input the suspended solids concentration will be higher.

The power required by the aerators to operate is calculated on the basis of the oxygen requirements, field conditions etc.
For treating municipal wastewater to obtain about 85% BOD removal in facultative aerated lagoon, the power requirement ranges from 0.75 – 1.0 KW/ 1000 m^3 volume of lagoon.

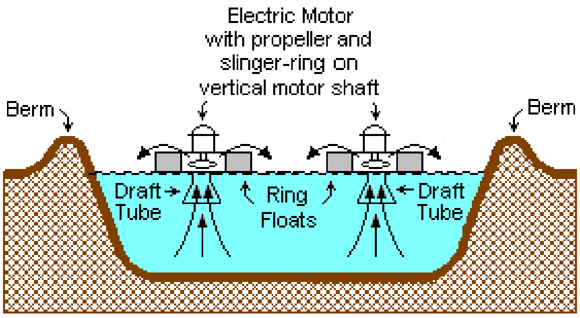


Figure 6. 20 : A typical surface aerated basin

- **Anaerobic Activity**

The bottom part of the facultative lagoon shows anaerobic activity by the presence of facultative and bacteria collectively called acid formers, which hydrolyze and ferment carbohydrates, proteins and fats to their acid groups. Under favourable conditions, another group of bacteria called methane formers which are commonly termed as anaerobic bacteria, convert these substances to CO_2 and methane. This results in BOD reduction. Methane is formed in absence of oxygen by the anaerobic bacteria which cannot thrive in the presence of oxygen. Hence, the anaerobic activity can only occur in the combination of sufficiently low power unit with lesser dispersion of oxygen in the bottom layers of the lagoon and in warmer temperature appropriate for gasification, where lagoons are deep and highly loaded.
In contrary, in colder climates, lagoons are lightly loaded, and gasification does not occur as required, hence BOD removal in the anerobic zone is not even considered. However, liquefaction by acid forming bacteria occurs but anaerobic activity ceases due to presence of oxygen.

- **Performance/ Effluent Characteristics**

Removal of 70-90% BOD can be achieved in facultative aerated lagoons. The concentration of the suspended solids may be same as that of the lagoon or can be less if the outlet is baffled. For sewage treatment, SS concentration may be assumed as 40-60 mg/l.
5 day-BOD corresponding to volatile solids may be assumed as 0.77 mg of Volatile Suspended Solids (VSS) in the effluent. Due to long detention time in such lagoons, only 50-80% of the Suspended Solids (SS) is assumed to be VSS. Thus-
Final Effluent BOD_5 = S + 0.77 VSS ………..Equation 6. 33

Nitrification does not occur in the facultative aerated lagoon.
Coliform removal is temperature dependent; it drops from 90% in summer to 60% in winter.
Higher removal rates can be achieved if the lagoons are operated in series and also in conditions which ensure low values of D/UL.

- **Sludge accumulation**

Sludge accumulation occurs at the rate of 0.03 to 0.05 m^3 per person per year as in the case of facultative aerated ponds and is manually removed once in 5 to 10 years and used as good agricultural soil. The depth of the lagoon may be increased a little to allow for sludge accumulation, if desired.

6.5. Phytorid Treatment of Wastewater

6.5.1. Introduction

Figure 6. 21 : Phytorid Bed in Shahdara

The phytorid technology is an effective and safe method of treating wastewater using the plants based on principle of natural wetlands. The technology utilizes wetlands plants, gravel, porous stones and their associated microorganisms to mimic natural wetland ecosystem processes for the treatment of wastewater. The phytorid technology was developed by NEERI and patented in Indian, European, and Australian countries. The advantages of this technology are to compensate and offset the rate of existing wetland loss, improve wetland quality, provide flood control. The system is based on use of specific plants normally found in natural reed with filtration and treatment capability. This system can be utilized for a wide variety of applications. It can be used for secondary and tertiary treatment of municipal wastewater, sludge management, treatment of industrial or agricultural effluent as well as for the treatment of landfill leachates.

6.5.2. Applicability of Phytorid Technology [4]

Phytorid system is useful for treatment of wastewater in following:

a. Domestic wastewater including decentralized municipal wastewater treatment
   - Colonies, airports, commercial complexes, hotels
   - Open drainage
   - Cleaning of nallah water

b. Agricultural wastewater
c. Dairy waste
d. Slaughterhouse waste
e. Pre-treated industrial wastewater, sugar industries
f. Lake restoration

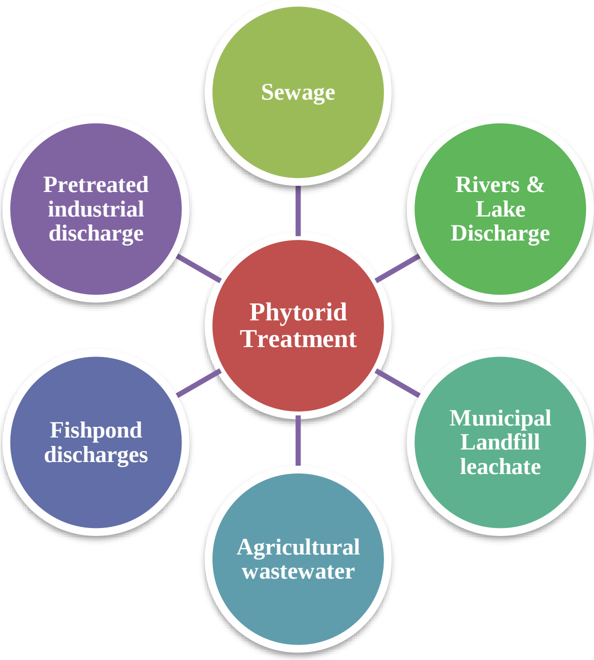


Figure 6. 22: Applicability of Phytorid Technology

6.5.3. Role of Plant in the Treatment Process

- ➢ The most significant functions of plant species in relation to water purification are the physical effects brought by the presence of the plants.

- The plants provide a huge surface area for attachment and growth of microbes. The physical components of the plants stabilize the surface of the beds, slow down the water flow thus assist in sediment settling and trapping process and finally increasing water transparency.
- Plants play a vital role in the removal and retention of nutrients and help in preventing the eutrophication of wetlands. A range of plants has shown their ability to assist in the breakdown of wastewater. Cattail (Typha spp) are good examples of marsh species that can effectively uptake nutrients. These plants have a large biomass both above (leaves) and below the surface of the substrate.
- The sub-surface plant tissues grow horizontally and vertically, and create an extensive matrix, which binds the particles and creates a large surface area for the uptake of nutrients and ions. Hollow vessels in the plant tissues enable oxygen to be transported from the leaves to the root zone and to the surrounding soil.

Figure 6. 23 : Plants in Phytorid Treatment

- This enables the active microbial aerobic decomposition process and the uptake of pollutants from the water system to take place.
- Macrophytes stabilize the surface of plant beds, provide good conditions for physical filtration, and provide a huge surface area for attached microbial growth. Growth of macrophytes reduces current velocity, allowing for sedimentation and increase in contact time between effluent and plant surface area, thus, to an increase in the removal of Nitrogen. Hydraulic conductivity is improved in an emergent plant bed system. Turnover of root mass creates macropores in a system allowing for greater percolation of water, thus increasing effluent/plant interactions.
- Decomposing plant biomass also provides a durable, readily available carbon source for the microbial populations.
- Plant species mediate transfer of oxygen through the hollow plant tissue and leakage from root systems to the rhizosphere where aerobic degradation of organic matter and nitrification will take place. The plant species have additional site-specific values by providing habitat to make wastewater treatment systems aesthetically pleasing.

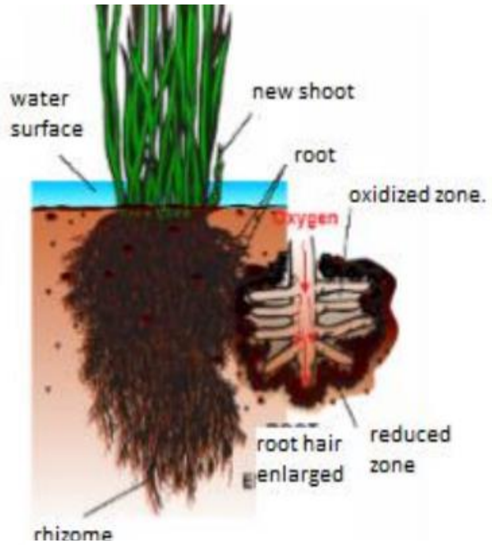


Figure 6. 24 : Root Treatment Process

The system is based on the specific plants, such as Elephant grass (*Pennisetumpurpurem*), Cattails

(*Typha sp*.), Reeds (*Phragmites sp*.), Cannas pp. and Yellow flag iris *(Iris pseudocorus*), normally found in natural wetlands with filtration and treatment capability. Some ornamental plants as well as flowering plants species such as Golden Dhuranda, Bamboo, Nerium, Colosia, etc. can also be used for treatment as well as landscaping purposes.

6.5.4. Design Procedure

Phytorid system is a subsurface flow constructed wetland system with successful demonstration in the field for years. The wastewater is applied to cell / system filled with porous media such as crushed bricks, gravel, and stones. The hydraulics is maintained in such a manner that wastewater does not rise to the surface retaining a free board at the top of the filled media. It serves as a standalone sewage treatment system.

The design procedure is same as described in **subsurface flow constructed wetlands**. However, the porous media is responsible for efficient removal mechanisms in the system.

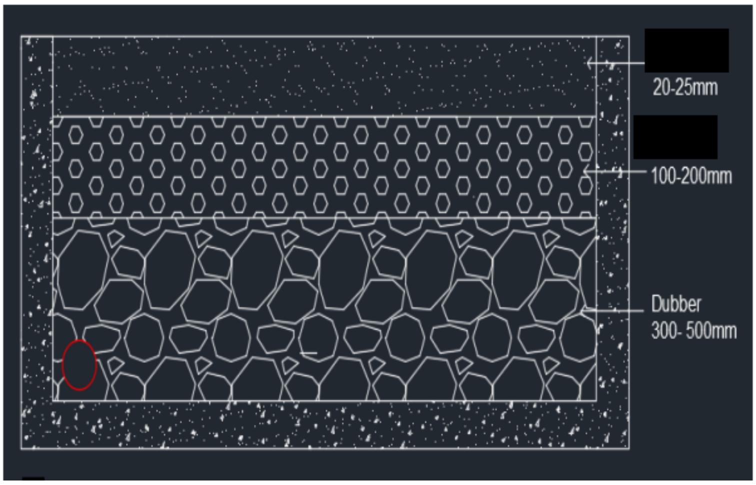


Figure 6. 25 : Phytorid Media

This technology is recommended in decentralized treatment plants with varying capacities ranging from 5000 L/day to 10 MLD. The best feature of this technology system is that it required no mechanical or electrical machineries. This gives an advantage for sustainable operation of Phytorid.

The system consists of the following three zones:

- Inlet zone comprising of crushed bricks and different sizes of stones
- Treatment zone consisting of the same media as in inlet zone with plant species
- Outlet zone

The design parameter includes minimum requirement of about 35.0 m^2 of land area for treating wastewater load of 20 m^3/day.

6.5.5. Components of the treatment system:

a. Sewage Collection Tank
b. Settler/Screening Chamber
c. Phytorid Bed
d. Treated water Storage Tank

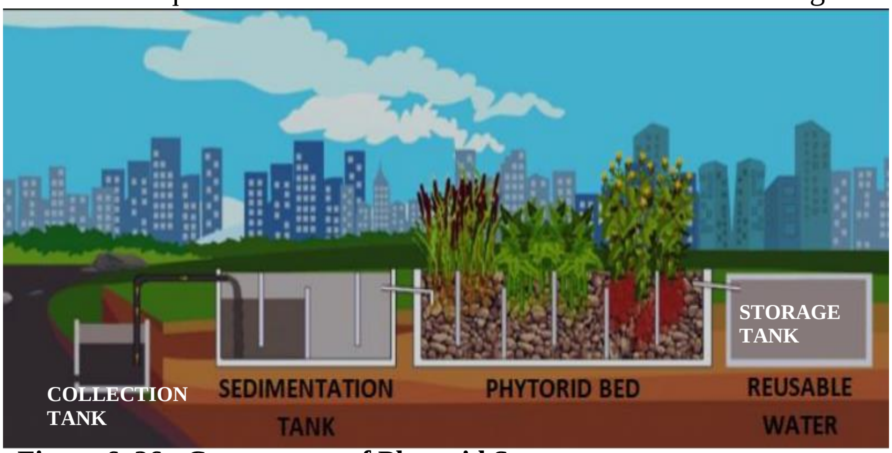
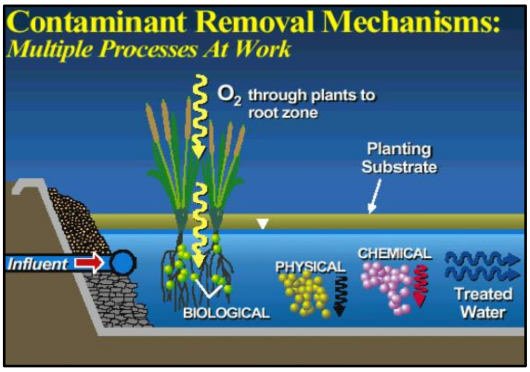


Figure 6. 26 : Components of Phytorid System



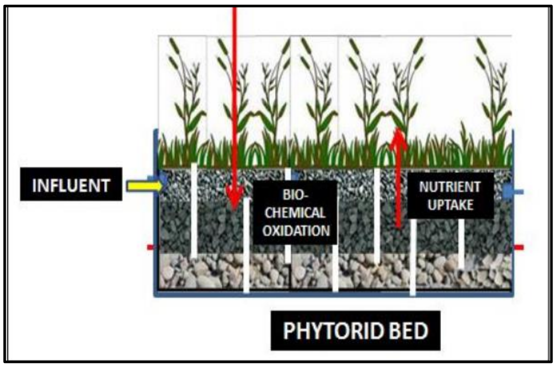


Figure 6. 27 : Removal Mechanism of Phytorid Treatment System

Table 6. 11: Removal Mechanisms of Phytorid Treatment Technology [40]

Sl. No	Pollutant	Removal Mechanisms
1	**Suspended solids**	Sedimentation/ Filtration
2	**BOD**	Microbial degradation (aerobic and anaerobic) Sedimentation (accumulation of organic matter/ sludge on the sediment surface)
3	**Nitrogen**	Ammonification followed by microbial nitrification and de-nitrification, Plant uptake, Ammonic volatilization
4	**Phosphorus**	Media sorption (adsorption precipitation reactions) Plant uptake
7	**Pathogens**	Sedimentation / filtration, Natural die-off

Table 6. 12: Performance of Phytorid for Sewage typical results (Rajesh B. Biniwale)

Parameters	Inlet sewage quality	Treated water quality
pH	7.1 – 7.5	7.2
BOD (mg/l)	40 – 130	< 10
COD (mg/l)	130 – 350	< 30
TSS (mg/l)	80 – 120	< 10
Faecal Coliform (MPN/ 100 ml)	10^6 – 10^7	80 -95%
Ammoniacal N (mg/l)	10 – 15	4 - 5
Phosphate (mg/l)	1 – 2	0.4 – 0.5

6.6. Duckweed Pond Treatment

6.6.1. Introduction

Floating aquatic plant systems using duckweed have been used in wastewater treatment for a variety of purposes including secondary treatment, advanced secondary treatment, and nutrient removal. The treatment systems are suggested in case of further treatment required to be given for algal pond effluents or enhanced denitrification to be achieved before discharging wastewater to lakes and rivers. The duckweeds have varied advantages such as-

a) high protein content,
b) high productivity,
c) significant nutrient uptake,
d) easy handling and harvesting,
e) low fiber content and
f) tendency to reduce development of mosquitoes (Ghangrekar et al., 2007).

Figure 6. 28 : Duckweed Pond

The harvested duckweed is rich in proteins and can be used as fish feed or poultry feed after passing certain tests. Duckweed treatment is thus a wastewater treatment system which can generate revenue to pay for its own operation and maintenance. However, in the circumstances of wastewater containing heavy metals, the duckweed cannot be used as fish feed as heavy metals are also removed by duckweeds. Also, duckweeds can effectively be used as pellets for fish feeds after sun-drying, since the wax coat on their upper surface prevents fungal growth, thereby facilitating longer storage periods (Ansal et al., 2010).

6.6.2. Features of Duckweed species

Duckweed (*Lemna spp*.) are small freshwater plants with leaves (fronds) that are 1 to 3 mm in width and roots are less than 10 mm long. They are abundantly found in many parts of the world and sometimes mistaken for algae. The duckweed tissue is metabolically active and useful for fish food. From preliminary studies, it is found that sewage-fed duckweeds are richer in proteins and amino acids than those grown in controlled manner. Apart from being used as a fodder to fish,

Figure 6. 29 : Different Species of Duckweed (From Left: Lemna, Wolffia and Spirodela)

duckweeds can be used as poultry feed, composting, and other purposes.

A floating homogenous layer of duckweeds tends to form a continuous mat on the water surface which prohibits penetration of sunlight and oxygen transfer to the surface of the ponds. Hence, the water below the mat is devoid of sunlight and oxygen- this in turn promotes the denitrification. Under quiescent conditions solids get settled to some extent.

Features of duckweed plants are as follows:

- Grow at a rate 30% faster than water hyacinth with better nutrient accumulation and easy harvesting.
- Surface mat of biomass has the potential to double its surface area in 2-4 days depending upon wastewater content and climatic condition.
- More cold-tolerant than water hyacinth minimum operating temperature of 7^{o} C and maximum up to 33^{o} C. However Indian climate is mostly suitable for duckweeds.
- More responsive to wide range of pH ranging from 5-9 (6.5-7.5 considered as optimum).
- Ability to control over mosquito breeding and bad odour problems that may be caused in other open pond systems.
- Potential for community-based job creation and revenue generation when coupled with fishponds.

6.6.3. Design Aspects of Duckweed Pond System

Duckweed ponds are the simplest of all wastewater systems if design constraints are considered. They are constructed in many ways such as simple pond, sheltered pond (pond divided in small divisions using floating bamboo type materials to avoid waves and flow caused due to wind), ponds in series or raceway ponds maintaining plug flow regime.

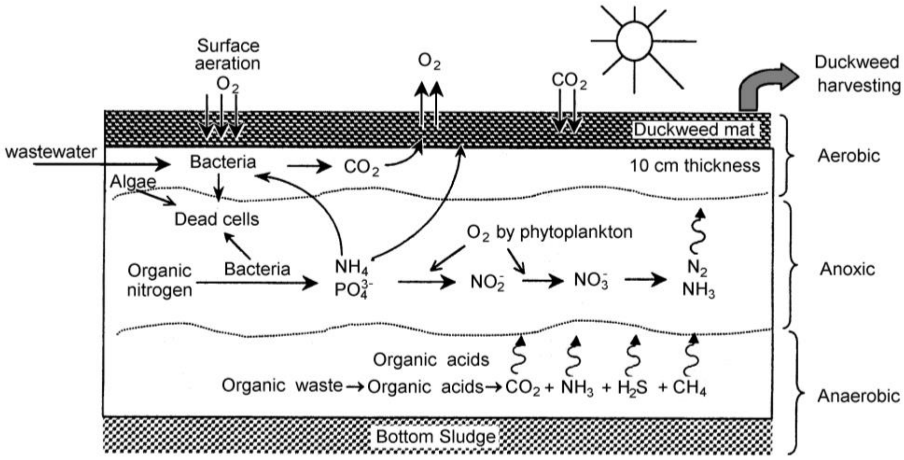


Figure 6. 30 : Biological Processes in Duckweed Pond

- **Pre-treatment**

Pre-treatment in duckweed ponds is recommended by using aerobic/facultative process such as aerated lagoon or an algal waste stabilisation ponds. In either case, following influent characteristics need to be maintained for wastewater entering duckweed pond for treatment.

Table 6. 13: Influent Characteristics of Duckweed Pond (Arceivala, 2007)

Influent Characteristics	Values
Biochemical Oxygen Demand	≤ 80 mg/l
Ammonia	≤ 50 mg/l
pH	≤ 9.0
Total Suspended Solids (TSS)	≤ 100 mg/l
Total Dissolved Solids (TDS)	≤ 4000 mg/l

The limiting values shown are both approximate and indicative.

- **Pond Sizing**

The pond sizing depends on either of the following factors:

a. Detention time required to give desired effluent quality
b. Yield of fish production

If both the criteria have to be met, then the duckweed pond size has to be calculated separately for both purposes, and the larger of the two has to be adopted.

a. Detention Time and effluent quality

Following are the approximate values of parameters after duckweed pond treatment

Table 6. 14: Approximate values of parameters after duckweed pond treatment (Arceivala, 2007)

Duckweed Pond Treatment		**Approximate values of parameters**					
		BOD	**TSS**	**TKN**	**Heavy Metals**		
		mg/l	**mg/l**	**mg/l**	**As**	**Cu**	**Ni**
Pond influent		60-70	100-120	35-40	10	15	15
Pond effluent after	7 days	40-50	60	20			
	12-13 days	20-25	30	10			
	20 days	5-6	< 10	< 5	4	Below detection limit	0.9

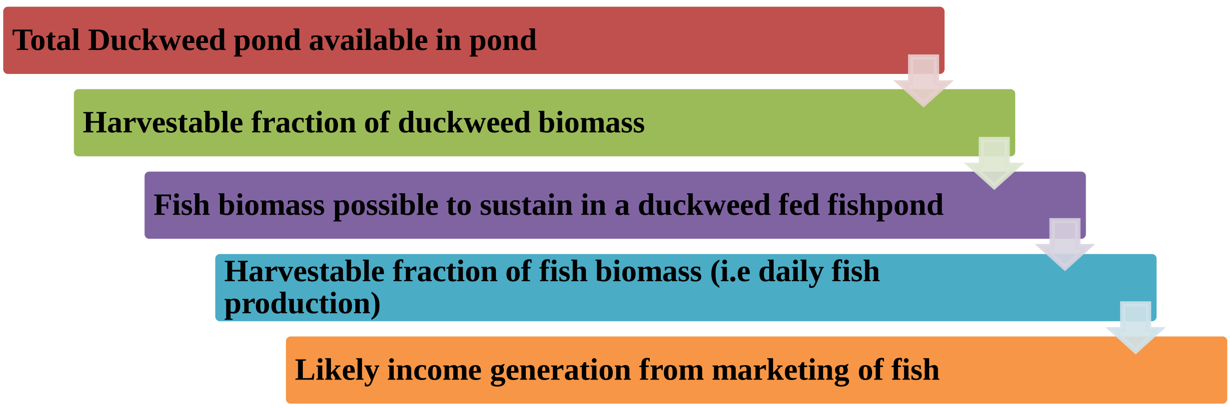
Once the detention time and pond depth are fixed, the water surface area of the pond can be determined.

Table 6. 15: Land requirement for duckweed pond systems, adopted from (Arceivala, 2007)

Pond detention time (days)	**Pond depth (m)**	**Approximate pond water surface area required (m^2/person)**
7	2	0.5
13	2	1.0
20	2	1.5

b. Duckweed yield and fish production

Relation between duckweed yield and fish production is as follows:



- ***Duckweed Yield Estimation***

The duckweed density is expected to be maintained as 650-800g/m^2 or 6.5-8 tons/ha of duckweed. As the harvestable fraction for any plant is 10% of plant production, the duckweed harvestable fraction is found to be 65-80g/m^2 or 0.65-0.8 tons/ha-day.

- ***Fish Production Estimation***

It is found 1 ha of net water surface of duckweed pond would require about 3 ha of fishponds.

- **Removal Mechanisms**

Table 6. 16: Mechanisms occurring in duckweed ponds for removal of various pollutants (Verma and Suthar, 2015); (To et al., 2020); (Willett, 2004) [37]

Sl. No	Pollutant	Removal Mechanisms
1	Biodegradable organics	Bioconversion by aerobic microorganisms attached to duckweed fronds, digestion by anaerobic and anoxic bacteria that forms sediments
2	Suspended solids	Sedimentation, biodegradation into organic matter, absorption for duckweed growth
3	Nitrogen	Plant uptake, denitrification, volatilization of free ammonia
4	Phosphorus	Plant uptake for growth
5	Heavy metals	Uptake by plant fronds, adsorption on tiny roots and bacteria, sedimentation
6	Toxins	Lipophilic toxins and accumulated by duckweeds cells through their lipids in cell membrane
7	Pathogens	Natural decay due to long detention times

Despite faster removal of nitrates and phosphates in duckweed ponds in comparison to oxidation ponds, the dissolved oxygen (DO) levels were observed to be too low to sustain fish cultivation. The floating duckweed biomass hindering the penetration of sunlight is the main reason for reduced DO levels.

About 99.8% removal efficiency of fecal coliform was reported through treatment by *Lemna*. This high removal of coliform makes it a promising tertiary treatment with great potential in developing countries and rural areas (Ansal et al., 2010).

CHAPTER 7. : Comparative Study, Merits and Demerits

Natural technologies of wastewater treatment use modified natural self-treatment processes that take place in the ground soil, water and wetland environment. These ways of treatment are classified according to the treatment technology and general arrangement.

Natural treatment methods are mainly used for wastewater treatment from decentralized houses, small settlements, dwelling, hotels, recreational facilities, restaurants and summer camps, smaller municipalities or their parts, usually up to 2000 population equivalent (p.e). According to the composition of wastewater, these methods are also applicable for treatment of industrial wastewater from the food processing industry, trade facilities (workshops) and selected small industrial plants, landfill leachate treatment, organically low-loaded agricultural runoff and wastewater agricultural facilities, polluted storm water runoff, erosion washes of polluted surface water.

Wastewater with high organic content of and high load of fats, oils, oil derivatives, extremely acidic or alkaline mine water, extremely polluted water from roads and car parks and industrial wastewater containing toxic substances exceeding the limits of toxicity, wastewater with the excessive content of surfactants, pesticides, radioactive substances, wastewater from hospitals, veterinary facilities, rendering plants, etc. are without pre-treatment (treatment) is unusable for natural technologies of treatment.

The advantages of natural treatment methods lie mainly in the natural character of the sewage facility, the possibility of its inclusion in a favourable environment, in relatively simple technological implementation, lower operating costs, investment costs comparable with conventional wastewater treatment plant, low energy consumption, possibilities of being overload by ballast water, the possibility of short-term and long-term shutdown, relatively rapid incorporation of the treatment process and achievement of the performance efficiency quality target in a short period of time after the start of operation, removal of the part of nutrients, especially nitrogen and phosphorus by biomass uptake, treatment of organically low-loaded wastewater that cannot be treated by conventional methods (treatment plants based on activation processes). At the irrigation by treated wastewater, the economic effect is based on the use of water and fertilizer value of wastewater, total use of plant nutrients, improvement of soil fertility and thus significant rise of crop yields simultaneously with the high treatment effect of topsoil.

Drawbacks of natural treatment methods do not primarily consist in the technology of natural treatment methods but in poor design and the lack of functionality of the mechanical pre-treatment stage, creating conditions for the rapid clogging.

A certain disadvantage is the relatively high area, low efficiency in removing ammonia nitrogen in classic simple arrangement in the anaerobic filtration environment of constructed treatment wetland. The problem of oxygen regime and nitrification of ammonia was, from the research point of view, satisfactorily resolved by the facilities of the other generation, particularly by using pulsed filling or emptying of filters (intermitted flow filters, irregularly flow systems, etc.).

The most common natural methods of treatment include constructed treatment wetlands, soil filters, stabilization ponds, especially final treating stabilization ponds and the use of aquatic plants or floating islands. Globally, irrigation by treated wastewater clearly dominates.

Following Sections highlighted different common natural wastewater treatment technologies and their relative merits and demerits.

7.1. Merits and Demerits of Various Natural Treatment Technologies

7.1.1. Constructed Treatment Wetlands (CTW)

CTWs are ranked to the so-called natural (sometimes also called "extensive ") technologies. These ones are constructed water tight beds filled with a filter material and planted with locally relevant, or ornamental, wetland vegetation (most often reed, reed canary grass, cattail, iris, reed sweet grass). The filter environment must fulfil the pre-defined requirements in terms of hydraulic conductivity and load of wastewater by pollution, flow rate, frost penetration, or the possibility to bind phosphorus and heavy metals. The filtration material must be sufficiently permeable to prevent clogging.

- ***Merits***
  - Aesthetic integration into the environment, increase in biodiversity of the landscape by creating an artificial wetland
  - They favourably affect the microclimate in the immediate vicinity due to the relatively significant evaporation of water by vegetation
  - Very energy-saving treatment element, it can function without electricity supply
  - Operation costs are low
  - A relatively simple construction, it is possible to construct it on the self-help basis, or with the use of human resources and machinery of municipalities and communes
  - The proper design can achieve high treatment effects of insoluble substances, organic and bacterial contamination
  - Pulse emptying, or filling of filters may sufficiently provide oxygen saturation of the environment and the removal of ammonia nitrogen
  - The removal of ammonia nitrogen is sufficient even during the implementation of constructed wetland filter with the vertical flow when the filtration environment is not still saturated with water
  - Continuously washing filters, permanently filled with water with the anaerobic environment may serve to denitrification of wastewater – removal of nitrate nitrogen
  - When there is an appropriate arrangement, it is possible to backwash particularly smaller filters by treated wastewater without the necessity of filter material extraction

- ***Demerits***
  - When used as the main treatment stage, there is the high surface demand (depending on the design from 2 to 5 m2 per capita equivalents in case of the request for the removal of insoluble substances, ammonia, organic and bacterial pollution)

- In the basic configuration – the filter with the continuous horizontal flow, permanently filled with water has the low effectiveness in removing ammonia nitrogen
- Stable removal of phosphorus from water is only possible by using special filtration materials with elevated sorption capacity with limited potential of P removal
- The risk of clogging of the filtration material in case of inappropriately designed pre-treatment or insufficient function and maintenance (sludge pumping, slot cleaning) of the installations of mechanical pre-treatment
- Difficult regulation of the ongoing processes, particularly in case of necessity of quick adjustments and changes

7.1.2. Waste Stabilization Ponds

Stabilization ponds are an important part of the natural treatment ways. The desired treatment effect is achieved by physical, chemical and biological processes, taking place in the aquatic environment with the participation of aquatic and wetland biocenosis (bacteria, phytoplankton, zooplankton), higher vegetation and organisms. Their task is to regulate and stabilize the physical, chemical and biological properties of treated wastewater. They are divided into low- and high-loaded ponds.

Merits

- Environmental-friendly treatment of pre-treated wastewater using natural methods taking place in the aquatic environment
- Low demands on energy, significantly lower operation costs for comparable investment costs with artificial (machinery) pre-treatment methods
- Relatively rapid incorporation, the possibility of short-term and long-term operation shutdown, resistant to short-term hydraulic and pollution overloads
- Comparable pollution removal efficiency treatment effect with convention methods for wastewater treatment, high efficiency removal of bacterial contamination
- The use as a third treatment stage treatment for sewage
- The convenient combination with the other natural treatment methods and final wastewater treatment, especially by means of irrigation by cleaned wastewater, aquaculture etc.
- The beneficial integration into the environment and natural landscape

Demerits

- The main disadvantage is relatively high surface requirements for the construction of the system of biological tanks. This drawback will not be reflected in the occupation of infertile or rather otherwise economically unusable land
- Slightly lower pollution removal treatment effect in the winter when it is necessary to supply the missing oxygen by means of artificial aeration
- The necessity to capture and subsequently use excessive biomass from the tanks

- ❖ The removal of sediments (sludging process) of particular tanks and their subsequent utilization. The necessity of the sludging process of tanks is significantly lowered by quality mechanical pre-treatment
- ❖ Increased costs on the maintenance of the littoral zone and surroundings of tanks (mowing of grassy vegetation) · If do not harvest sediments or biomass, odour may occur due to the biological breakdown

7.1.3. Land Treatment: Wastewater irrigation

Wastewater irrigation is a complex multi-economic measure that uses water and fertilizer value of wastewater while using a high treatment effect of the soil environment to their treatment or rather final treatment. Pre-treated or treated wastewater and sewage, municipal, agricultural and selected industrial for irrigation. Wastewater irrigation is in many cases only one available sources of irrigation water.

Merits

- ❖ Irrigation water contains significant amounts of plant nutrients (N, P, K, Ca, Mg), trace elements and organic substances able to form humus
- ❖ Wastewater irrigation is a very important intensification agent contributing to considerable increase of crop yield and fast-growing woody plants
- ❖ The treatment effect of soil environment commonly achieves and, in many cases, exceeds the treatment effect of other wastewater treatment methods
- ❖ Wastewater irrigation belongs to economical means of final treatment of wastewater
- ❖ Wastewater irrigation is one of few possibilities of designing of drainless systems

Demerits

- ❖ The accumulation of wastewater during the off-vegetation periods is necessary for the year-round exploitation
- ❖ Much of wastewater after mechanical and mechanical-biological treatment requires prior to irrigation use either sanitation (UV radiation) or the design of protection zones around the irrigated area and setting the deferred (protective) period between the last irrigation, harvest (grazing) crops
- ❖ When overloading the soil environment with high doses of irrigation and within accidents, there might emerge the contamination of ground water
- ❖ It is not possible to irrigate crops (fruit, vegetables) consumed by man in a raw state by wastewater
- ❖ Irrigation cannot be used when close to of water sources

7.1.4. Facultative Aerated Lagoons

Merits

- ❖ The aerated lagoons are simple and rugged in operation, the only moving piece of equipment being the aerator.

- The removal efficiencies in terms of power input are comparable to some of the other aerobic treatment methods.
- Civil construction mainly entails earthwork, and land requirement is not excessive. Aerated lagoons require only 5 to 10 percent as much land as stabilization ponds.
- The aerated lagoons are used frequently for the treatment of industrial wastes.

Demerits

- Nitrification does not occur in facultative aerated lagoons.
- In warm climates, presence of algae is unavoidable in both filtered and unfiltered samples, for which. Algae increases the TSS content in the effluent.
- It shows 90% of efficiency in coliform removal during warmer temperature which eventually drops down to 60% with decrease in temperature.
- Anaerobic activity at the bottom of the lagoon decreases with decrease in temperature as a result the performance efficiency declines. Sometimes when temperature drops below 5^{o} C even liquefaction stops.

7.1.5. Phytorid Technology

Merits

- Very low maintenance and requires unskilled labour. It is not dependent on any mechanical or electrical machineries.
- It requires much less pace being a natural treatment process than other similar treatment systems like waste stabilization ponds. 1-day residence time of Phytorid is equivalent to 10 – 18 days for WSP.
- Treated water quality meets irrigation standards specified by CPCB.
- Systems can tolerate fluctuations in flow.
- It can be used as a technology for rejuvenation and restoration of natural lakes, and rivers.

Demerits

- It is susceptible to clogging, which results in ineffective treatment
- Though it comparatively requires lesser area, the land area requirement is quite high.

7.1.6. Duckweed Pond

Merits

- Sewage fed duckweed plants are rich in protein and amino acids hence serve as feed for fish.
- Duckweed can also be used as poultry feed, composting.
- Heavy metals can also be removed with the help of duckweed pond, however the duckweed plants from such system cannot be used as fodder for fish or poultry.
- The anaerobicity in the duckweed pond discourage mosquito breeding.

- Duckweed pond can generate some financial return from duckweed-fish cultivation which can sustain the O&M cost to some extent and can also attract local community to participate in the plant maintenance.

Demerits

- Being small, the floating macrophyte, duckweed tends to be moved by water current and wind, which breaks the continuity of the duckweed mat. This in turn exposes the pond to sunlight resulting in algal growth. The algal growth increases the TSS content in the effluent.
- Presence of blue-green algae inhibits the growth of duckweed in the pond.

CHAPTER 8. : Process Design of Different Natural Treatment Technologies

Considering the design calculations mentioned in Chapter 5, the process design has been carried out for the mentioned natural treatment technologies, considering a certain flow and wastewater characteristics.

8.1. Process Design of Waste Stabilization Pond [6]

Process Design of Waste Stabilization Pond for treatment of **blackwater of peri-urban area**, considering following criteria:

Capacity Average Flow	0.1	MLD
Sewage Generation	108	LPCD
Temperature	20	ºC
Latitude	26.92473	ºN
Longitude	61.2974	ºE
Characteristics		
pH	7-7.5	
TSS	375	mg/l
BOD	250	mg/l
Faecal Coliform (MPN)	100000	/100 ml

1. Design of Anaerobic Pond

Design Flow	0.1	MLD
Average Flow	100000	l/day
	100	m^3/day
Volumetric Loading	300	gm/m^3 day
BOD	250	mg/l
Total BOD load entering in pond	25	Kg/day
However, adopting organic volumetric loading to be 250 g/m^3 day, we get		
Volume of Anaerobic Pond	100	m^3
Detention time	1	day
Adding volume for Sludge Storage		
Flow	100	m^3/day
Equivalent Population	926	
Sludge Accumulation rate	0.02	m^3/cap/year
Taking Interval of cleaning as 2 years		
Volume of Sludge accumulated in 2 years	37.04	m^3
Total Volume	137.04	m^3
Assuming the Volume	150	m^3
Considering Liquid Depth	4	m

Surface Area at mid depth	37.5	m^2
Top level of pond above mid depth	2	m
Bottom level of pond below mid depth	2	m
Taking free board	0.5	m
Total Depth of the pond	4.5	m
Ratio of Length : Breadth	2	
Mid Depth Breadth	4.33	m
Mid Depth Length	8.66	m
Taking Side Slope as 1V:2H		
Total top length	16.66	m
Total top breadth	8.33	m
Total area of the top of Anaerobic Pond	138.78	m^2
Total bottom length	0.66	m
Total bottom breadth	0.33	m
Total area of the top of Anaerobic Pond	0.22	m^2
BOD removal in anaerobic pond	60	%
BOD of the effluent at the outlet of the Anaerobic Pond	100	mg/l

2. *Design of Facultative Ponds*

Influent BOD	100	mg/l
As per CPHEEO Manual & Duncan Mara		
Latitude	28	^{o}N
Organic Loading	200	Kg BOD/ha/day
Latitude	24	^{o}N
Organic Loading	225	Kg BOD/ha/day
Therefore for Latitude	26.92473	^{o}N
Organic Loading	206.72	Kg BOD/ha/day
BOD expected to reach the facultative pond	10	Kg/day
	0.05	ha
Required area for Facultative Pond	484.00	m^2
Depth of the Facultative Pond	1.5	m
Volume of the Pond	726	m^3
Free board	0.5	m
Total Depth of the pond	2	m
Detention Time	7.26	days
	8.00	days
K_{pond} at 20^{o}C	0.12	/day
BOD of the effluent at the outlet of the Anaerobic Pond	10.96	mg/l

Faecal Coliform Reduction	1274.21	/100 ml

3. Design of Maturation Pond

Influent BOD	10.96	mg/l
Assuming the Faecal Coliform Count be 200/100 ml		
Number of Maturation Pond (n)	2	
K_T at 20°C	2.6	/day
N_i	100000	/100 ml
N_e	200	/100 ml
Detention Time	4.1	days
Depth of the Pond	2	m
Area of the Pond	207.00	m^2
K_{pond} at 20°C	0.12	/day
BOD at the effluent of the Maturation Pond	3.49	mg/l
Effluent FC	9.17	/100

4. Summary

Table 8. 1: Summary of the Waste Stabilisation Pond for blackwater

Area of mid depth requirements		
Anaerobic Pond	150	m^2
Facultative Pond	500	m^2
Maturation Pond 1	210	m^2
Maturation Pond 2	210	m^2
Total Area for WSP	1070	m^2

Process Design of Waste Stabilization Pond for treatment of **greywater for rural areas**, considering following criteria:

Capacity Average Flow	0.1	MLD
Sewage Generation	36	LPCD
Temperature	20	°C
Latitude	26.92473	°N
Longitude	61.2974	°E
Characteristics		
pH	7-7.5	
TSS	150	mg/l
BOD	100	mg/l
Faecal Coliform (MPN)	1000	/100 ml

1. Design of Anaerobic Pond

Design Flow	0.1	MLD
Average Flow	100000	l/day
	100	m^3/day
Volumetric Loading	300	gm/m^3 day
BOD	100	mg/l
Total BOD load entering in pond	10	Kg/day
However, adopting organic volumetric loading to be 250 g/m^3 day, we get		
Volume of Anaerobic Pond	100	m^3
Detention time	1	day
Adding volume for Sludge Storage		
Flow	100	m^3/day
Equivalent Population	2778	
Sludge Accumulation rate	0.02	m^3/cap/year
Taking Interval of cleaning as 2 years		
Volume of Sludge accumulated in 2 years	111.12	m^3
Total Volume	211.12	m^3
Assuming the Volume	150	m^3
Considering Liquid Depth	4	m
Surface Area at mid depth	37.5	m^2
Top level of pond above mid depth	2	m
Bottom level of pond below mid depth	2	m
Taking free board	0.5	m
Total Depth of the pond	4.5	m
Ratio of Length : Breadth	2	
Mid Depth Breadth	4.33	m
Mid Depth Length	8.66	m
Taking Side Slope as 1V:2H		
Total top length	16.66	m
Total top breadth	8.33	m
Total area of the top of Anaerobic Pond	138.78	m^2
Total bottom length	0.66	m
Total bottom breadth	0.33	m
Total area of the top of Anaerobic Pond	0.22	m^2
BOD removal in anaerobic pond	60	%
BOD of the effluent at the outlet of the Anaerobic Pond	40	mg/l

2. *Design of Facultative Ponds*

Influent BOD	40	mg/l
As per CPHEEO Manual & Duncan Mara		
Latitude	28	ºN
Organic Loading	100	Kg BOD/ha/day
Latitude	24	ºN
Organic Loading	225	Kg BOD/ha/day
Therefore, for Latitude	26.92473	ºN
Organic Loading	206.72	Kg BOD/ha/day
BOD expected to reach the facultative pond	4	Kg/day
	0.02	ha
Required area for Facultative Pond	193.00	m^2
Depth of the Facultative Pond	1.5	m
Volume of the Pond	289.5	m^3
Free board	0.5	m
Total Depth of the pond	2	m
Detention Time	2.90	days
	4	days
K_{pond} at 20ºC	0.12	/day
	13.25	mg/l
BOD of the effluent at the outlet of the Anaerobic Pond		
Faecal Coliform Reduction	24.37	/100 ml

3. *Design of Maturation Pond*

Influent BOD	13.25	mg/l
Assuming the Faecal Coliform Count be 200/100 ml		
	2	
Number of Maturation Pond (n)		
K_T at 20ºC	2.6	/day
N_i	1000	/100 ml
N_e	200	/100 ml
Detention Time	0.1	days
Depth of the Pond	1.5	m
Area of the Pond	5	m^2
K_{pond} at 20ºC	0.12	/day
BOD at the effluent of the Maturation Pond	11.12	mg/l
Effluent FC	17.54	/100

4. Summary

Table 8. 2: Summary of the Waste Stabilisation Pond for treating greywater

Area of mid depth requirements		
Anaerobic Pond	150	m^2
Facultative Pond	200	m^2
Maturation Pond	10	m^2
Total Area for WSP	400	m^2

Table 8. 3 : Removal efficiency of Waste Stabilisation Pond

BOD Removal	Greywater	Blackwater
Total	**98.60%**	**95.61%**

Note: In reality, the effluent BOD concentration will be much higher than the theoretical BOD as obtained in the process design because of the presence of Nitrogenous BOD , soluble BOD etc. However, there is little evidence for nitrification (and hence denitrification, unless the wastewater is high in nitrates). The populations of nitrifying bacteria are very low in WSP due primarily to the absence of physical attachment sites in the aerobic zone, although inhibition by the pond algae may also occur. For nitrogen removal, equations developed in North America may not accurately predict performance in India. [6]

8.2. Process Design of Constructed Wetlands (FWS)

Process Design of FWS constructed wetland for treatment of blackwater of peri-urban area, considering following criteria:[8]

Capacity Average Flow (Q_{avg})	0.1	MLD
Sewage Generation	108	LPCD
Temperature	20	ºC
Characteristics		
pH	7-7.5	
TSS	375	mg/l
Inlet BOD (C_o)	250	mg/l
Nitrogen (N_o)	45	mg/l

Parameters considered for designing of the FWS Constructed Wetlands		
Plant Porosity (n)	0.7	
Aspect Ratio	3	
Desirable combined effluent BOD (C)	10	mg/l
Desirable effluent Nitrogen concentration (N)	10	mg/l
Depth (m) (d)	0.3	m

1. Determine Detention Time (t)		
From BOD Removal		
$t = -\ln(C/C_o)/k$		
Here, k at 20ºC = 0.678 day^{-1}		
Hence,		
Detention time (t)	6.3	days
	6.5	days
From Nitrogen Removal		
$t = -\ln(N/N_o)/k$		
Here, k at 20ºC = 0.2187 day^{-1}		
Hence,		
Detention time (t)	6.87	days
	7	days
Out of these, 7 days of detention time is considered for effective BOD and Nitrogen removal		
2. Determine the area of the wetland		
$A= (Q_{avg} \times t \times F)/(d \times n)$		
Here, F= conversion factor = 10^{-4} ha/m^2		
Hence,		
Area (A)	**0.333**	**ha**
	3330	**m^2**
3. Determine the dimension of the wetland		
From the aspect ratio, Length : Width= 3 : 1		
Hence,		
Width= $(Area/Aspect\ Ratio)^{1/2}$		
Hence.		
Width	**33.32**	**m**
	34	**m**
Length	**102**	**m**
4. Determine Hydraulic Loading Rate (L_w)		
$L_w = Q/A$		
Hence,		
Hydraulic Loading Rate	**30.03**	**mm/day**

Process Design of FWS constructed wetland for treatment of **greywater for rural areas**, considering following criteria:

Capacity Average Flow (Q_{avg})	0.1	MLD
Sewage Generation	36	LPCD
Temperature	20	ºC
Characteristics		
pH	7-7.5	
TSS	150	mg/l
Inlet BOD (C_o)	100	mg/l

Parameters considered for designing of the FWS Constructed Wetlands		
Plant Porosity (n)	0.7	
Aspect Ratio	3	
Desirable combined effluent BOD (C)	4.4	mg/l
Depth (m) (d)	0.3	m

1. Determine Detention Time (t)

From BOD Removal

$t = -\ln(C/C_o)/k$

Here, k at 20ºC = 0.678 day^{-1}

Hence,

Detention time (t)	4.6	days
	5	days

2. Determine the area of the wetland

$A = (Q_{avg} \times t \times F)/(d \times n)$

Here, F= conversion factor = 10^{-4} ha/m^2

Hence,

Area (A)	**0.238**	**ha**
	2380	**m^2**

3. Determine the dimension of the wetland

From the aspect ratio, Length : Width= 3 : 1

Hence,

Width= $(Area/Aspect\ Ratio)^{1/2}$

Hence.

Width	**28.2**	**m**
	28.5	**m**
Length	**85.5**	**m**

4. Determine Hydraulic Loading Rate (L_w)

$L_w = Q/A$

Hence,

Hydraulic Loading Rate	**42.02**	**mm/day**

Table 8. 4: Performance of FWS CW

Criteria	Greywater	Blackwater
Detention Time (days)	5	7
Area (m^2)	2380	3330

8.3. Process Design of Constructed Wetlands (SSF)

Process Design of SSF constructed wetland for treatment of **blackwater of peri-urban area**, considering following criteria: [7]

Capacity Average Flow (Q_{avg})	0.1	MLD
Sewage Generation	108	LPCD
Temperature	20	^oC
Characteristics		
pH	7-7.5	
TSS	375	mg/l
Inlet BOD (C_o)	250	mg/l
Nitrogen (N_o)	45	mg/l

Parameters considered for designing of the SSF Constructed Wetlands		
Plant Porosity (n)	0.7	
Desirable combined effluent BOD (C)	10	mg/l
Desirable effluent Nitrogen concentration (N)	10	mg/l
Depth (m) (d)	0.6	m

1. Determine Detention Time (t)

From BOD Removal

$t = -\ln(C/C_o)/k$

Here, k at 20^{o}C = 0.678 day^{-1}

Hence,

Detention time (t)	6.3	days
	6.5	days

From Nitrogen Removal

$t = -\ln(N/N_o)/k$

Here, k at 20^{o}C = 0.2187 day^{-1}

Hence,

Detention time (t)	6.87	days
	7	days

Out of these, 7 days of detention time is considered for effective BOD and Nitrogen removal

2. Determine the surface area of the wetland

A= (Q_{avg} x t x F)/(d x n)

Here, F= conversion factor = 10^{-4} ha/m^2

Hence,

Area (A)	**0.333**	**ha**
	3330	**m^2**

3. Determine the cross-sectional area of the wetland (A_c)

A_c = Q/ (k x s)

Here, k= hydraulic conductivity= 1.0 x 10^{-3} m/sec

s= slope = 0.05 m/m

Hence,

Cross Sectional Area (A_c)	**23.15**	**m^2**

4. Determine Dimensions of the wetlands

Width (w) = A_c/d

Hence,

Width (w)	**38.58**	**m**
	39	**m**

Length (L) = A/w

Hence

Length (L)	**86.31**	**m**
	87	**m**

Aspect Ratio (R) = L/w

Hence,

Aspect Ratio (R)	**2.23**	

Process Design of SSF constructed wetland for treatment of **greywater for rural areas**, considering following criteria:

Capacity Average Flow (Q_{avg})	0.1	MLD
Sewage Generation	108	LPCD
Temperature	20	^oC
Characteristics		
pH	7-7.5	
TSS	150	mg/l
Inlet BOD (C_o)	100	mg/l

Parameters considered for designing of the SSF Constructed Wetlands		
Plant Porosity (n)	0.7	
Desirable combined effluent BOD (C)	4.4	mg/l

Depth (m) (d)	0.6	m

1. Determine Detention Time (t)

From BOD Removal

$t = -\ln(C/C_o)/k$

Here, k at 20°C = 0.678 day^{-1}

Hence,

Detention time (t)	4.6	days
	5	days

2. Determine the surface area of the wetland

$A = (Q_{avg} \times t \times F)/(d \times n)$

Here, F= conversion factor = 10^{-4} ha/m^2

Hence,

Area (A)	**0.238**	**ha**
	2380	**m^2**

3. Determine the cross-sectional area of the wetland (A_c)

$A_c = Q/(k \times s)$

Here, k= hydraulic conductivity= 1.0×10^{-3} m/sec

s= slope = 0.05 m/m

Hence,

Cross Sectional Area (A_c)	**23.15**	**m^2**

4. Determine Dimensions of the wetlands

Width (w) = A_c/d

Hence,

Width (w)	**38.58**	**m**
	39	**m**

Length (L) = A/w

Hence

Length (L)	**61.1**	**m**
	62	**m**

Aspect Ratio (R) = L/w

Hence,

Aspect Ratio (R)	**1.6**

Table 8. 5 : Performance of SSF Wetlands

Criteria	Greywater	Blackwater
Detention Time (days)	5	7
Length (m)	62	87
Width (m)	39	39

Note: The process design of the constructed wetlands may show there will be about 90% BOD removal efficiency in constructed wetlands. However, it has to be kept in consideration there would be decaying of plants which would contribute to additional BOD concentration. This will result in decreasing the removal efficiency to about 50%. [8]

8.4. Process Design of Facultative Aerated Lagoon [5]

Process Design of Facultative Aerated Lagoon for treatment of **blackwater of peri-urban area**, considering following criteria:

Capacity Average Flow (Q_{avg})	0.1	MLD
Sewage Generation	108	LPCD
Temperature	20	^oC
Characteristics		
pH	7-7.5	
TSS	375	mg/l
Inlet BOD (C_o)	250	mg/l
Faecal Coliform (MPN)	100000	/100 ml

Parameters considered for designing of the SSF Constructed Wetlands		
Plant Porosity (n)	0.7	
Desirable combined effluent BOD (C)	3.5	mg/l
Depth (m) (d)	4	m

1. BOD Removal Efficiency		
Removal Efficiency = % of (Inlet BOD-Outlet BOD)/ Inlet BOD		
Hence,		
Efficiency	**98%**	

2. Determine detention time		
Assuming plug flow conditions, with D/UL =0.1 and removal efficiency =98%		
K_L x t	5.6	
K_L at 20^{o}C = 0.7 day^{-1}		
Hence, t	**8**	**days**

1. Determine Lagoon Size		
Lagoon Volume	**800**	**m^3**
Surface Area= Volume/ Depth	200	**m^2**
Considering Length : Width = 8 : 1		
Hence,		

Width	**5**	**m**
Length	**40**	**m**

3. Susbstrate Removal		
$S = S_o \times e^{-kt}$, where S = Effluent Substrate		
S	**1.39**	**mg/l**
Volatile Suspended Solids= 0.6 x S		
BOD of VSS	0.64	**mg/l**
Hence total BOD of effluent	**40.64**	**mg/l**

4. Power Requirement		
With 92 % efficiency		
Oxygen Requirement	1265	Kg/day
	52.71	Kg/hr
Power Requirement	32.94	KW

5. Sludge Accumulation		
Cleaning interval = 5 years		
Accumulation occurs at 0.05 m^3/person-year		
Sludge volume	**231.5**	**m^3**
Extra depth = Sludge Volume / Lagoon Floor area		
Extra depth	**1.16**	**m**
Total Depth	**5.16**	**m**

6. Land Requirement		
Net Lagoon Area	200	**m^3**
Area including embankments and slopes	**300**	**m^3**
Area/person	**0.30**	**m^2/person**

7. Coliform Removal		
Removal Efficiency = $K_b \times t$		
$K_b = 1.2\ day^{-1}$		
$K_b \times t$	9.6	
From the value of Kb x t, removal percentage	99%	

Faecal coliform in the effluent	**1000**	**/100 ml**

Process Design of Facultative Aerated Lagoon for treatment of **greywater for rural areas**, considering following criteria:

Capacity Average Flow (Q_{avg})	0.1	MLD
Sewage Generation	36	LPCD
Temperature	20	ºC
Characteristics		
pH	7-7.5	
TSS	150	mg/l
Inlet BOD (C_o)	100	mg/l
Faecal Coliform (MPN)	1000	/100 ml

Parameters considered for designing of the SSF Constructed Wetlands		
Plant Porosity (n)	0.7	
Desirable combined effluent BOD (C)	4.4	mg/l
Depth (m) (d)	4	m

1. BOD Removal Efficiency

Removal Efficiency = % of (Inlet BOD-Outlet BOD)/ Inlet BOD

Hence,

Efficiency	**97%**	

2. Determine detention time

Assuming plug flow conditions, with D/UL =0.1 and removal efficiency =97%

K_L x t	4.4	
K_L at 20ºC = 0.7 day^{-1}		
Hence, t	**7**	**days**

1. Determine Lagoon Size

Lagoon Volume	**700**	**m^3**
Surface Area= Volume/ Depth	175	**m^2**
Considering Length : Width = 8 : 1		
Hence,		
Width	**5.00**	**m**
Length	**40.00**	**m**

3. Susbstrate Removal		
$S = S_o \times e^{-kt}$, where S = Effluent Substrate		
S	**1.12**	**mg/l**
Volatile Suspended Solids= 0.6 x S		
BOD of VSS	0.52	**mg/l**
Hence total BOD of effluent	**40.52**	**mg/l**

4. Power Requirement		
With 92 % efficiency		
Oxygen Requirement	281.75	Kg/day
	11.74	Kg/hr
Power Requirement	7.34	KW

5. Sludge Accumulation		
Cleaning interval = 7 years		
Accumulation occurs at 0.01 m^3/person-year		
Sludge volume	**194.46**	**m^3**
Extra depth = Sludge Volume / Lagoon Floor area		
Extra depth	**1.11**	**m**
Total Depth	**5.11**	**m**

6. Land Requirement		
Net Lagoon Area	175	**m^3**
Area including embankments and slopes	**245**	**m^3**
Area/person	**0.07**	**m^2/person**

7. Coliform Removal		
Removal Efficiency = $K_b \times t$		
$K_b = 1.2\ day^{-1}$		
$K_b \times t$	8.4	
From the value of Kb x t, removal percentage	99%	
Faecal coliform in the effluent	**10**	**/100 ml**

8.5. Process Design of Duckweed Pond

Process Design of Duckweed Pond for treatment of **blackwater of peri-urban area**, considering following criteria:[5]

Before proceeding with the process design, it is needed to be highlighted that pre-treatment is very much necessary before the wastewater flows into the duckweed pond. The duckweed pond can yield the desired results when clubbed with other anaerobic or aerobic treatment processes, such as aerated lagoon or algal waste stabilization ponds. In either case, the following parameters has to be abided to get desired results from duckweed pond:

BOD ≤ 80 mg/l

TSS ≤ 100 mg/l

TKN ≤ 50 mg/l

Capacity Average Flow	0.1	MLD
Sewage Generation	108	LPCD
Temperature	20	°C
Characteristics		
pH	7-7.5	
TSS	100	mg/l
BOD	80	mg/l

Parameters considered for designing of duckweed pond		
Desirable combined effluent BOD (C)	3.5	mg/l
Organic Loading rate	250	Kg/ha.d
Detention time	8	days
Depth	1.5	m

1. Determine the surface area of the duckweed pond

Total BOD entering the duckweed pond = Average Flow x BOD

Hence, Total BOD	8	Kg/day
Surface area= Total BOD/ Organic Loading rate		
Hence, Total BOD		
Surface area required per day	0.032	ha/day
	320	m^2/day
Surface area (A)	**1920**	**m^2**
	0.19	**ha**

2. Determine the volume

Total volume required= Surface Area x Depth		
Hence,		
Total volume	2880	m^3

3. Duckweed yield		
Considering duckweed yield intensity = 0.8 tons/ha-d		
Total duckweed yield	0.15	ton/day

Process Design of Facultative Aerated Lagoon for treatment of **greywater for rural areas**, considering following criteria:

Capacity Average Flow	0.1	MLD
Sewage Generation	36	LPCD
Temperature	20	ºC
Characteristics		
pH	7-7.5	
TSS	75	mg/l
BOD	30	mg/l

Parameters considered for designing of duckweed pond		
Desirable combined effluent BOD (C)	4.4	mg/l
Organic Loading rate	250	Kg/ha.d
Detention time	8	days
Depth	1.5	m

1. Determine the surface area of the duckweed pond		
Total BOD entering the duckweed pond = Average Flow x BOD		
Hence, Total BOD	3	Kg/day
Surface area= Total BOD/ Organic Loading rate		
Hence, Total BOD		
Surface area required per day	0.012	ha/day
	120	m^2/day
Surface area (A)	**720**	**m^2**
	0.072	**ha**

2. Determine the volume		
Total volume required= Surface Area x Depth		
Hence,		

Total volume	1080	m^3

3. Duckweed yield		
Considering duckweed yield intensity = 0.8 tons/ha-d		
Total duckweed yield	0.06	ton/day

Table 8. 6 : Performance of Duckweed Pond

Criteria	Greywater	Blackwater
Area (m^2)	720	1920

8.6. Comparative Study of Different Technologies vs Activated Sludge Process

Table 8. 7 : Comparative Study of Different Technologies vs Activated Sludge Process (0.1 MLD capacity)

Technology	Area (m^2)	BOD Removal	FC Removal	N- removal	Power (KW)
Waste Stabilisation Pond	1070	90-95%	99%	-	-
Constructed Wetlands	3330 *(for 7 days detention period for N-removal)*	75%	99%	√	-
Facultative Aerated Lagoons	280 *(for 8 days detention period)*	98%	90-95%	-	32
Duckweed Pond	1920 *(for 8 days detention period)*	95%	90-95%	√	-
Activated Sludge Process	42	95%	99%	√	90

CHAPTER 9. : Way Forward

Presently, economic growth in developed nations, human population explosion in certain areas of Asia and Africa, deforestation, and destruction of natural habitats for the conservation of biodiversity are the biggest challenges for implementing the principles of ecological engineering in most of the developing nations. Economic crunch in many developed as well as developing nations is forcing to implement low-cost natural treatment systems for the domestic and industrial wastewater treatment. In case the technological treatment facilities are installed in many developing countries, the energy input is difficult to be supplied in view of the global energy crisis, and very high operational cost is a bottleneck to their affordability. These all factors are compelling the employment of low-cost natural treatment systems for not only waste treatment but also for conserving biological communities in poor nations of the world. The conventional systems that may be appropriate in industrialized regions and densely populated areas with guaranteed power supplies, easily replaceable parts, and a skilled labour force to ensure operation and maintenance requirements might not be suitable for those regions with limited resources. Hence, natural treatment systems particularly suit to developing countries of the world. In this context, it is desirable that Waste Managers and Policy Makers of India should also explore the feasibility of implementing Natural Wastewater Treatment as the viable option to cater rapidly growing peri-urban areas of the country in decentralised manner for the treatment of black and grey water (used water). In addition, selective natural technologies may also be adopted for industrial wastewater treatment for extensive reclamation and reuse of water.

Since 1990s, CWs have been used for the treatment of wastewater to remove solids, N, P, heavy metals, and organic pollutants. CW have also been used for the removal of coliforms from storm water, municipal sewage, and agricultural runoff. The presence of angiospermic plants in a wetland ecosystem improves treatment efficiencies. The unique wetlands along the coastline of tropical and subtropical regions are mangroves. Mangroves could be used in CWs for wastewater treatment as shown by different studies.

The rapid increase of shortages in resources of chemical elements (and ores) used for an increasing industrial production raises the question of alternative strategies for their acquisition. Simultaneously, the elemental load in aquatic ecosystems increases by anthropogenic activities. Polluted waters are purged actively by technical treatment plants or passively by wetlands. Wetlands are known to eliminate/fix pollutants with a potentially high efficiency.

Mangroves are sole wetlands along the coastline of tropical and subtropical areas. They have unique adaptations to stressed environments and a massive requirement for nutrients because of fast growth, high primary productivity, metabolism, and yield. Many studies have demonstrated that mangroves could be used in CWs for wastewater treatment. Plants can affect their growth medium by excreting exogenous enzymes and can also affect microbial species composition and diversity by releasing oxygen into the rhizosphere that in turn indirectly influences enzyme activity. The subsurface vertical flow constructed wetland (SVFCW) system with unsaturated flow possesses greater oxygen transport ability than the horizontal subsurface flow beds and is more effective for the mineralization of biodegradable organic matter.

Land treatment systems comprise a possible alternative solution for wastewater management in cases where the construction of conventional (mechanical) wastewater treatment plants (WWTPs) are not afforded or other disposal option are not accessible. They have established to be an ideal technology for small rural communities, homes, and small industrial units due to low energy, low operational, and maintenance costs. They depend upon physical, chemical, and biological reactions on and within the soil. Slow rate OF systems require vegetation, both to take up nutrients and other contaminants and to slow the passage of the effluent across the land surface to ensure the maximum contact times between the effluents and the plants/soils. Slow rate subsurface infiltration systems and RI systems are "zero discharge" systems that rarely discharge effluents directly to streams or other surface waters.

The OF systems are a land application treatment technique in which treated effluents are ultimately discharged to surface water. The major profits of these systems are their low maintenance and technical manpower requirements. Subsurface infiltration systems are designed for population of less than 2,500 people. They are usually designed for individual homes (septic tanks), but they can be designed for clusters of homes. Although they do require specific site conditions, they can be low-cost methods of wastewater disposal.

The use of subsurface infiltration systems has been expanded to treat various types of wastewaters, including landfill leachates, dairy effluents, meat processing wastewater, olive oil mill wastewater, agricultural drainage, and contaminated groundwater. Recognizing the importance of wastewater management in meeting future water demands, preventing environmental degradation, and ensuring sustainable growth, the use of subsurface infiltration systems in wastewater management is expected to increase.

Natural aquatic systems work on the natural ecological principals where aquatic plants, algae, and other microbes absorb pollutants found in the wastewater to accomplish treatment. Stabilization pond is one of the frequent wastewater treatment methodologies where inexpensive land is available. Facultative ponds and land application processes can produce excellent quality effluent with smaller energy budgets.

The socio-economic situation and the context of urbanisation highlight the need for decentralised wastewater solutions. In such circumstances, local reuse and recycling of treated wastewater through natural treatment process holds immense potential in terms of overall urban environmental sustainability.

Reuse and Recycle

With the country hurtling towards a water crisis and treated wastewater a possible alternative, using models that are different from the centralised approach, is a sustainable and cost-effective solution

India, one of the world's most water-stressed countries, will become water-scarce with time. Per capita water available is set to decline to 1,465 cubic metres by 2025 from 1,544 m^3 in 2011 (and 1,816 m^3 in 2001), according to a 2018 Niti Aayog study.

If appropriate and time-bound measures are not taken, the country may have to confront a series of associated problems, ranging from health issues due to poor sanitation and conflicts over water access, to food security and climate change.

India will need 1.5 trillion m^3 water by 2030, according to the Central Pollution Control Board.

A proposed alternative to India's growing water crisis that is doing the rounds is the recycling and reuse of treated wastewater. This can be one of the measures to reduce the pressure on water resources.

Central urban development schemes — such as Jal Shakti Abhiyan, Swachh Bharat Mission, Atal Mission for Rejuvenation and Urban Transformation (AMRUT), Smart Cities Mission and Namami Gange — are crucial for wastewater treatment. They also emphasise the reuse of wastewater (including grey and blackwater) for various purposes, especially non-potable ones like horticulture and flushing.

Almost 80 per cent of the water supplied to a household is discharged as wastewater. The discharge is mostly untreated. So, it is a potential pollutant of ground water or being discharged into the natural drainage system, causing pollution in downstream areas and water bodies.

As of now, only 30 per cent of India's urban wastewater is recycled. The apathy with regard to sewage treatment plants (STPs) lies in the fact that those in urban spaces are neither properly financed nor designed.

For example, in Delhi, the situation of wastewater treatment is better on paper. A consumption of 3,420 million litres per day (MLD) leads to wastewater of over 2,600 MLD. Of this 1,600 MLD is treated and 338 MLD is reused.

Mumbai is worse. According to officials in the Municipal Corporation of Greater Mumbai, out of a supply of 3,750 MLD, 2,300-2,400 MLD goes into the sea, almost untreated.

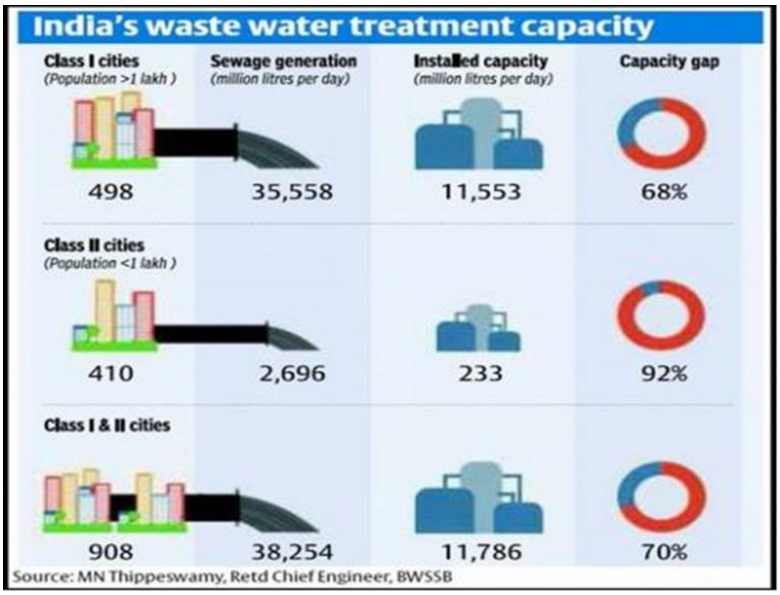


Figure 9. 1 : Treatment capacity gap in India [38]

Instead of constructing large conventional STPs in which emphasis is placed on setting up a large infrastructure network, what we need to look at are alternative methods which will not burden the economy and environment.

Emerging Pollutants Removal

In case of removing organic compounds, the focus is generally on three types of compounds, that is, chlorinated solvents, petroleum hydrocarbons, and explosives. But researchers also addressed the potential of plant species to treat other organic contaminants, such as polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCB). The removal of such pollutants is only possible through wetlands.

The natural systems containing various plant species were regarded as very effective and inexpensive technology for the clean-up of hazardous waste sites polluted with hydrocarbons, metals, pesticides, and chlorinated solvents. The treatment of organic pollutants by plants may involve four mechanisms:

(1) direct uptake, accumulation, and metabolism of contaminants, in plant tissues (detoxification),

(2) transpiration of volatile organic hydrocarbons from leaves (avoidance),

(3) release of exudates from the roots that will stimulate microbial activity and biochemical transformations (chelation), and finally,

(4) the presence of mycorrhizal fungi and microbial consortia associated with the root surfaces can enhance the mineralization of pollutants in rhizosphere.

Photosynthetic activity and growth rate of plants are the two factors which render economic success of the treatment process by plants. Due to fast growth and large biomass production, water hyacinth (Eichhornia crassipes) is largely used for the wastewater treatment. Water hyacinth through uptake and accumulation can effectively remove inorganic contaminants such as nitrate, ammonium and soluble phosphorus, and heavy metals. Different organic pollutants such as phenols can also be absorbed, but their removal mechanisms were rarely studied to confirm that the removal of these pollutants involved uptake or the enhancement of mineralization by microbial consortia associated with the root surface.

Decentralisation

A proper mechanism is needed to deal with wastewater. The existing centralised approach should not be considered the only method. This is due to the approach's limited sewerage network access, inadequate functional STPs and budgetary restrictions.

Instead, decentralised wastewater management approach can be considered as a sustainable and cost-effective alternative as it treats, discharges, or reuses the effluent in the relative vicinity of its source of generation. Like other systems, decentralised systems must be properly designed, maintained, and operated to provide optimum benefits.

In the rapidly urbanising cities and the towns of developing countries, decentralised wastewater treatment systems are an attractive solution for addressing the problems of water pollution and scarcity. They have been promoted extensively in some countries due to their low operation and maintenance requirements and smaller scale investments.

Decentralised wastewater treatment systems could be a feasible alternative for areas which are not connected to sewer networks as well as ones which are newly developed, so that the construction of their infrastructure is inadequate, not ready or would be executed in the future.
Based on the size of the served area, there are different scales of decentralisation:

- Decentralisation at the level of a suburb or satellite township in an urban area — These systems are applied to small towns.
- Decentralisation at the level of a neighbourhood — This category includes clusters of homes, gated communities, small districts, and areas which are served by vacuum sewers.
- Decentralisation at 'on-site' level (on-site sanitation) — In these cases, the whole system lies within one property and serves one or several buildings.

Decentralised and low-cost wastewater treatment systems can augment limited treatment capacity. The mainstreaming of decentralised wastewater treatment systems needs a policy-level thrust from the government.
Hence, sound policy and regulatory interventions by the Central and state governments are a prerequisite for launching innovative reuse projects. Government interventions will need to focus on incentivising the use of reclaimed water and developing institutional support mechanisms.
States including Gujarat, Maharashtra, Rajasthan, Chhattisgarh, Karnataka and Madhya Pradesh have announced a wastewater treatment policy.
The National Green Tribunal in August said decentralised technologies such as bioremediation and / or phytoremediation or any other remediation measures could be started as an interim measure until STP units become functional.

India adopting natural treatment in treatment of used water:

1. The East Kolkata Wetlands (EKW), located on the eastern fringes of Kolkata city bordering the Salt Lake township on the one hand and the new township at Rajarhat on the other, forms one of the largest assemblages of sewage fed fishponds.

Figure 9. 2 : East Kolkata Wetlands

2. A waste stabilisation pond, located Tiruchi, next to the Koraiyar, a small tributary of the Cauvery. The plant here is designed to treat 80 million litres per day but currently is operating at around 40 million litres per day. The oxidation pond water is ready for use for agricultural purposes.

Figure 9. 3 : WSP at Tiruchi

3. Delhi has planned to implement 16 STPs at Bawana to discharge treated water into Yamuna that would follow natural treatment technology following sedimentation tank and phytoremediation through aquatic plants.

Figure 9. 4 : A view of a pilot Sewage Treatment Plant (STP) that is built with pebbles and plants, at Bawana, in New Delhi

4. The Municipal Corporation of Tirupati (MCT) has recently taken up an eco-friendly project – Natural Sewage Treatment Plant (STP) of five million litres per day (MLD) capacity. It would follow natural treatment technology following sedimentation tank and phytoremediation through aquatic plants.

5. 25 KLD Constructed wetlands have been built in IIT Bombay campus that would follow the technology of Constructed Wetlands.

Figure 9. 5 : The wetland project at IIT-Bombay- an idea from Professor Shyam Asolekar from the Centre for Environmental Science & Engineering

6. Phytorid treatment has been adopted in the following places:
   - Rajyapal Bhavan, Mumbai (completed)
   - Nabi Lake, Lonar (for preventing sewage being overflown to Lonar lake)
   - Teen Murthi Bhavan, New Delhi (in progress)
   - Smriti Vatika, New Delhi (in progress)

Future Scope of Study

It needs to be appreciated that there is a dearth of extensive field level studies on Natural wastewater treatment technologies in India. Most policy makers for various reasons are reluctant to implement these technologies in urban areas. However, under National flagship Programme, SBM , the policy makers can advocate for these technologies in vast peri-urban and rural areas including satellite townships especially for the faecal sludge and septage management,

In order to document a comprehensive compendium cum manual for these technologies needs convergence of brainstorming of experts, researchers and field level implementors supported with huge practical information and data in different climatic conditions and geographical locations is required.

This study can be enriched with collection of yearlong, reliable field level information from various parts of the country and dissemination and collation of the same.

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