

DESIGN ECOSYSTEM FOR THE RESTORATION AND MANAGEMENT OF LAKES

Rakesh Kumar*, Sandeep T. Tayade*

ABSTRACT

Almost half of the world's lakes are degraded, depleted, and contaminated mainly by human activities. The main causes are inflow of domestic sewage, agricultural runoff, discharge of industrial effluents, over-fishing, introduction of exotic species and habitat degradation from population growth, expansion of cities. As more water is withdrawn for human use and more of it is returned to lakes and rivers badly polluted there is less available to maintain vital freshwater ecosystems. Major degrading factors include excessive eutrophication due to nutrients and organic matter loading from domestic wastewater. Thus, it is necessary to take a step for management and restoration of lakes. Looking for a problem, a pilot scale study based on phyto-treatment concept was setup in National Environmental Engineering Research Institute (NEERI) laboratory, Mumbai. Treatment efficiency of subsurface design ecosystem were evaluated for pollutant parameters such as total suspended solids (TSS), biochemical oxygen demand (BOD), nitrogen (N), phosphorus (P) and fecal coliform (FC). The results indicate high removal efficiencies particularly for BOD, TSS and FC. Wetland bed was prepared with locally available plants such as bulrush and cattails. This technology offers several advantages such as simple operation, maintenance, economically and environmentally sound treatment of wastewater as well as for aquatic habitants.

Keywords: Eutrophication, restoration, phyto-treatment, bulrush and cattails.

1. INTRODUCTION

Water pollution remains one of the most visible and persistent signs of our impact on the natural world. Cleanup of some older pollutants has been offset by new contaminants that threaten freshwater ecosystems and foul our drinking water (Carmen Revenga, 2000). Lakes are unique and valuable ecosystems for both people and nature. Lakes and their surrounding watersheds are critical storage tanks for freshwater. More than 90% of all available liquid surfaces freshwater are contaminated in lakes and reservoirs (Shiklomanov, I. 1993). In most developing countries, the problems of traditional pollution sources like sewage and new pollutants like pesticides have combined to heavily degrade water quality, particularly near urban industrial centers and intensive agricultural areas. **Table 1** outlines the summary of major pollution sources and their effects

Lakes provide human being with services that include water for irrigation, drinking, industry, and dilution of pollutants, hydroelectric power, transportation, recreation, fish, and esthetic enjoyment (Postel, 1997). These services are impaired by

* Author is Scientist with NEERI

* Author is Project Fellow, NEERI, Mumbai Zonal Laboratory, 89-B, Dr. A. B. Road, Worli. Mumbai-18

exploitation of lakes and the lands of their catchments (Hasler, 1947). Because human effects on lakes are growing, concern increases that lake ecosystem services are in jeopardy (Naiman et al. 1995). These concerns parallel those for the sustainability of services from many ecosystems and the biosphere itself (Arrow et al., 1995).

Table 1 : Common Water Pollutant and their Sources

Pollutant	Primary Sources	Effects
Organic matters	Industrial wastewater and domestic sewage	Depletes oxygen from the water column as it decomposes, stressing, or suffocating aquatic life.
Nutrients	Runoff from agricultural lands and urban areas	Excess growth of algae
Microbial contaminants	Domestic sewage, cattle, natural sources	Spreading infectious diseases through contaminated water supply
Slit and suspended particulates	Soil erosion and construction activities	Increase in turbid levels and effects on aquatic habitat
Toxic organic compounds	Industrial sources, agricultural runoff	Vide range of toxic effects on aquatic flora and fauna and also in human
Heavy metals	Industries and mining sites	Persists in fresh water environment and accumulates in aquatic fauna

Reservoirs and dams are constructed for the purposes of flood control and power generation too. Accordingly, it is difficult to focus on a single issue when considering the long-term use and protection of these important and finite water resources.

The drainage basin is the logical management unit for lakes and reservoirs because the drainage basin is (i) the source of water, (ii) the place where it is used, and (iii) where human activities impact both water quantity and quality, Activities that generate pollutants (e.g., urbanization, industrialization, agricultural production) are similar in both lake and reservoir drainage basins, whether from point or nonpoint pollution sources. Point sources are ‘pipeline’ discharges of pollutants to receiving waters, e.g. domestic sewage discharges or industrial waste effluents from factories or plants. They are relatively easy to identify and isolate. In contrast, nonpoint pollution results from storm runoff or snowmelt, which transports polluting materials diffusely and over land in urban and agricultural areas to rivers, lakes and reservoirs. Thus, non-point source pollution is closely tied to precipitation and runoff events, and less predictable and more variable in nature. Because of their diffuse nature, nonpoint pollutant sources are also more difficult to identify and deal with.

Of particular importance in addressing lake and reservoir problems is the need to consider an “ecosystem approach”. Here, rather than adopting the sectoral approach that focuses on a single water use, the ecosystem approach considers both human water needs within the larger context of the drainage basin and environmental water needs or ecological requirements. This approach, therefore, is a prudent means of balancing the water needs for economic development and environmental protection.

Water quality problems typically involve water pollution issues. Major water pollutants include a variety of organic and inorganic chemicals such as heavy metals and industrial compounds. They can affect human health and/or interfere with industrial or agricultural water use. If the level of a pollutant in the water supply exceeds an acceptable level for a given water use (e.g., domestic or industrial water supply), the water is considered unsafe or too degraded for that use. Solutions to lake and reservoir pollution problems, therefore, usually focus on reduction of pollution at the source and/or treatment of the polluted water prior to use.

Virtually all lake and reservoir water problems are related either to issues of (1) quantity – there is too little or too much water, or (2) quality – the water is too degraded (polluted) for drinking water supply, agricultural irrigation and/or industrial or other purposes. The problem of too little water results either from limited precipitation or excessive water usage. In contrast, the problem of too much water is typically manifested as floods. Solutions to these problems, therefore, usually involve developing larger water supplies or reducing current water uses, respectively.

Considering a problem of pollutants in lakes or reservoirs, a pilot scale study of design ecosystem was developed in National Environmental Engineering Research Institute (NEERI), Mumbai Zonal Laboratory for treatment of wastewater reaching lakes or runoff water.

Design Ecosystem Technology is one such technological solution, which can be easily implemented nearby lakes and/ water bodies. The system is based on filterable wetland being utilized for a wide variety of applications throughout the world. This treatment system reflects phenomena observed in natural marshland settings. They act as filters for removal of organic matter (carbon, nitrogen and phosphorous), suspended solids, and pathogenic organisms.

The filterable wetland is sown with aquatic plants where wastewater flows in horizontal outflow zone. This zone are designed in such a manner that mainly removes BOD and also phosphorous and oxidizes nitrogen.

The technology can be utilized for municipalities, industries and even for municipal landfills (USEPA, 2000). The technology works on gravity, without a need for any chemical and major pumping. It provides greater flexibility with regard to loads and desired outputs.

2. MATERIALS AND METHODS

The pilot scale study of design ecosystem consisted of single bed, which is designed for a small flow. The municipal wastewater used in the experiment was primary treated sewage collected from Lovegrove pumping station.

The treatment system has three components:

- Inlet chamber; consists of crushed bricks and sand
- Treatment zone; consists of three layers viz., upper layer of crushed bricks; middle layer of sand and lower layer of stones.
- Outlet zone

Plants species were collected from naturally occurring wetland region and transferred in the filled bed and initially treated with fresh water. Treatment bed was planted with

bulrush (*Scripus* sps) and cattails (*Typha latifolia*). Hydraulic loading rate and hydraulic retention time of the treatment bed were 0.25 m³/m²/day and 3.5 day respectively.

The samples of influent and effluent were collected for a period of eight month, two samples a month and analyzed for parameters mention in **Table 2**.

Table 2 : Analytical Methods for Pollutant Parameters

Parameters	Methods	Remarks
TSS (Total Suspended Solids)	SM 2540 D	Glass Fiber Filter Paper
Total Kjeldhal Nitrogen	SM 4500 NH3-E	
Phosphorus	SM 4500 P D	Spectrophotometer 108, Systronics
BOD (Biochemical Oxygen Demand)	SM 5210 B	3 Day BOD Test at 27 °C
FC (Fecal Coliform)	SM 9215 D	Membrane Filter Method

SM- Standard methods (APHA, 1998)

3. RESULTS AND DISCUSSION

The results of the study are presented in **Table 3**.

Table 3 : Efficiency of the Ecosystem

Parameters	Ave. Concentration*		Efficiency (%)
	Influent	Effluent	
TSS (mg/l)	144 ± 3.0	25 ± 2.1	83.00
BOD (mg/l)	152 ± 5.0	23 ± 3.5	85.00
N (mg/l)	24 ± 1.8	9.4 ± 0.8	60.00
P (mg/l)	2.8 ± 0.02	1.37 ± 0.05	51.00
FC (colonies/100ml)	4.5 x10 ⁷ ± 210	1.7 x10 ⁶ ± 180	96.00

There are average 16 samples.

3.1 Suspended Solids Removal

TSS concentrations were quite high in the influent wastewater and were dramatically reduced in the effluent water due to filtering action of the treatment media present in the bed. Most of the suspended solids are removed through sedimentation and filtration, as vegetation obstructs the flow and reduces velocities. In most of the applications, a sedimentation pond is added upstream of the treatment bed to promote the removal of larger suspended particles and minimize chances of clogging the bed. The pond can also dilute the raw influent if it is considered too strong. These processes remove a significant portion of the BOD, nutrients (mostly nitrogen and phosphorus) and pathogens. Ideally, however, wastewater reaching the bed should not have any floatable and grits, which are likely to clog the system quickly and reduce the HRT.

3.2 Biochemical Oxygen Demand Removal

BOD removal of bed is high in influent (152 mg/l) and reduces to 23 mg/l in treatment zone due to the microbial population and bacteria present on the root structure of the plant species. Wastewater is aerobically degraded by bacterial biofilm that is attached to the plants. In treatment bed, the aquatic plants supply oxygen to the wetland floor through their roots, thereby promoting the aerobic digestion of organic material. Some anaerobic degradation of organic material also occurs in the bottom sediments. Wetlands provide a diversified micro-environment which plays an important role in pollutant processing. Various processes occur within the water column, on the plants, in the wetland substrate and in concentrated areas of microbial activity known as biofilms. Biofilms are formed as bacteria and microorganisms attach themselves to the plant roots and the substrate matrix to form a biological filter from the water surface to the wetland floor. As wastewater passes through the thick growth of plants, it is exposed to this living biofilm, which provides a treatment process similar to that found in conventional sewage treatment plants.

3.3 Nitrogen and Phosphorous Removal

Similarly, nitrogen and phosphorus of bed shows lower reduction as compare to TSS and BOD. Treatment systems promote the process of nitrification/ denitrification, which removes nitrogen from the wastewater. In simple terms, a bacterium in the wastewater (*Nitrosomonas*) oxidizes ammonia to nitrite in an aerobic reaction. The nitrite is then oxidized aerobically by another bacteria (*Nitrobacter*) forming nitrate. Denitrification occurs as nitrate is reduced to gaseous forms under anaerobic conditions in the litter layer of the wetland substrate. This reaction is catalyzed by the denitrifying bacteria *Pseudomonas* spp. and other bacteria's. Wetland plants play an important role in nitrogen removal by providing biofilm attachment points and by supplying oxygen for nitrification in the root zone. Phosphorous removal in wetlands is based mainly on the phosphorous cycle and can involve a number of processes such as adsorption, filtration, sedimentation, complexation /precipitation and assimilation/uptake. Nutrients reaching lakes during rains, if made to pass through the design ecosystem, can be removed to a large extent.

3.4 Pathogens Removal

Pathogens of concern in aquatic treatment systems are parasites, bacteria and viruses. Because it is impractical to monitor all pathogens, indicator organisms such as Fecal coliform (*E. Coli*) are used to measure the removal efficiency of a treatment system. These indicators are used because they are easy to monitor.

Fecal Coliform shows the higher removal efficiency compared to other pollutants parameters. Coliform removal is achieved through a combination of natural die-off, temperature, sunlight (ultraviolet light), water chemistry, predation and sedimentation. Despite the presence of water, a wetland is a hostile place for pathogens. A proportion of bacteria are removed by sedimentation, especially those attached to particles. Biofilm filtering removes some of the pathogens by direct contact. Predation occurs as the wetland provides a habitat for a variety of microorganisms, some of which are pathogen predators such as zooplankton. The shallow water columns found in wetlands allow the penetration of ultra-violet light from sunlight, which also destroys pathogens.

4. SUITABILITY OF THE METHOD

Designed Ecosystem Technology can be implemented with a pond or other treatment systems, which can remove grit or large floating material, setup nearby lakes or water bodies. Advantages of this system include such as flood protection and flow control, water quality improvement, landscape and recreational amenity and provision of wildlife habitat. Wetland ecosystem planning should not overlook the need for long-term maintenance. Additional vegetation planting may be required to speed plant coverage, replace damaged plants or to try more suitable varieties. Perimeter fencing may be required. Maintenance may be needed to control the spread of undesired plant species. Inlets and outlets can become blocked with debris, which will require periodic removal. Inlet and outlet structures should be inspected weekly. Most importantly, if the wetland functions well as a sediment and nutrient trap, it may eventually require dredging to remove accumulated materials. Thus, vehicular access to the site must be provided for maintenance and possibly dredging equipment. Before implementation, it is necessary to monitor the pollutant load and fluctuation of wastewater flow to decide the area for treatment zone. **Fig 2** depicts the different element of design ecosystem for lakes or water bodies.

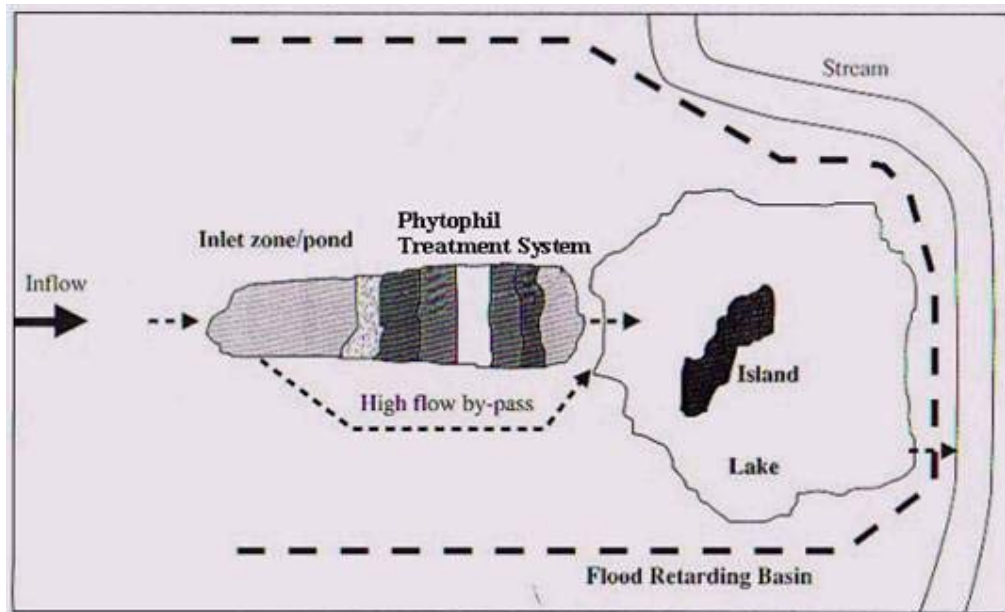


Fig. 2 Modular Element in an Integrated Design Ecosystem

These elements are:

- Inlet zone/pond – to trap sand, to silt-sized particles and improve water quality. This module can have some secondary benefits, including landscape aesthetics and flow attenuation.
- Design ecosystem is an area where plants such as rushes, reeds and sedges – to improve water quality through the trapping of fine particles and soluble pollutants. This module can have some secondary benefits, including wildlife habitat and flow attenuation.

- Lake/island – to provide passive recreation, landscape enhancement and wildlife habitat. Depending on the outlet structure, lakes can significantly attenuate flow. Lakes can also provide water quality benefits, but this function can be compromised if the lake attracts large populations of wildlife, which can degrade water quality.
- Flood retarding basin – to protect downstream areas from flooding and to control stream hydrology. This module can provide more open space within the urban landscape. Treatment modules located in flood retarding basins can benefit from the extra hydrologic control provided by the basin.
- High flow by pass – pipeline or channel should be made for high flow during rainy season.

5. CONCLUSION

Design ecosystem is an effective technological option for on-site wastewater treatment when properly designed, installed, and maintained. This treatment system can be a viable secondary as well as tertiary treatment alternative for municipal wastewater. These systems are potentially good, low-cost and appropriate technology for domestic wastewater treatment in areas where land is inexpensive.

6. ACKNOWLEDGEMENT

Authors are thankful to Director, NEERI.

7. REFERENCES

- APHA, 1998 "Standard Methods for the Examination of Water and Wastewater, 20th Edition, Washington D. C.
- Arrow, K., B. Bolin, R. Costanza, P. Dasgupta, C. Folke, C.S. Holling, B. Jansson, S. Levin, K. Maler, C. Perrings, and D. Pimentel. 1995. Economic growth, carrying capacity, and the environment. *Science* 268: 520-521.
- Carmen Revenga and Greg Mock. 2000 Pilot Analysis of Global Ecosystems: Freshwater Systems
- Hasler, A.D. 1947. Eutrophication of lakes by domestic drainage. *Ecology* 28: 383-395.
- Igor Shiklomanov, "World Fresh Water Resources," in *Water in Crisis: A Guide to the World's Fresh Water Resources*, Peter H. Gleick, ed. Oxford University Press, New York, 1993), Table 2.8, p. 20. .
- Naiman, R.J., J.J. Magnuson, D.M. McKnight, and J.A. Stanford. 1995. *The freshwater imperative*. Island Press, Washington, D.C., USA.
- Postel, D.M., S.R. Carpenter, D.L. Christensen, K.L. Cottingham, J.R. Hodgson, J.F. Kitchell, and D.E. Schindler. 1997. Seasonal effects of variable recruitment of a dominant piscivore on food web structure. *Limnology and Oceanography*, in press.
- United States Environment Protection Agency (USEPA); 2000. "Constructed Wetlands and Aquatic Plant Systems for Municipal Wastewater Treatment", EPA/625/R-99/010