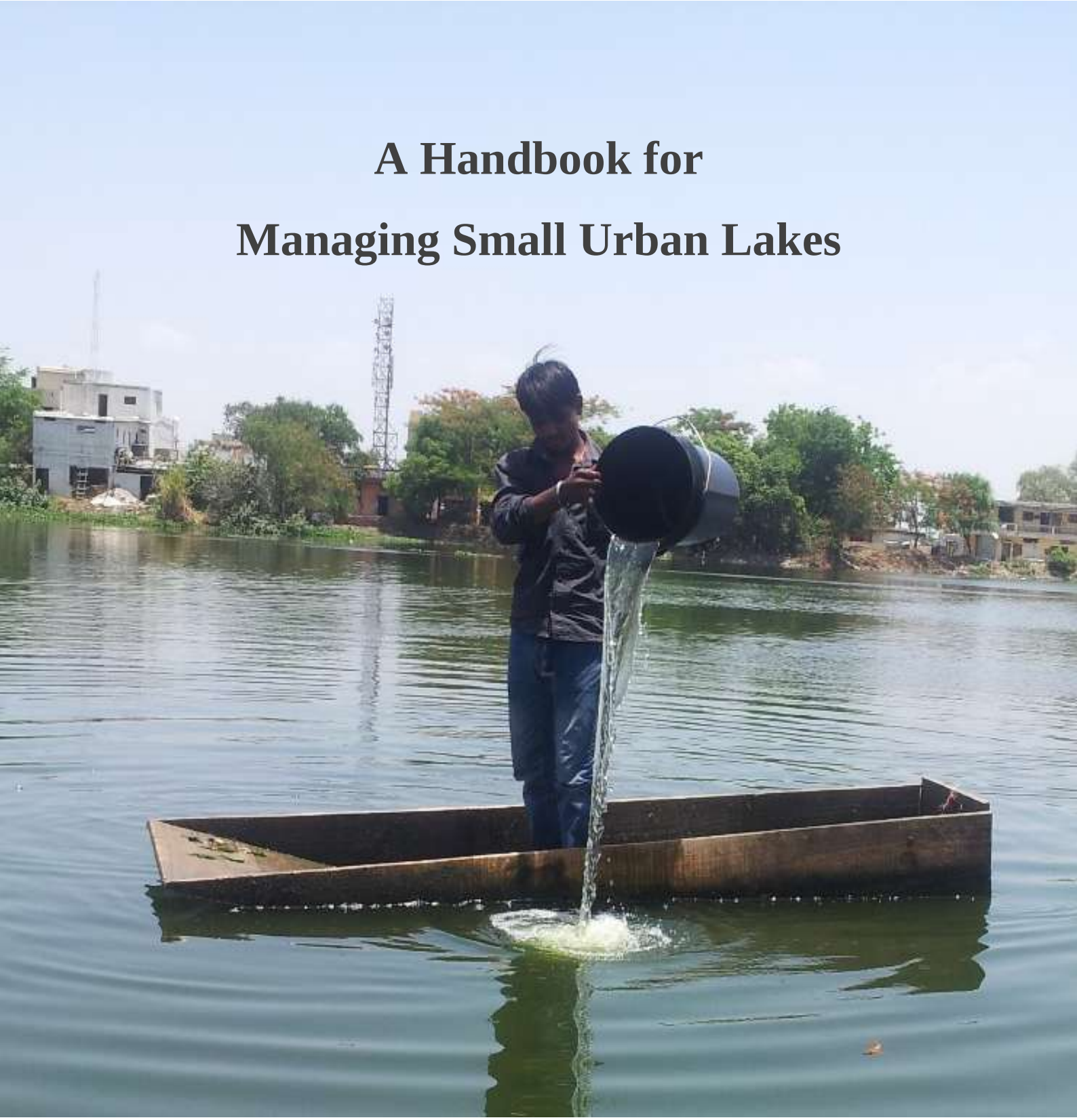
A Handbook for
Managing Small Urban Lakes



An Initiative under ACCCRN

Submitted by

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1 PURPOSE OF THIS HANDBOOK

This book is addressed to citizens, urban managers and civil society organizations interested in conservation and restoration of small urban and peri-urban lakes. The main aim of this hand book is to provide information about challenges and guidance on options to conserve urban lakes. While many states have formed Lake Development authorities, there are no technical guidance manuals for development and management of urban lakes useful for the stakeholders available.

The hand book covers the causes of degradation of urban lakes, provides methods and tools for analysis of lake status and then explains about possible options for restoration of urban lakes. Technical, ecological, social and institutional aspects of lake restoration are covered. The urban limnology is complex due to diverse anthropogenic impacts and the expected roles of urban lakes. This book only provides basic information and suggests methods and tools for understanding these water bodies and possible measures to restore them.

The hand book is specifically written in simple language so that multiple stakeholders are able to understand the concepts and options. Expert advice may be required to support some of the technical lake conservation activities. It is suggested that the readers may take external support, wherever necessary. Local academic institutions, government & municipal departments can provide such expert support and facilities. Local laboratories of these departments have most of the equipment for water and other analysis necessary.

1.1 Types of Lakes

In nature both natural as well as manmade lakes are found. The natural lakes form due to hydrological and tectonic conditions. The ox bow lakes are found in alluvial plains due to shifting of rivers in a flat terrain with old defunct channels forming lakes. Disruption of the drainage by faulting and earthquakes can form tectonic lakes.

Over the human history, communities have built lakes to manage water, especially in arid and semi-arid regions facing seasonal water scarcities. The lakes enabled communities to intensify and expand agriculture and to support domestic and livestock needs. Oasis in deserts as well as chain tanks of India is best examples of manmade lakes.

Figure 1: Chain Tanks Of Tamil Nadu

Source: Google Earth, (Digital Globe)

Location: 9.986032°N 78.965929°E Dated:08MAR2004

Since Independence, India has built several large, medium and small dams. Also under watershed development projects several small reservoirs have been built. While these conventional structures have increased, the traditional structures have decayed due to neglect. Shift to farmer owned ground water irrigation systems and decay of traditional maintenance institutions are some of the main causes of their neglect and decay. The total wetland area in India is estimated at 10.002 Mha (excluding rivers)[1].

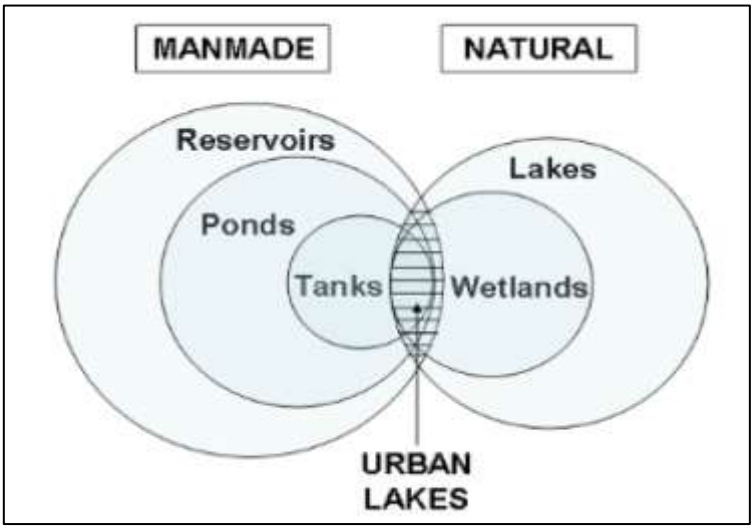
1.2 Urban lakes

There is no specific definition for urban lakes that is globally accepted. Reddy and Char[2] (2004) defined "urban lakes as the subset of all fresh water bodies such as reservoirs, lakes, ponds, tanks, etc., those that are surrounded by land on all sides and located in urban situations". The following Figure 2 presents simple classification of the lakes based on size location and context.

[1] http://saconenvis.nic.in/publication%5CNWIA_National_atlas.pdf

[2] Reddy, M. S., Char, N. V. V., (2006): Management of Lakes in India, Lakes & Reservoirs: Research &Management, Volume 11, Issue 4, pages 227–237

Figure 2: Type of lakes based on size and location



Source: Reddy and Char (2004)

Mist of the urban lakes in India are natural or man-made standing freshwaters with a maximum depth of less than 5 m and a mean depth of usually less than 2 m located in urban situations. They are primarily used for amenities and recreation and mainly do not include reservoirs used either for potable supply, industrial abstraction or irrigation.

Characteristics of Urban Lakes in India

The urban lakes in India show following characteristics.

- *Small, with a surface area less than 10 square kilometers*
- *Tend to be shallow, with an average depth of less than 10 m.*
- *Catchment area/lake area ratio is generally in the range 10:1 to about 20:1. Their catchments exert a strong influence on the lake.*
- *Catchment area has more than 10% impervious cover.*
- *Their water quality is highly influenced by human activities*

The urban lakes must be managed for serving recreation, water supply, flood control and other direct human uses.

The urban lakes in generally face several visible problems like greenish color with low visibility, frequent algal blooms, bank sides devoid of vegetation, water hyacinth/duckweed covering the lake with little or no aquatic vegetation, no fish or frequent fish kills, flotsams of plastics. These make unpleasant environment and people often do not like to use lakes for recreation.

1.3 Role of Lakes

Lakes and water bodies are important components of rural as well as urban ecosystems. Though some of them relatively small in size, they perform significant environmental, social and economic functions as presented in the following Table:

Table 1: Functions of urban lakes in India		
Function	Example	
Water source	Bhoj wetlands, Bhopal	
Ground water recharge	Khajrana Lake, Indore	
Flood buffers	Ramgarh Tal, Gorakhpur	
Biodiversity habitats	Chilka Lake	
Livelihoods (agriculture, fishing, gathering aquatic products, recreation)	Loktak lake, Manipur http://1.bp.blogspot.com/-AOHheNk1xkw/UcqasBRpHXI/AAAAAAAAAeY8/3Xb8lkEwLs0/s1600/Loktak+Lake+Largest+Floating+Lake+in+India+0.jpg Floating farms of Loktak lake	
Recreation	Husain Sagar lake	

1.4 Lakes in rural areas

The philanthropists, village communities, kings, rural religious institutions financed like temples built tanks in rural areas of semi-arid India. These tanks are named after temples and names of the leaders. Elaborate inspirational arrangements developed to manage the water as well as lakes. Religious beliefs and rituals strengthened sustainability of these water bodies. The *Neer katti*, the irrigation functionary, was appointed by the village or government to manage water from tanks and canals. These water societies developed strong links between communities, water and ecology.

Community efforts to maintain lakes

In lakes of Delhi, people who come to collect water or wash take out a pan of soil from the tank bed, as a symbolic way of de-silting. Tanks were de-silted by communities, when they dry up during droughts as a drought relief measure.

These systems collapsed due to various reasons like:

- Farmer owned ground water systems resulting in decay of the management systems.
- Fertilizer use replacing the lake bed soil for farming.
- Government focuses on large irrigation systems reducing investments on tank management.
- Encroachment of tanks for agriculture.

The irrigated are under these traditional tank systems have been declining, especially since Independence. Only during last few decades, the international donors have invested on rejuvenation of these tanks.

Figure 3: Rural lakes of Indore

Tigriya Badshah Lake	Meetha Talab, Kanadiya
	
 Satellite image	 Satellite image

Source: TARU Study, Google Earth

1.5 Transition of lakes (Rural –Peri urban- urban)

As the cities expand in to neighboring region, the land prices increase and the catchment and command areas are converted to housing plots and colonies. The land price of the catchments is sometimes higher due to better land for conversion and less water logging problems.

The rural water bodies are either owned by the Panchayats or sometimes small tanks are revenue lands are owned by the individuals or religious institutions. The fishing rights are often vested with the state fisheries departments. Some of the tanks are also owned by the forest department. There is considerable diversity and ambiguity about the ownership of the

water bodies in the villages across the states. Until villages are taken over by the municipality, the clarity about the conversion of agricultural to built-up land is often lacking. The Panchayats do not have development plans resulting in arbitrary conversion from agricultural land. Expansion of settlements takes place before the ULBs take over the villages. Lands are used as an investment by the real estate developers.

Since basic services like sewerage, storm water drainage and solid waste management systems are not commissioned before development, the solid waste and sewage is often diverted to the natural drainage lines. This results in filling up of the water bodies by disposal of solid waste, construction wastes and sewage. Also, the natural drainage is blocked by compound walls. Since the cadastral maps do not delineate the minor drainage lines, the constriction across narrow drainage channels further block the inflow in to the lakes.

Figure 4 Sewage inflow in to the lakes

Khajrana Lake

Lasudiya mori lake

Source: TARU

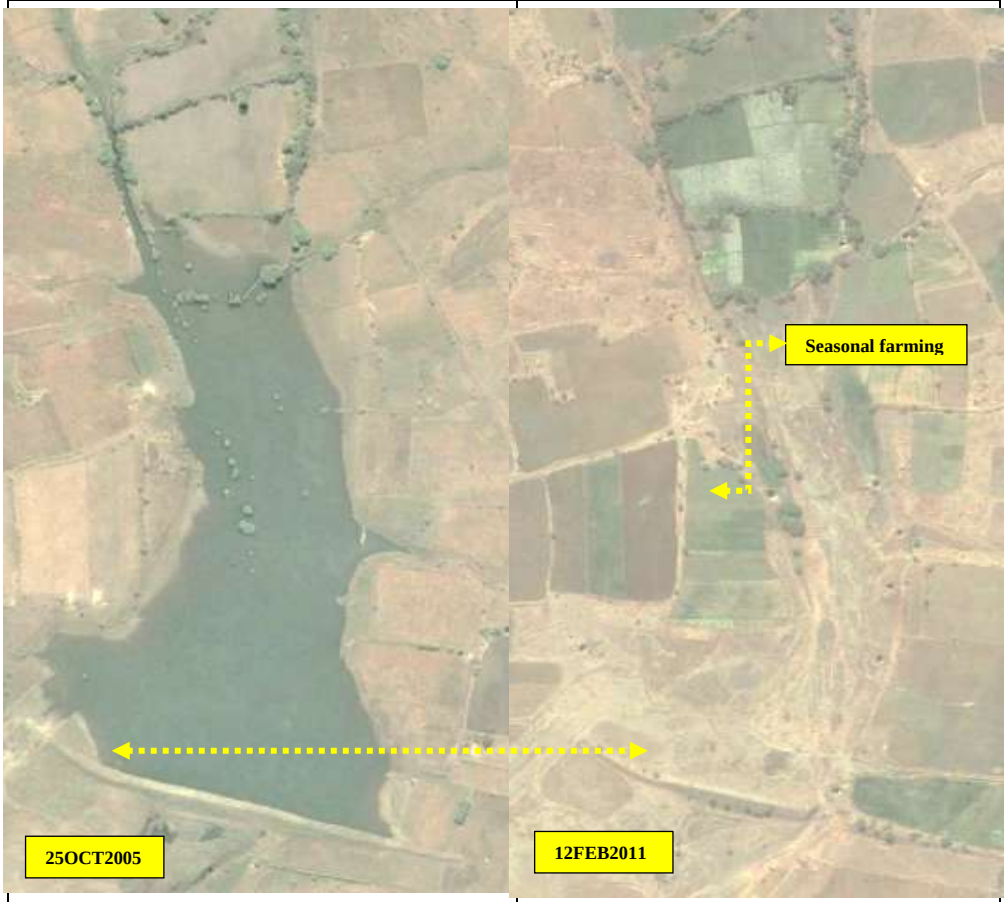
The catchment hydrology gets significantly affected by increase in paved areas and blockage of natural drainage system resulting in occasional floods even in the catchment, as evidenced in Khajrana lake catchment. As the built up area in the catchment area increases these events become more frequent.

Figure 5: Flood in Khajrana lake Catchment 2013

Source: Local resident

Many of the small water bodies dry up during normal summers or there is considerable reduction in water spread areas during summers. During drought years they totally dry up. These droughts provide opportunity for de-silting the tank beds. With increasing sewage inflow these water bodies become perennial the rate of silt accumulation increases (solid waste, construction wastes and sewage) but rural desalting mechanisms die due to lack of stakes among new owners.

Figure 6: Seasonal drying of water bodies (Near Indore)



Location: 23.927776^{o} N, 76.347016^{o}N

The major impacts on lakes due to urbanization are presented in the following Table:

Table 2: Changes in lake environments due to urbanization

Details	Rural	Peri urban	Unplanned Urban
Catchment	Agriculture, hills	Mixed use	Mostly urban
Density	Low, very few houses or none	Moderate, sparsely spread	High
Surface	Soils with rocky and hilly areas	Paved areas increasing	Mostly paved areas
Hydrology	Percolation and some runoff during heavy rains	Runoff percentage increases due to paved areas	High runoff very low percolation

Water inflow	Natural rainy season runoff	Runoff + sewage input	Runoff + sewage/ Domestic drainage
Environment	Pleasant, no issues.	Mosquitoes increase	Mosquitoes, foul smell, Weeds
Pollution/Silting	Soil from agricultural use	Solid/construction wastes	Solid waste and sewage
Use	Fishing, Bathing, Washing clothes, Animal use, Drinking water from recharged wells	Washing clothes, Animal wading	Washing clothes, Animal wading, or not use
Seasonality	Seasonal	Increasing months with water	Perennial
Area shrinkage	Constant area	Shrinkage starts	Encroachment, filling up and alternate use
Depth	Constant due to regular desilting	Starts reducing	Decreases, Increases only by desilting
Flora and Fauna	Habitat for varied animal and plant species	Reduction in number and variety	Drastic fall in number and variety, weeds dominate
Livelihoods	Fishing, water chestnut, seasonal farming	Livelihoods diversity reduces.	Few or none, unless conserved
Recurrent problems	None	Mosquitoes	Mosquitoes, foul smell, Weeds
High intensity risks	Rare Bund breaches	Bund breaches, Few floods in catchment	Recurrent floods in catchment & command,

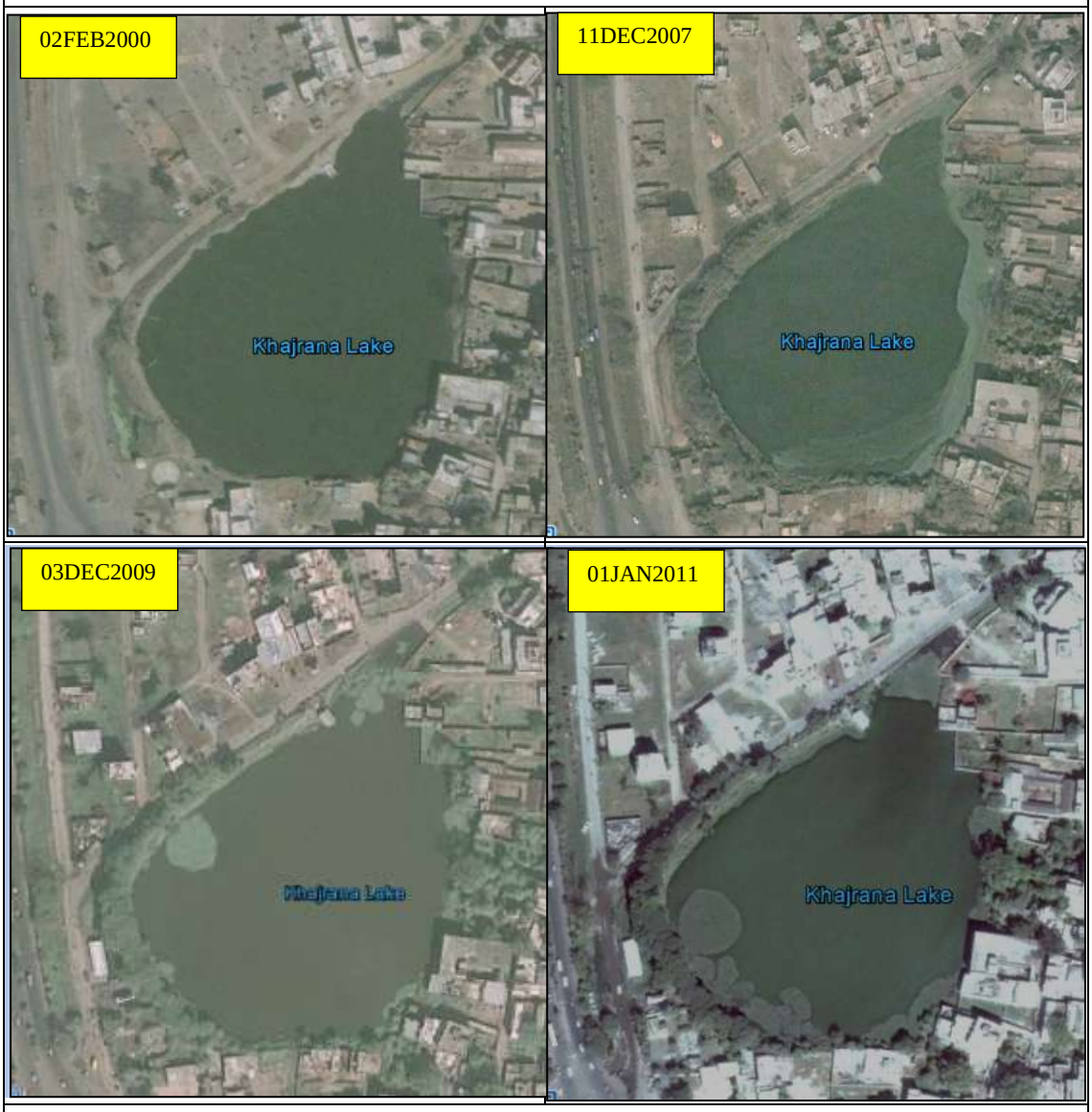
There has also been a change in lake management and administration, from lakes managed by village communities living in their vicinity to formal governance structures imposed by city municipal authorities. This abruptly disengages and alienates local communities whose lives and livelihoods are often linked with the lake for generations. With weed growth and frequent fish kills, the traditional stakeholders, especially fishermen, often out-migrate.

Figure 7: Encroachment of Lasudiya Mori lake

Source: TARU

Since the urban residents have no direct stakes on marinating the lakes, the increasing problems (mosquitoes, foul smell) often lead to demands for filling up the lake. New stakeholders also often come up due to high real estate values. The solid waste dumping on edges shrinks the water spread area and often leads to slow encroachment of informal settlements. Since the lakes are owned by the government (Panchayat, ULB), the encroachments are often not removed resulting in permanent shrinkage of water spread. The building up of nutrients like nitrogen and phosphate from the sewage leads to proliferation of water hyacinth, as presented in the Figure 8 through time series imagery of the Khajrana Lake.

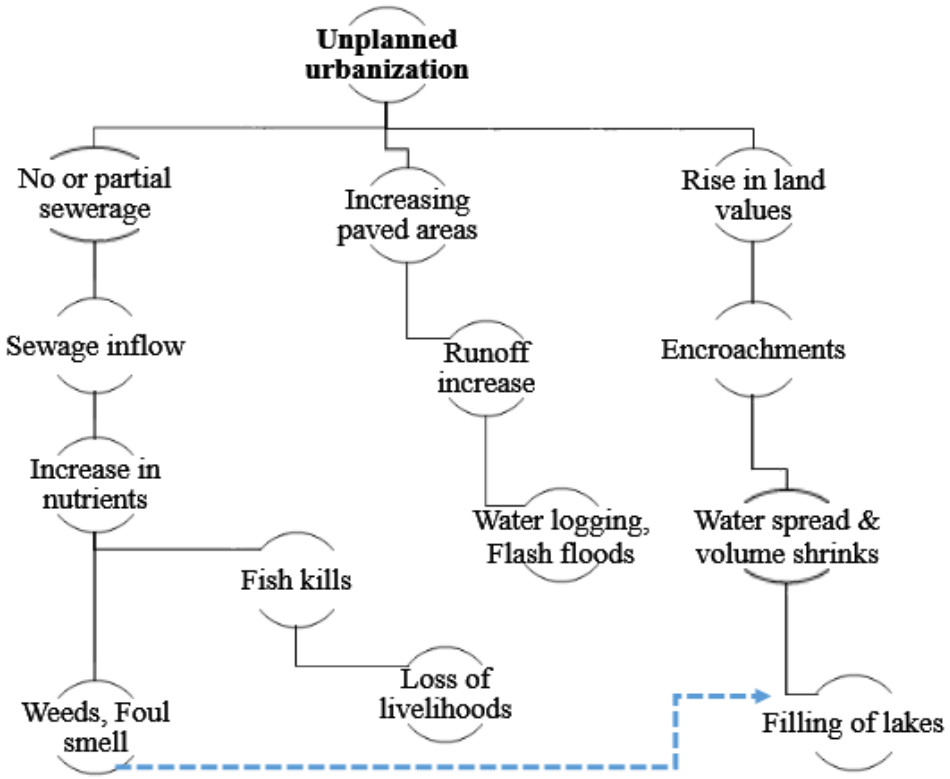
Figure 8: Weed growth due to eutrophication: Khajrana Lake



Source: Google Earth

Depending on the size, rainfall and catchment context, some of the changes may appear early or late in the sequence of urbanization. The impact chain of informal urbanization is presented in the following Figure 9.

Figure 9: Sequence of urbanization impacts



Source: TARU

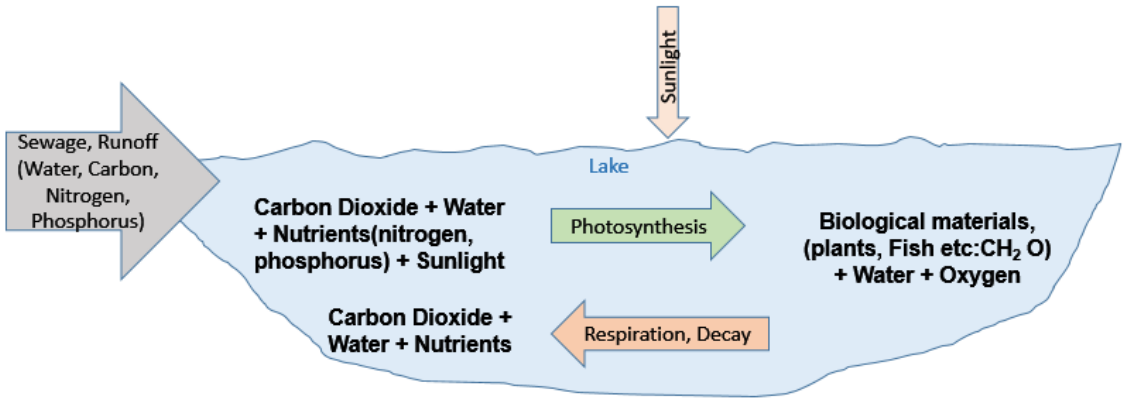
Many lakes across the Indian cities have been filled up over last several decades. Only during the last decade, civil society groups and resident welfare associations have been demanding the conservation of lakes. Resident welfare society groups many urban local bodies (ULB) have taken up lake conservation projects. Some of these successful interventions can provide insights in to the design of lake restoration efforts by citizen and ULB partnerships.

1.6 Chemical and biological impacts of urbanization.

The urbanization leads to large inputs of sewage and grey water inputs with dissolved nutrients. They include nitrogen, phosphorous and dissolved organic compounds including pesticides. Some of these are nutrients which catalyze growth of algae and plants. Nutrients flow in to lakes by drainage from its catchment and direct rainfall. Informal urbanization without sewerage system adds sewage and grey water flow in to the lakes.

The main elements of interest are carbon, nitrogen and phosphorous. Decay of organic matter in water results in consumption of dissolved oxygen in water. Both nitrogen and phosphorous can cause algal blooms and rapid spreading of weeds like water hyacinth, which can lead to reduction of sunlight penetration, decrease in dissolved oxygen and lead to fish kills. The interrelationship between nitrogen and phosphorous are complex, but both of them can cause algal blooms and water hyacinth problems. It is necessary to understand sources, their behavior in the lakes and the impacts of increased nitrogen and phosphorous inputs to lakes.

Figure 10: The relationship between photosynthesis- respiration-decomposition processes



Source: TARU

Carbon is present in all types of food, plant and animal wastes. The dumping of food and plant wastes results in decay of the food and vegetable matter. Decay results in absorption of oxygen from water resulting in reducing dissolved oxygen. Foul smells from lakes are the result of decay of organic matter. Sewage treatment strips off carbon while air diffusers are used to increase oxygen availability in the lake waters.

Water quality of lakes

Water contains a number of dissolved and suspended materials including nutrients (e.g., nitrogen, phosphorus, dissolved carbon), contaminants (e.g., pesticides, petroleum hydrocarbons), and other constituents (e.g., dissolved oxygen, salts, metals, suspended sediments). Some chemicals (e.g., nutrients) can be either beneficial or toxic, depending on how much is present. Water quality usually refers to how "healthy" the water is for humans, animals and plants. An aquatic area with "good" water quality has the water chemistry typical of the ecosystem and region, including the levels of dissolved oxygen, contaminants, and other constituents (nutrients, suspended sediments) that result in healthy populations of native plants and animals.

Source: An introduction and user guide to wetland restoration, creation and enhancement[3]

Two nutrients are important causes of eutrophication are nitrogen (N) and phosphorus (P). They can come from natural sources or from anthropogenic sources. Eutrophication that is induced by human activity, beyond natural levels, is known as cultural eutrophication. The following Table presents some of the sources of cultural eutrophication. Nitrogen from waste waters mostly comes from grey water and sewage sweat, urine and plant/animal wastes.

Some of the organic compounds break down by exposure to sunlight and chemical reaction with water and soils; while others persistent chemicals (e.g. DDT) can stay for long time in the lake environment. The toxic compounds like insecticides and pesticides can cause fish kills and can the concentration of these persistent toxic build up in plant tissues liver and bones of the aquatic animals and their concentration can get magnified.

[3] http://www.habitat.noaa.gov/pdf/pub_wetlands_restore_guide.pdf

Table 3: Sources of Nitrogen and Phosphorus in lake waters	
Source	**Type of problem**
Non-Point Sources	
Agriculture	Farming practices, including use of fertilizers rich in N and P, deposit increased amounts of these nutrients in the soil. Run-off from these farms causes eutrophication in water bodies.
Sewage	Direct discharge of sewage from domestic sources, not connected to treatment plants, will eventually make its way into water bodies.
Point Sources	
Power plants	Combustion of fossil fuels emits nitrogen products into the atmosphere, which are carried down by rainfall and other processes, causing eutrophication in water bodies.
Sewage Treatment Plants	Treatment process releases oxides of N and P in effluents, which drain into water bodies.
Industrial Plants	Industrial processes release N and P products in effluents, which drain into water bodies.
Source: UNEP Japan Website[4]	

It is important to understand the nutrients balance in lakes to maintain healthy aquatic life and to avoid fish kills and eutrophication. Water quality analysis of inflow water (runoff, sewage) can be used to estimate nutrient inputs and lake water quality can provide early warring of impending eutrophication. Prevention of nutrient build up is more cost effective than restoring lake after the eutrophication or weed growth.

1.7 Impacts on communities

As the catchments get converted, new residents are neutral towards the lakes, since they are not affected by the impacts. As the natural drainage gets disrupted, the water logging and flood frequency increases. The water logging is first noticed in impervious soil regions (e.g. Black cotton soils, as in case of Indore). In rural environments, since the only input is rainfall, water logging was not an issue. As the value of the infrastructure (houses, roads) is high in urban areas, the value of flood and water logging losses increases.

Initially in the sequence of change, the fish production may increase due to additional nutrient inputs, but as the eutrophication sets in the fish kills become common with total extinction. The fishermen often dewed the lake as long as they can catch fish. In Indore, they often use slaked lime to neutralize acidity to improve fish production. Once fish become extinct, there is none to manage the lake.

Liming of Lakes: Fishermen's role in lake conservation

Liming," as the word suggests, is the addition of limestone (calcite), primarily calcium carbonate (CaCO3), to neutralize acid waters and soils and buffer them from rapid fluctuations in pH. Liming is one of the most cost-effective methods of slowing the effects of acidification, restoring acidic waters, and enhancing the abundance and diversity of aquatic life. It also reduces the toxic effects of metals, especially aluminum, copper, cadmium, lead, nickel, and zinc, which can threaten fish, other aquatic life, and human health[5].

[4] http://www.unep.or.jp/ietc/publications/techpublications/techpub-11/5-3-1.asp
[5] http://pubs.ext.vt.edu/420/420-254/420-254.html

The other main impact is from mosquitoes. As the urban lakes become perennial, and the fishes become extinct, and the weeds proliferate, the lake become ideal habitat for the disease carrying insects throughout the year. In many cities, the areas neighboring the water bodies become prone to vector borne diseases like Malaria, Dengue and *Chikun Gunia*. Anecdotal evidence from medical practitioners (Hyderabad) indicates that maximum incidences of malaria are reported from areas neighboring water bodies (up to a km).

Figure 11: Fish Kills and overgrowth of weeds

Source: TARU

Foul smell reduces the property values and people do not prefer such lake view properties. Even though lake views properties offer wonderful views, a eutrophied lake is a nuisance. This often leads to people demanding filling up of lakes, which has led to many lakes being filled up, instead of restoring them. High land value in urban areas creates some stakeholders preferring to fill the lakes.

Due to availability of perennial water (surface and percolated groundwater), many of the rural lakes had settlements adjacent to them, especially in semi-arid areas. As the urbanization unfolds, these settlements became larger with in-migration and expand in to the lake boundaries. Most of these are informal settlements and poor predominantly build houses at the lakes shores, which are prone to frequent flooding. As the solid waste is dumped, they encroach further in to the earlier water spread areas shrinking the total area. As the lakes become shallower the littoral weed species start growing further exacerbating the shore environment.

These zones are often used by the poor people for open defecation, further fouling the shore and also creating habitat for snakes and other pests.

Figure 12: Lake degradation

Ipomeas weed growth on lake bank

Solid waste dumping

Source: TARU

1.8 Characteristics of Healthy urban lakes

Healthy urban lakes need to be perennial and will have low nutrient that ensures minimal weed growth and no foul smell. These lakes will have healthy benthic flora, sufficient enough to ensure oxygen generation. The dissolved oxygen should be high enough to support fish and other species necessary to prevent breeding of mosquitoes and other insect vectors.

The siltation rate should be minimal so that there is little shrinkage of volume and water spread area. It may be necessary to desilt these water bodies, especially the small ones from time to time.

It has to be noted that such lakes require healthy catchments. The catchments should be preferably fully sewered, but it may be necessary to divert some sewage and grey water after treatment in to the lake to maintain water levels, especially in arid and semi-arid environments and tropical regions with high evaporation as well as percolation losses.

Lakeshores, riverbanks, littoral zones and floodplains are critical to the survival of the ecological and biological components of watercourses and bodies of water[6]. While it may be necessary to protect the banks to prevent encroachment, healthy littoral zones are necessary, especially in the upstream part of the lake. Social fencing by the resident groups may be preferred.

The urban lakes should serve a variety of functions including flood buffers, recreation and creating microclimates. The lake banks need to become vibrant places for social interactions. Sufficient areas for these activities along the banks are necessary.

The urban lakes should also provide limited opportunities for direct use like washing etc. In India, lakes are used for religious purposes like immersion of idols and religious materials after the prayers. The urban lakes should have clearly marked zones, which should be safe and may be clearly marked. It may be necessary to have special mechanisms to prevent pollution. These activities need to provide sufficient incomes to ensure sustainable management.

1.9 Summary

This chapter provided a brief summary of the lakes, their transition from rural to urban environments. The changes due to transition from rural to urban environment are explained. The impact of deterioration of ecology on neighboring settlements is briefly explained.

[6] Protection Policy for Lakeshores, Riverbanks, Littoral Zones and Floodplains http://www2.publicationsduquebec.gouv.qc.ca/dynamicSearch/telecharge.php?type=2&file=//Q_2/Q2R35_A.htm

2 UNDERSTANDING LAKES

It is necessary to understand the changes that affect the lake before any restoration activities are taken up. Many urban lake restoration projects are limited to treatment of lake and development of recreational facilities on their banks. Several interventions like fencing of the boundaries, beautification is done under lake restoration projects. The other measures include draining and desalting of the lakes, physical removal of weeds from time to time. These do not solve the root causes of damage and do not offer sustainable solutions of lake management.

The root problems of eutrophication lie in increase inflow of nutrients through sewage and storm water. These can be solved only by understanding the catchment characteristics and solving the sewerage and storm water inflow issues. Some projects have installed large-scale sewage treatment plants to reduce inflow of nutrients into the Lakes (e.g. Hussain Sagar Lake Hyderabad). Lake Aerator systems are often installed to increase the dissolved oxygen, but these cannot solve nitrogen and phosphorus buildup of problems.

A combination of ecological and physical interventions is most cost-effective solutions to restore lakes and ensure sustainability of interventions. Involvement of local communities and urban local bodies is necessary to ensure sustainability. The urban lakes should also generate sufficient incomes and provide opportunities to build local stakes to ensure sustainability. Considering multi-faceted challenge, it is necessary to understand various factors that impact the Lake ecosystem as well as stakeholders.

2.1 Catchment studies

As the catchment becomes urbanized, three main changes takes place that impact the lake chemistry and ecology. They are increases in:

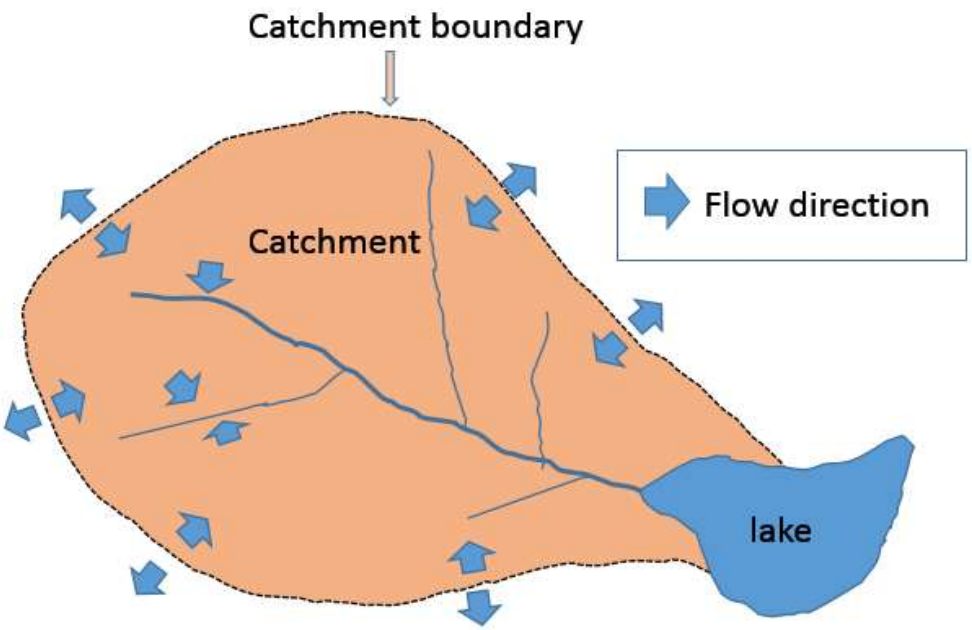
- Storm run-off,
- Volume of inflow (seasonal to perennial)
- Nutrient inflow

Catchment studies provide qualitative and quantitative information on the above parameters necessary for designing the interventions as well as to build scenario of possible changes in the future. The future scenarios are very important, especially in peri-urban lakes undergoing major transition. In fully urbanized catchments, the main changes are expected are diversion of sewage from the catchment, increased population density and changes in lifestyles. While the former will reduce water inflow into the lakes, the latter can change nutrient content in the sewage. For example, increased use of washing machines can significantly change the nutrient inflow into the lakes.

Study of the catchment includes analysis of population density, socio-economic situations settlement pattern, paved areas, water consumption pattern as well as the status of sewerage and storm water infrastructure. These are necessary to assess changes in the above parameters.

Catchment delineation: First of all the catchment need to be delineated. The Google maps and GPS can be used for delineating the catchment. It is necessary to conduct a ground survey of the catchment with points marked at various locations to identify direction of flow of rainwater. The survey can be done through transects. The following figure presents the flow directions and the catchment area of a lake by marking the direction of flow of run-off. This can be best done with involvement of local residents who will be able to provide information on flow directions. On the areas flowing into the Lake can be enclosed by a polygon, which is the catchment area of the Lake.

Figure 13: Catchment boundary delineation



Source: TARU

The catchment boundaries can be exported in to a GIS platform to get catchment area and also to further study the settlement characteristics. In peri-urban areas, the reliable terrain data or contour maps maybe also be used.

Roof and paved area calculation:

The GIS software or a paper map of Google earth can be used to assess the roof and paved areas. The building footprints can be marked on the Google earth images and can be exported to GIS. Services of local GIS professionals or local Engineering/ Geography departments can be sued wherever available.

Figure 14: Paved areas in Khajrana urban lake catchment (Indore)

Source: Google Earth, TARU study

The total roof area and the unpaved area can be used to calculate the runoff from the catchment, which will be used to model storm runoff. The daily rainfall pattern can be used to derive the total runoff across seasons. The rainfall data can be collected from local agricultural universities and airports or national meteorological departments.

Sewage and grey water inputs: Sample household surveys can be conducted to assess the household level water consumption and waste water generation. During the study, existing

sewage and grey water drainage systems can be studied to assess the volume of sewage and grey water generated and as well as the volume discharged in to the lake's inflow. These estimates can be cross checked with the actual flow measurements at the inflow points of the lake.

2.2 Water Management

Water inflow monitoring is quite important for managing the urban lakes, since the urban lakes face major fluxes in storm water, sewage and nutrient inflow. That is always a risk of eutrophication, especially due to influx of nutrient laden water from sewage or storm run-off from flash floods. While eke water management is a complex subject requiring expert inputs, it can be simplified by the experts The Lake water management will include following parameters.

2.2.1 Water balance of lakes

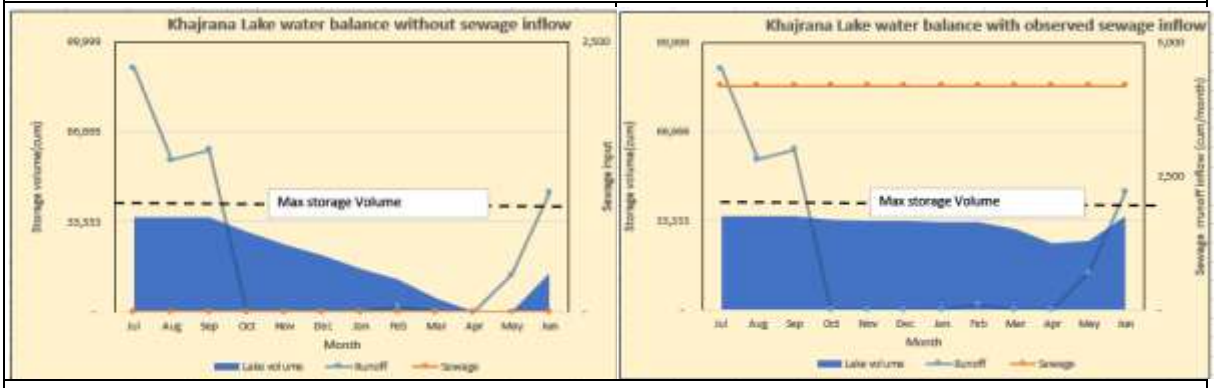
The water budget, using simple excel based model is explained in the earlier section. In small lakes, the flow/circulation can generally be ignored. The lake water balance model is very important to understand the water levels and perenniality of lakes. Since Indore has only small water bodies of up to few hectares, simple excel based models are sufficient to understand the lake volume changes over seasons. A excel based water balance model was developed to understand seasonal changes in stored water over seasons, and also under various scenarios of sewage inflows.

It is a simple model considering:

- Storm water inflow based on catchment land use (open area, paved area, gardens etc.) and rainfall.
- Sewage and grey water inflow.
- Evaporation losses.
- Infiltration losses (based on soil type).
- Over flow (based on maximum water storage).

The model includes inflow from storm water and sewage and losses due to percolation, evaporation and overflow. The results of normal rainfall scenario with observed sewage input and normal rainfall with no sewage input is provided in the above figure. The above analysis

Figure 15: Two scenarios of water levels in Khajrana lake, Indore



Source: TARU Analysis

indicates that diversion of sewage through sewerage network can cause drying up of the lake during peak summers. The results with no sewage/grey water inflow and with sewage inflow for Khajrana lake is presented in the following Figure 15.

As the peri-urban areas get absorbed by the urban local bodies, the sewerage systems are laid and the lakes, which were perennial with sewage inputs, lose the perennial inflow and can dry up. This can result in encroachment of the lake banks and also can result in changes in ecology of the lake. It may not be able to serve the role of urban lakes like boating, recreation etc. The lake models can provide insights in to possible changes in lake by changing the hydrology of the lakes. For example: The Indore Municipal Corporation has been laying sewerage system to intercept the sewage from the Khajrana catchment. This can result in drying up of the Khajrana Lake during summers, and therefore may not be available for recreation activities during summers. It is necessary to treat part of the sewage and treated sewage can be used to balance the evaporation and percolation losses.

2.3 Water quality

Water quality includes chemical and biological parameters. The healthy lakes have delicate balance of nutrients and they generally stay within narrow ranges to support healthy vegetation. Increases in nutrient ripples through the biological system through algal blooms, explosion of weeds on the surface as well as fish kills due to reduction of dissolved oxygen in water.

Water Quality management is necessary for following purposes:

- For rational planning of pollution control strategies and their prioritization.
- To assess nature and extent of pollution control needed in different water bodies or their part.
- To evaluate effectiveness of pollution control measures already in existence.
- To evaluate water quality trend over a period of time.
- To assess assimilative capacity of a water body thereby reducing cost on pollution control.
- To understand the environmental fate of different pollutants.
- To assess the fitness of water for different use.

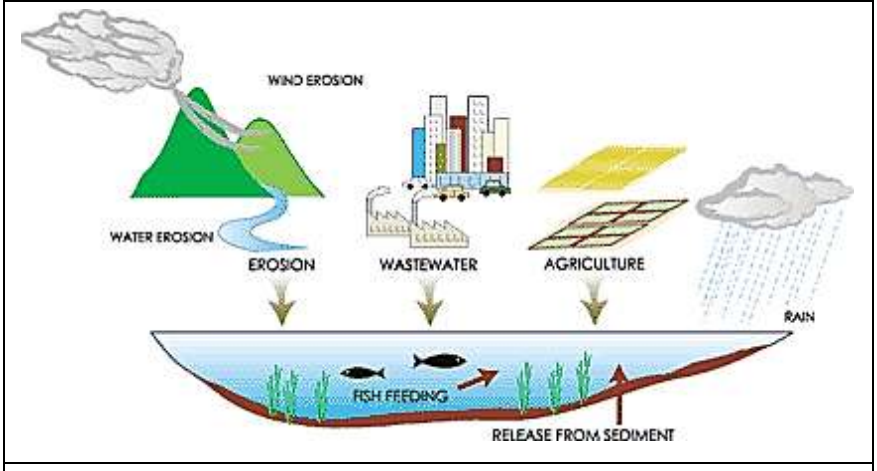
Chemical quality parameters

Dissolved oxygen, Biochemical and chemical oxygen demand, pH, Total dissolve solids, Nutrients (mainly Nitrogen and Phosphorus) are essential chemical parameters that determine the flow and recycling and sedimentation of nutrients within the lake systems. These analyses require laboratories. In most cities the State pollution boards, academic and research institutions as well as Agricultural departments have laboratories, which can conduct these analyses. It is advisable that these services are used and they may be asked to collaborate in lake conservation. It is necessary to understand the basics of nutrient balance, especially to understand the linkages between nutrients and the impacts on the lakes.

Nutrient inflow and quality of lake water: The Figure 16 presents the major sources of nutrient in lake waters. In small urban lakes sewage and industrial waste waters are the major sources.

In rural lakes, there is a delicate balance between the nutrient inflows, use in the lake by the biota as well as outflow during over flow of the lakes. This delicate balance is lost with inflow of anthropogenic nutrient inflow resulting in algal blooms, weed proliferation, fish kills and foul smells.

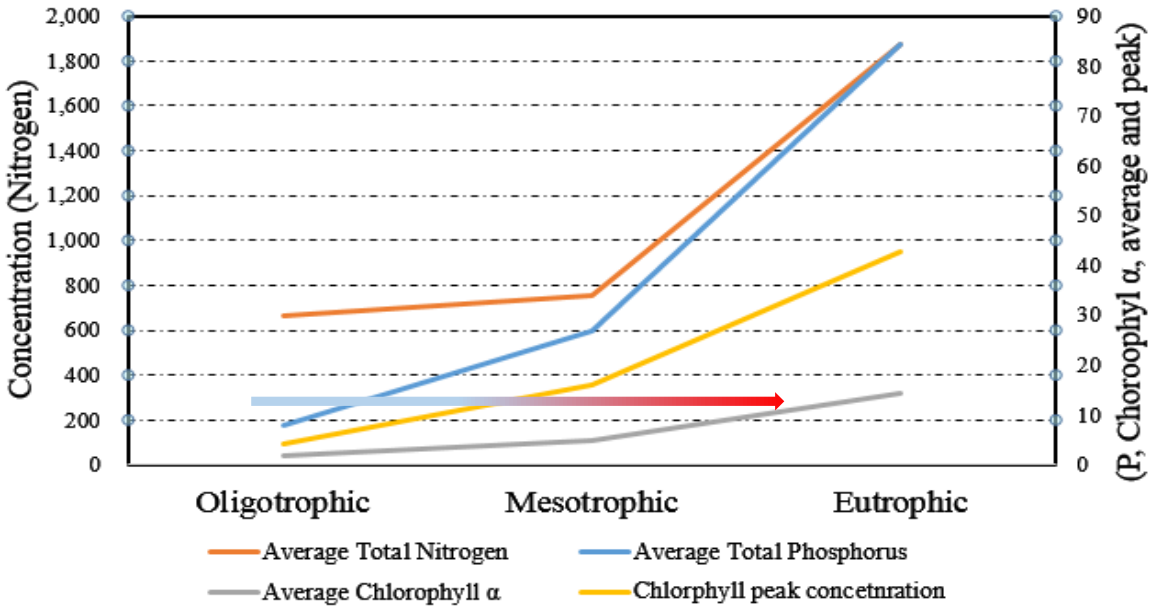
Figure 16: Major sources of nutrients in lakes.



Source: UNEP Website [7]

Since the dissolved phosphorus and nitrogen are two main limiting factors in eutrophication the lakes can be classified in to several categories of eutrophication based on phosphorus and nitrogen. The classification is presented in the following Figure 17..

Figure 17: A classification of lakes according to their extent of Eutrophication (in µg/l)



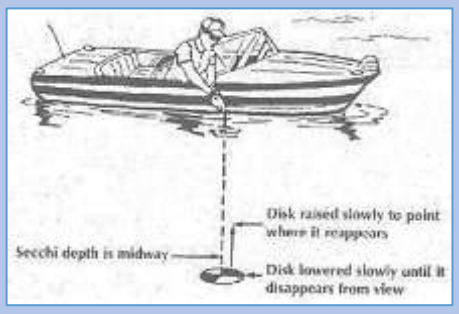
Source: Modified from UNEP website7

Oligotrophic condition generally represents natural environment with minimal amount of nutrients in the lake. As the nutrient is low, algal growth is minimum and weeds like water hyacinth and duck weeds cannot proliferate. Due to higher transparency of water (except during rainy seasons), sunlight penetrates to deeper layers of the lake water.

[7] http://www.unep.or.jp/ietc/publications/short_series/lakereservoirs-3/3.asp

Use of simple tools for assessing Trophic conditions

Three variables, chlorophyll pigments, Secchi disk depth, and total phosphorus, can be used to independently estimate algal biomass, which is used to define trophic state index. Simple test like Sechi disk can be used to assess the transparency of the lake waters, which can indicate trophic conditions in otherwise clean lake waters (suspended sediments also reduce transparency, especially during rainy season). Also time series remote sensing imagery (like Google Earth) can be used to assess qualitative changes, especially the presence of weeds and transparency. These tools can supplement the water quality analysis and can offer simple methods to assess lake conditions.



Local pollution control laboratories and academic institutions can conduct chlorophyll and water quality analysis. The Sechi disk data can be correlated with these advanced techniques for each lake, so that low quality-low quality local data collection with Sechi disks can be used as a method for local community level monitoring. These methods can be standardized modified after detailed study of each lake. Further details can be accessed from literature[8]*. (Blue Planet project website*[9]*)*

The eutrophication can reach to hypertrophic levels when phosphate levels can be higher than 200 µg/l (*micrograms per liter*) and the nitrogen higher than 2000 µg/l. The peak Chlorophyll can cross more than 500 µg/l, which will effectively cut off sunlight penetration in to deeper layers. Episodes of high Biological oxygen demand by putrefaction of dead plant materials and sold wastes can lead to fish kills, and eventually the fish may become extinct, giving rise to no predators for mosquito and other vector larvae. The Limnologists use trophic state index (TSI) to define the trophic levels in lakes. The following table presents TSI and the value ranges of Chlorophyll (**Chl**), Secchi disk depths (**SD**) and Total phosphorus (**TP**) in water for temperate lakes. These values are indicative and can be calibrated for Indian tropical conditions.

[8] http://www.secchidipin.org/tsi.htm
[9] http://theblueplanetproject.blogspot.in/2006/04/eutrophication-in-lakes.html

Table 4: List of possible changes that might be expected in a north temperate lake as the amount of algae changes along the trophic state gradient.

TSI	Chl (µg/L)	SD (m)	TP (µg/L)	Attributes	Water Supply	Fisheries & Recreation
<30	<0.95	>8	<6	**Oligotrophy:** Clear water, oxygen throughout the year in the hypolimnion	Water may be suitable for an unfiltered water supply.	Salmonid fisheries dominate
30-40	0.95-2.6	8-4	6-12	Hypolimnia of shallower lakes may become anoxic		Salmonid fisheries in deep lakes only
40-50	2.6-7.3	4-2	12-24	**Mesotrophy:** Water moderately clear; increasing probability of hypolimnetic anoxia during summer	Iron, manganese, taste, and odor problems worsen. Raw water turbidity requires filtration.	Hypo limnetic anoxia results in loss of salmonids. Walleye may predominate
50-60	7.3-20	2-1	24-48	**Eutrophy:** Anoxic hypolimnia, macrophyte problems possible		Warm-water fisheries only. Bass may dominate.
60-70	20-56	0.5-1	48-96	Blue-green algae dominate, algal scums and macrophyte problems	Episodes of severe taste and odor possible.	Nuisance macrophytes, algal scums, and low transparency may discourage swimming and boating.
70-80	56-155	0.25-0.5	96-192	**Hypereutrophy:** (light limited productivity). Dense algae and macrophytes		
>80	>155	<0.25	192-384	Algal scums, few macrophytes		Rough fish dominate; summer fish kills possible

Source: http://www.secchidipin.org/tsi.htm

Even before reaching eutrophic levels, the water hyacinth can cover the whole lake resulting in ideal habitats for mosquitoes. It is necessary to maintain the water quality at oligotrophic to mesotrophic levels to maintain the health of the lake, which requires continued monitoring across seasons and control of nutrient inflow. Special measures of denitrification and removal of phosphorus will be required. As phosphorus is more easily and less expensively removed from wastewater than nitrogen, in many cases (but not all) the best environmental management strategy for lakes and reservoirs is to remove as much phosphorus as possible from wastewater[10]. Simple measures like coagulating by dosing alum may be sufficient to remove excess phosphorus in many lake environments.

Role of biota in maintaining nutrient balance in lakes

In natural ecosystems, the nutrients should be just sufficient with maximum recycling of available nutrients. Biotic growth, grazing, predation and harvesting and export (as food) depletes the nutrients from the system and it gets replenished by import from rain/upstream (e.g. nitrates) or by release of the stored nutrients in rocks (e.g. Phosphorus. If the nutrient availability increases, it gives rise to serious imbalance in the system, resulting in weed/algal growth and structural changes within the system. Balanced input-output and recycling only can maintain healthy lake ecosystem.

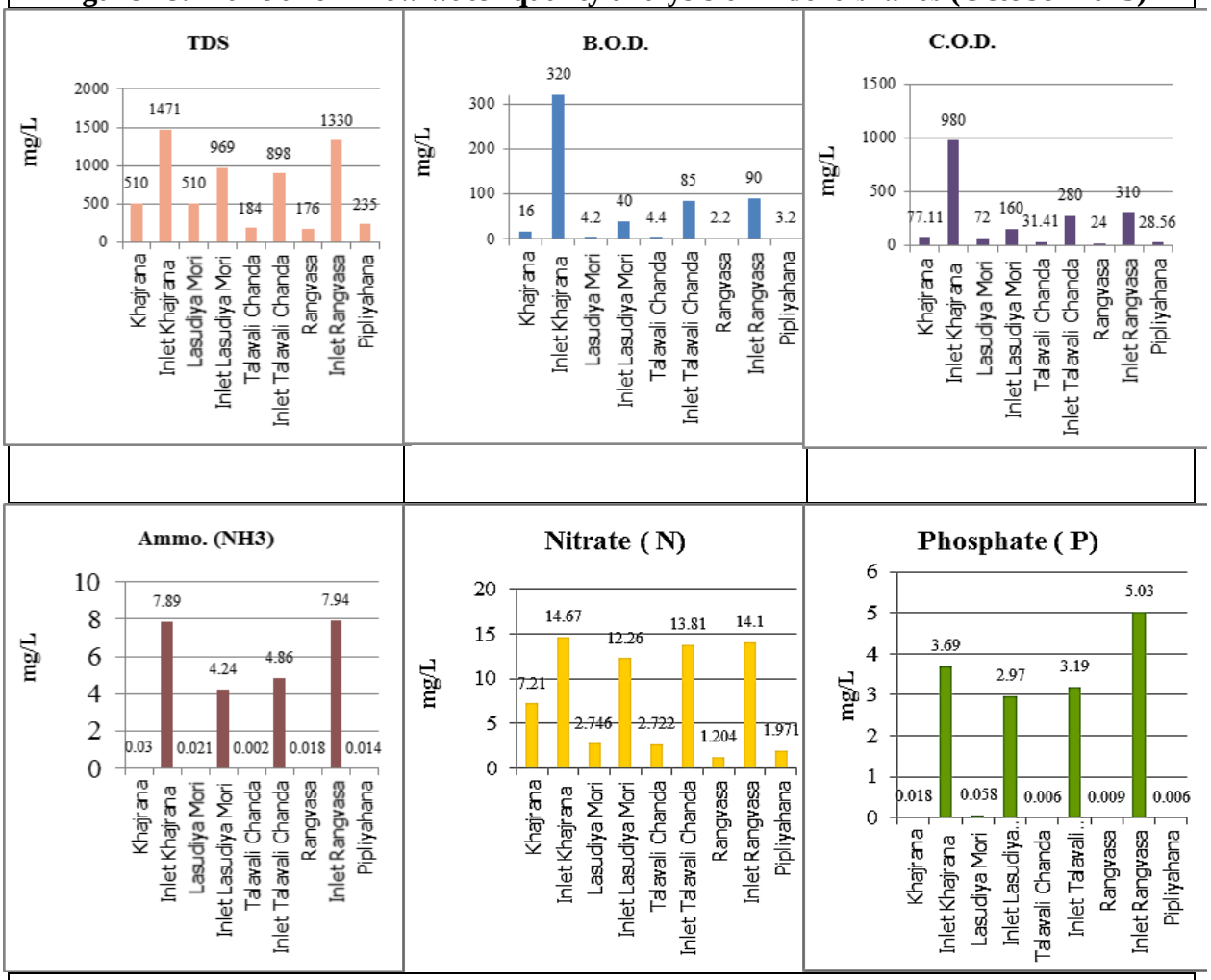
[10] http://www.unep.or.jp/ietc/publications/short_series/lakereservoirs-3/3.asp

Inflow water as well as the lake water quality analysis can be conducted at monthly/trimonthly intervals to understand the nutrient inputs as well as the status at the lake. It is suggested that following parameters are analyzed to that local environmental engineers/limnologists can suggest restoration options:

Table 5: Major chemical parameters to be assessed for lake restoration		
Parameter	**Description/Remarks**	**Range (milligram per liter)**
Dissolved oxygen	amount of dissolved oxygen in the same	14 at 0^{o} C to about 7 mg at 35^{o}C
Biological oxygen demand	Amount of dissolved oxygen consumed aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period.	Clean waters < 1; Sewage 200 or more
Chemical oxygen demand	Indirectly measures the amount of organic compounds in water.	Clean water < 10; Sewage >400
Nitrates	Indicates the nitrogen availability for biota	0.6 or less to 3 or ore mg/l
Phosphate	Indicates Phosphorus availability for biota. Phosphorus is a limiting factor for eutrophication	0.01 to 0.1 or more
Chlorophyll content	Good indicator for assessing trophic conditions. Requires more complex sample collection, preservation and laboratory methods.	<0.95 (Oligotrophic) to more than 150 microgram/l in case of Hypertrophic conditions
Source: Sechi disk website[8], TARU Analysis		

Analysis of inflow water across seasons will provide estimates of the total amount of inflow of nutrients in to the lake. Some of the nutrients will degrade (example nitrates will degrade in to gaseous nitrogen), some will be absorbed and converted in to biomass and some of the nutrients will be get precipitated or absorbed by the bottom sediments. The chemical analysis of different waters (inflow, lake and outflow- if any, during rainy seasons) will be useful to understand nutrient cycle of the lake. The following Figure 18 presents some of the chemical analysis results of Indore Lake and inflow water in to the lakes.

Figure 18: Lake and inflow water quality analysis of Indore's lakes (October 2013)



Source: TARU Analysis

2.3.1 Lake ecology

It is important to conduct longitudinal study of flora and fauna in and around the lake. The flora and fauna are indicators of health of the lake. The algae and macrophytes (large plants) consume the nutrients and provide food for the other aquatic animals. As the nutrients build up, prolific growth of algae and weeds results in unpleasant colors, odors and fish kills due to decay of excessive organic matter being produced. Also, the diversity in fish species reduces. The flora and fauna studies indicate the biodiversity of the lake and can provide early warning of impending eutrophication.

The biological studies are necessary to develop options for maintaining biodiversity as well as to monitor the health of the Lake. These studies can be conducted by local academic or research institutions. The biological studies need to include algae, plants, micro fauna as well as fish, mollusks etc. Longitudinal studies across seasons will be required to understand changes as well as to understand the linkage between water quality parameters and biota. These studies should be able to provide lake specific bio-indicators, which can be further monitored by local people. Establishing linkage between subject matter specialists and local communities is necessary to provide useful inputs for lake management.

It is necessary to see the relationship between chemical water quality with flora and fauna composition and diversity. After few years of study, biological indicators can be identified to monitor the lake status. These indicators can be used as low cost and local community based methods for monitoring the lakes. It is suggested that at least a year of monitoring is done by a multi-disciplinary team before such indicators are identified for each lake. Algae have been extensively used as bio-indicators to assess lake water quality[11]. Other indicators include larvae of flying insects, water mites and snails[12]. Use of these indicators can base used for early warning of lake water quality and bio-diversity.

It is necessary to involve limnologists, botanists and zoologists in this exercise. Many of readily identified indicators can be used and further fine-tuned for local lake contexts Local fishermen can be trained to monitor the lake water quality, since they have stakes in ensuring fish productivity. Academicians from agricultural and fisheries colleges, as well as experts from state government's fisheries department can provide necessary research and training support.

2.3.2 Understanding Community Context

Most of the urban lakes in India have a long history and bathing *Ghats* and religious centers are often found on their banks. These are managed by rural institutions that get metamorphosed as the lake neighborhood gets urbanized. As neighborhoods get urbanized, the role of lakes also change from irrigation and domestic use to recreation and micro-climate control. These functions will often depend to some extent on the health of the lakes. For example, people will use lake banks for morning walks only as long as the there are no foul smells. There are many successful examples, where local residents joined together to improve lakes due to the nuisance value of the lakes. The urban lakes serve multiple social functions including.

- Religious activities (prayers, ritual baths, idol immersion.)
- Social gathering (morning walks, religious gathering etc.)
- Recreation (boating, bird watching.)

As the lakes get engulfed by the cities, the structure of the communities often change significantly. There are two major trajectories that can be observed in Indian contexts.

Many of the lakes had preexisting rural settlements, which continue to expand as the cities grow, but their livelihood portfolio may change slowly over time but remnants of the old systems continue for a long period. In such cases, the informal urbanization leads to densification and expansion of the settlement resulting in poor and lower middle class households dominating the community. The small houses and narrow streets of the original settlement continue to exist. Solid waste and sewerage network lying is a challenge and is often delayed until the neighboring areas are covered. The older community institutions continue to exist or get weakened by influx of new households. Khajrana lake catchment is the typical example of such a community. The community engagement needs to be centered on those old cultural/religious institutions. Conservation of lake and related institutions is essential in these types of catchments.

[11] http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3819078/pdf/tlsr-21-2-51.pdf
[12] http://scioly.org/wiki/index.php/Water_Quality/Macroorganism_List

Figure 19: Khajrana (Left) showing informal urban growth and Pipliyahana formal urban growth

Source: Google Earth

In water bodies without original settlements on the banks (tanks located away from rural settlements), the land is often bought by real estate developers and developed in to large colonies. In such cases, the formal colonies with wide roads are commonly observed. With the preference and value attached to lake side view, basic lifeline services are often built before construction of colonies. Retrofitting sewerage is easier. New communities settling in these catchments may have direct stakes in managing the lakes, especially the middle and upper socio economic groups. These formal colonies often have resident welfare associations and engaging with them is necessary.

As long as the water quality is tolerable, the communities use of water for low end uses. The possible uses include washing of clothes, animals, vehicles etc. as the water quality deteriorates; the lakes are used by buffaloes. All other uses reduce significantly as the water quality deteriorates. Fishermen use the lakes by taking them on contract. They are the only stakeholders who manage the lakes to some extent. They often remove the flotsam and also apply slaked lime to reduce pollutant load. These measures are helpful as long as the pollution is within control. Once the fish kills reduce the productivity of the lake, the fishermen have no stakes in maintaining the lake. It is important to maintain the fish population so that there are incomes to the fishermen and lakes are maintained to some extent.

A variety of cultural, religious and other types of stakeholder groups can coexist in the within the two possible types reported. Social mobilization process need to understand the diversities and have to design interventions based on ground contexts. Tools like focus group discussions and social mobilization will be required to involve citizen groups.

The communities as well as religious/cultural stakeholders are often silent users without investing much effort in managing the lakes. The government (urban local bodies) stakeholders take interest only if there are demands from locals for restoring lakes. In many cities, there are multiple water bodies and managing them is often not the priority of the urban local bodies. In the past due to persistent demand from the locals, many water bodies have been filled up (e.g. water bodies of Bangalore, Hyderabad).

Household surveys and focus group discussions can provide understanding of community context and their links with lakes. These surveys and discussions will be able to assess the stakes of different groups in lake restoration and management. Once the community issues are explored, it is necessary to engage them before planning any interventions. Support in articulating concerns with the urban local bodies can be facilitated.

Process

First of all the catchment and the neighboring regions can be reconnoitered and maps of different settlements can be prepared. Google Earth imageries are one of the cheapest sources for satellite remote sensing data. GIS software can be used, if resources are available or support of local academic institutions can be taken. This map will delineate different settlements and their socio-economic groups based on building footprints and density, which can be further validated by ground surveys. Reconnoiter will generate basic information on communities, settlements, drainage and sewerage conditions. The catchment map prepared earlier for assessing the water balance can be used as the base map,

The community context analysis surveys typically should cover:

- Socio economic conditions (livelihoods, expenditure pattern)
- Water sources, consumption pattern, sewerage and solid waste disposal arrangements
- Hydro-meteorological risks, disaster history (floods, droughts)
- Vector borne and water borne diseases history.
- Engagement with other stakeholders, involvement in social groups
- Usage of Lake for various purposes.
- Interest of communities/individuals in engaging with lake restoration

The data from the survey can be analyzed to understand the catchment level water resource use, consumption, vector borne and water borne disease patterns, willingness to engage with lake restoration efforts.

Based on the results, specific questions regarding the Lake and its environment can be formulated for further enquiry through focus group discussions. The focus group discussions should explore different facets of lake related challenges as well as their willingness to engage in lake restoration efforts. Leadership within the communities as well as conflicts between different communities, if any, can be explored. The focus group discussion can also explore possible roles the communities can play and mechanisms for ensuring sustainability of interventions. The outputs from focus group discussions can be used to engage with the urban local body, and departments and other institutions, which are entrusted with the management of the lakes.

2.4 Scenarios of catchment and lakes

The urban lakes require considerable attention to conserve them. As the peri-urban areas become urbanized, the population density as well as paved areas is expected to increase, therefore, scenarios of demographic and hydrological changes need to be built before conservation plans are taken up. These scenarios should include population growth, changes in built up area, sewerage, solid waste and storm water drainage infrastructure under business as usual, urbanization as well as hydrological changes from climate change.

Simple Excel based models explained earlier are sufficient to understand impacts of changes on urban local bodies. Such outputs can be used to build awareness as well as engage multiple stakeholders before the eutrophication and other challenges arise.

The climate change is expected to increase extreme precipitation including increase in frequency and intensity of droughts as well as floods. While extreme rainfall can increase the run-off, droughts can result in drying up or significant reduction of water spread areas. Increased temperatures can also result in increased algal growth and foul smells.

2.5 Institutional challenges

Traditionally, lakes were managed by local communities in the vicinity, and they had clear stakes like irrigation, fisheries or other livelihoods like seasonal farming in tank bends and water-chestnut collection. Temple tanks were often owned by temples and they collected tax/grains from water users. Often these religious institutions owned land in the command areas, which were leased out. The management of the ponds, tanks was done by local communities. There is evidence that resources were raised locally from philanthropists and royal grants to build tanks. To repair the tank, the village assemblies used boats to remove the silt; laborers were engaged to desilt tank and strengthen the bund; fisher folk were put in charge of certain duties like watching over the dam, regulate flow of water, inform villagers (Dying Wisdom, CSE,1997)

With the change in livelihoods due to urbanization, these stakes and roles of lakes change. With the change in management from local communities to ULB's or other institutions they have disengaged and alienated from lakes. Eventually the lakes lose their importance in the new urban community's priorities. Loss of community ownership poses major problem.

Between decay and restoration

As the urbanization process starts the old water institutions decay, but there is a vacuum created by no new institutions form. As result lakes become "de-facto no-man's land". During this period, the lake becoming dumping grounds of sewage, solid wastes and construction debris. Also they are encroached upon by the enterprising individuals and groups. By the time new stakeholders (residents, civil society groups and ULBs) want to conserve the lakes, the lakes get seriously damaged with shrunk water spread areas, drainages blocked and polluted. Disputes over encroachment and ownership often get dragged for years in courts with no clear outcomes.

Some states have set up lake development authorities (e.g. Madhya Pradesh), and others are in process of setting up such institutions (Karnataka). Only 26 large water bodies in India have come under Ramsar list of Wetlands of International Importance. Only two of them are urban water bodies (Bhoj wetland and East Calcutta Wetlands)

The rural water bodies are owned by village institutions (Panchayats), or by irrigation or forest department. Only a few water bodies are owned by individuals. Their fish production is often auctioned. As the urban local bodies take over these areas, the ownership gets transferred to the urban local body or handed over to forest departments for maintenance. In peri-urban areas with no sewage or solid waste disposal systems, lakes are often encroached and/or filled up by local stakeholders before they get absorbed into the jurisdiction of urban local bodies. The panchayats lose interest once the catchment areas are sold to real estate developers. Also, in many catchments of the small water bodies (especially in semiarid areas), the minor drainage lines are not delineated as common property or government land. Since the land prices are quite high, the real estate developers often fill them and include them in plots they sell to the prospective owners and the new owners often end up with occasional flash floods and water logging. Maintaining the drainage channels is important for conservation of lakes and also to prevent water logging. Such lakes slowly get filled up, either naturally or by dumping of solid wastes and construction debris.

As the city grows, the urban local bodies install sewerage and often divert the sewage away from the lake (by connecting to centralized sewerage system), which can potentially make the

water bodies seasonal, especially in case of small lakes in semi-arid regions. The reduction in water inflow during lean seasons can result in buildup of pollutants and can speed up the eutrophication process. It is necessary to create demand for conservation of the lakes from the local stakeholders and also necessary to engage with the urban local bodies.

Fragmented roles in urban lake management

Lakes are at present under different departments including Public Health Engineering, Water supply, Irrigation, Urban Development, Forest Department, Public Works Department, Municipalities, Corporations. Similarly the catchments are controlled and used by different agencies. The controlling and management agencies and their conflicting interests is the potential cause of degradation of water bodies. It has been seen that creation of a single apex authority in place of different lake owning agency is quite essential. This apex body will also be the in charge of managing the water bodies[13].

Though the urban local bodies delineate water bodies in the master plan maps, no separate plans are worked out to conserve them. Due to fragmentation of water supply, sewerage, storm water drainage and solid waste management between the different departments of the urban local bodies, conservation of catchment and water bodies become a major challenge for the urban local bodies. Awareness generation and engagement of multiple stakeholders is necessary throughout the urbanization process for conservation of the catchments as well as lakes. In many states, Lake Development Authorities' have been set up to enable a single point authority to manage lakes. These initiatives are often designed to attract much needed investments and to provide continued attention on the lake conservation.

Special Purpose vehicles for lake management[14]

Special Purpose Vehicles (SPVs) for lake management and conservation have also been set up in many parts of the country, such as, Bhoj Wetland Authority for the restoration and management of Bhoj wetlands in Madhya Pradesh, Chilka Development Authority (CDA) in Orissa for the Chilka Lake, Loktak Development Authority (LDA) for Loktak lake in Manipur, Lake Development Authority Bangalore (Karnataka) for Bangalore lakes, J&K Lakes and Waterways Development Authority for Jammu and Kashmir Lakes, Hyderabad Urban Development Authority for Hyderabad lakes in Andhra Pradesh, East Kolkata Wetlands Management Authority for the conservation and management of a large number of water bodies in district 24 Pargana in West Bengal and Jal Vikas Samiti in Udaipur (Rajasthan). This special Purpose Vehicle is playing an important role in the protection and management of water bodies in India. As the legislation does not give the responsibility for management of water bodies to a specific agency, these Special Purpose Vehicles are empowered to enforce provisions of the legislation.

It is necessary to conduct research and document the ownership and current arrangements for management of lakes in the peri-urban and urban areas. The master plans, constitutional amendments and town planning process can be studied to understand the ownership and management responsibilities of different institutions.

Flood events, weed blooms and other challenges can provide an opportunity to engage with the urban local bodies. Creating demand from the lake users, civil society groups and researchers for lake conservation is necessary. These can be best done by continued engagement with these stakeholders by creating platforms for engagement. Regular conducted lake visits other vents like informal discussion groups on lakes, can create awareness about lake and catalyze demand.

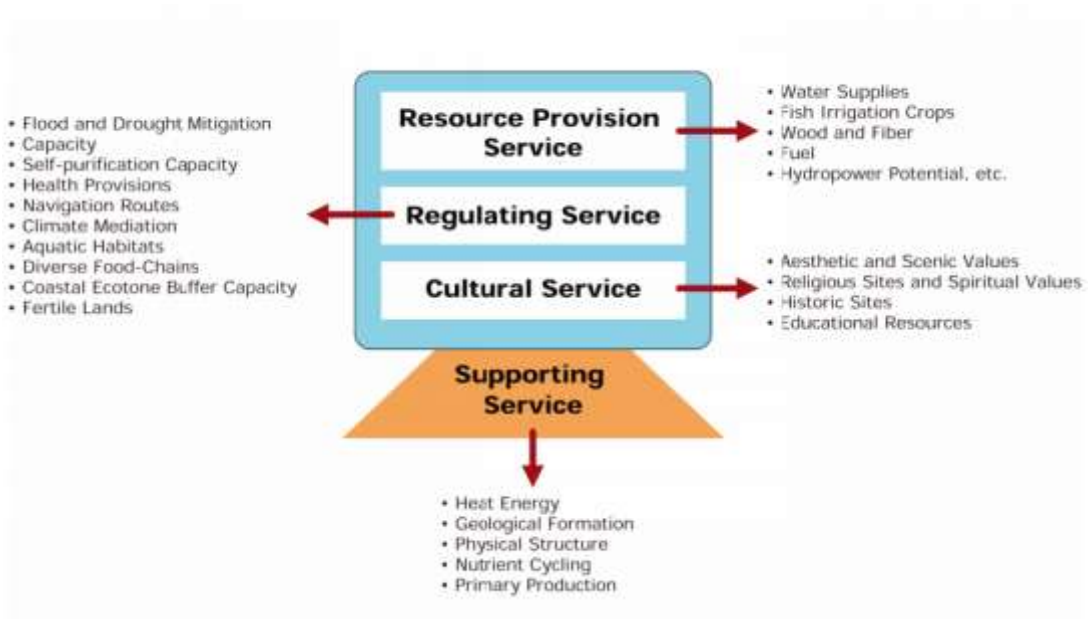
[13] http://cseindia.org/content/churning-still-water-briefing-paper-urban-waterbodies

[14] Protection and Management of Urban Lakes in India http://www.cseindia.org/userfiles/Lake%20Protection%20and%20Management%20of%20Urban%20Lakes%20in%20India.pdf

2.6 Role of urban lakes

Urban lakes are a major asset to the cities and serve several ecological as well as socio-economic functions. A brief summary of possible ecosystem services provided by the lakes is presented in the following Figure 20.

Figure 20: Possible Ecosystem Services of Lakes



Source: UNEP-DTIE-IETC & ILEC, 2010[15]

While these are possible ecosystem services, urban lakes can only provide few of those services due to context and size of the urban lakes. To provide services relevant in the urban context, they need to be perennial and also should have good water quality. The main functions of urban lakes include:

Ecological services

- Remediation of pollutant loads and improving water quality.
- Groundwater recharge.
- Flood buffers.
- Reducing heat island effect and increasing humidity. (beneficial in arid and semiarid regions)
- Conserving or improving biodiversity.

Social, cultural and economic services

- Recreation.
- Religious/cultural uses.
- Fishing and other economic activities.
- Emergency as well as low quality water sources.

Many of these services are feasible only with conservation of these water bodies. A well conserved urban lake has transparent water with healthy aquatic as well as bank vegetation. The aquatic growth should be minimal so that boating and other activities can be taken up. Lake should support fish as well as birds in the vicinity. Since the urban lakes are located

[15] http://www.unep.or.jp/ietc/ws/news-apr10/S6_1_DrVictorMuhandiki.pdf

within the manmade environment, considerable maintenance activities are necessary including,

- Catchment development. (storm water drainage, sewerage and solid waste management)
- Control of inflow including sewage treatment, if necessary.
- Water quality monitoring and control.
- Surface maintenance, Removal of flotsam.
- Managing fisheries.
- Recreation facilities.
- Income generation to support Lake Development and management.

3 OPTIONS FOR RESTORING URBAN LAKES

The urban lakes face many manmade changes in the catchment and have to face continued pressures from the surrounding regions. The earlier section presented the brief overview of the challenges facing the urban lakes. As the water and nutrient flows from the catchment impacts the water quality of urban lakes, restoration efforts should cover not only the lake, but also the catchment for ensuring the sustainability.

3.1 Planning lake restoration

It is necessary to develop detailed lake management plans to design restoration activities, engage different stakeholders and ensure operation and maintenance as well as sustainability of interventions. The Integrated lake basin management (ILBM) framework is widely used to design lake management systems across the world. The ILBM is based on following principles:

- Harmony between humans and nature.
- Lake drainage basin as unit of planning.
- Long-term preventative approach.
- Science and information.
- Conflict resolution.
- Stakeholder participation.
- Good governance.

These principles are used to develop the six pillars of management as presented in the following figure.

Figure 21: Six pillars of Integrated lake basin management

Source: UNEP, DTIE, IETC & ILEC 2010 [ibid]

These six pillars are necessary for successful management of lakes. The catchment/basin level management approach is especially relevant in case of urban lakes, where human interference is continuous and dynamic.

The **Ecohydrological** framework is useful for analyzing, exploring and designing cost effective options for lake restoration. Ecohydrology framework was first defined by the UNESCO International Hydrological Programme (IHP). Ecohydrology is a trans-disciplinary and applied science. It is based on the understanding of relationships between hydrological and biological processes at the catchment scale to achieve water quality improvement, biodiversity enhancement and sustainable development. The Ecohydrological design is based on the following verifiable hypotheses:

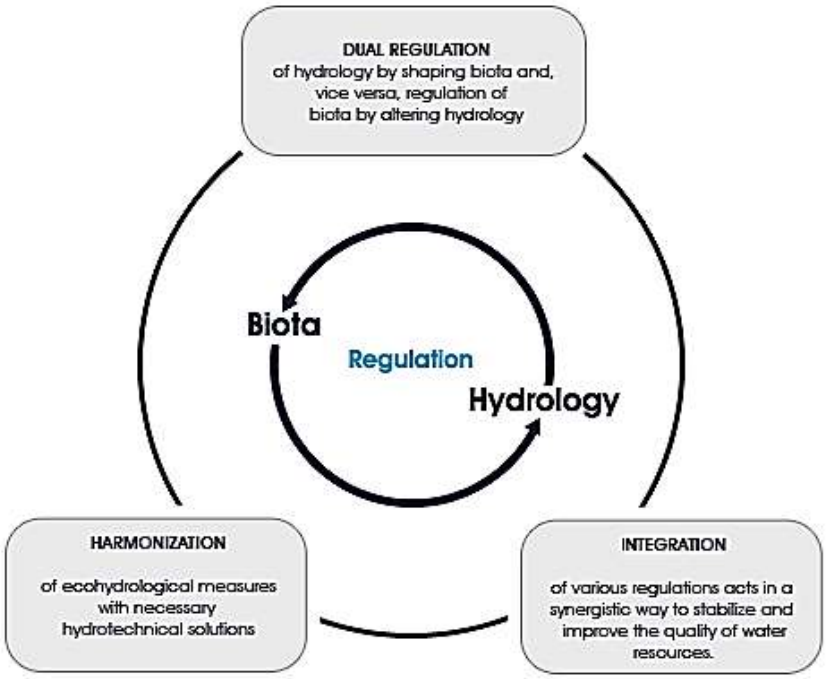
- H1: Hydrological processes generally regulate biota.
- H2: Biota can be shaped as a tool to regulate hydrological processes.
- H3: These two types of regulations (H1&H2) can be integrated with hydro-technical infrastructure to achieve sustainable water and ecosystem services.

The Ecohydrology approach is based upon the assumption that the sustainable water management can be achieved by:

- Restoring and maintaining evolutionarily established processes of water and nutrient circulation and energy flows at a catchment scale;
- Enhancing of carrying capacity of ecosystems against human impact based on evolutionarily established resistance and resilience to stress;
- Using ecosystem properties as water management tools16.

The following Figure 22 presents the Ecohydrology framework.

Figure 22: Ecohydrolological framework



Source: European Regional Centre for Ecohydrology[16]

[16] http://www.erce.unesco.lodz.pl/story/ecohydrology-concept

The application of ecohydrology to restore lakes is cost effective since a significant part of the nutrient control is achieved through biological processes, with the technical interventions used only to support maintenance of ecological systems. Both biota as well as technical hydrological measures are combined to achieve dual regulation benefits.

3.2 Catchment treatment

Treatment of watershed or catchment of lakes results in substantial improvements in the lake environment by basic hydrological infrastructure development (sewerage, storm water drainage and solid waste management) as well as improving ecological conditions. It is first necessary to carry out detailed studies to identify options for catchment treatment.

Some of the conventional catchment treatment measures are laying sewerage, effective solid waste management, construction of community toilets etc. All these will reduce the pollution in the catchment. Wherever early defined channels exist and sufficiently wide, ecological engineering methods can be used to absorb part of the nutrients. They include microbial treatment, sewage treatment plants to manage inflow water quality. Such technologies are readily available in India.

In semiarid regions, continued inflow of water with minimal nutrient loads is required to maintain water spread area through the year. As far as possible, the grey water should be intercepted and treated before it flows into the Lake. In catchments with sewerage and storm water drainage systems, sufficient water can be treated and allowed to flow into the lakes to replenish evaporation and percolation losses.

3.3 Physical Restoration (desilting, weed removal, aeration, diversion of sewage)

Physical restoration methods are required when the lakes system is highly polluted and degraded. The main problems in such systems include reduction of lake volume from siltation, full coverage of water hyacinth or very high nutrient load as indicated by excessive growth of blue green algae. In such cases, it is advisable to drain out the lake, wherever feasible. Draining out of large lakes may not be feasible. In shallow lakes up to a volume of 100,000 cubic meters, draining of Lake may be feasible. Draining should be preferably done during late summers (March to May period). This is to avoid the Lake being empty for long periods of time. The Lake should be preferably drained out within a week and the desilting works should be completed before the onset of monsoon.

Options for manual removal or removal through mechanical means such as excavators should be evaluated. The options are influenced by the characteristics of the sludge and its present condition. Presence of toxins and large quantity of sludge will discourage manual removal of sludge. Similarly, liquid and semi-solid status of the sludge will require conditioning measures such as pumping of excess water so as to initiate the process of dredging. The depth of lake and the condition of sludge (septic, dry or liquid) will also influence the options of sludge removal. All these parameters should be analyzed before selecting an option

3.3.1 Desilting

Before undertaking desilting works, the soil profile within the Lake should be assessed and if the deeper soils are permeable, it may be necessary to store the fine sediments from the upper horizons may be kept aside and used for covering the de-silted portion. Bentonite clay can be used to reduce the percolation losses, if necessary. The bentonite clay can be mixed with water and applied in the Lake water. A thin film of at least 0.2 mm may be required to reduce percolation losses. Microbial methods also can be used to supplement effectiveness of bentonite application. Puddling the bottom sediments during the refilling will also allow the fine clay particles to get in to suspension and settle back to reduce the percolation.

3.3.2 Construction of silt traps

Normally silting of lakes is due to the inflow of silt from the catchment area during the monsoon as well as solid waste disposal. The floating solid wastes are also carried by the wastewater and rainwater flowing into the lake. These solids need to be stopped before entering the lake to upkeep the lake as well as retain the storage capacity of the lake. The floating solids pollute and choke up the lake, as also spoils the beauty and the aesthetic view of the lake. To clean the silt and floating solids is often expensive and time consuming. By providing silt traps, the silt, floating solid waste can be mostly eliminated from entering the lake. The silt raps need to be emptied regularly, but it is much cheaper than the desilting

3.3.3 Water hyacinth removal

Water hyacinth is a major problem in many urban lakes. This weed can cover the whole Lake within a matter of months, which can completely cut off sunlight penetration into the Lake which can seriously impact the ecology of the Lake and also increase mosquito menace in the nearby areas. It may be necessary to physically remove the water hyacinth before any remedial measures can be taken. The water hyacinth can clog the outlet and can cause breaching of the Lake Bund, which can cause major disaster downstream. Once the lakes is fully covered with water hyacinth, removal is a costly operation involving manual and will depend on the water spread area of the lake. Mechanical weed removal equipment are available but they also require considerable human efforts.

Weed removal: Khajrana Lake

In 2013, the Khajrana Lake catchment faced extremely high floods. These floods and subsequent water logging resulted in heavy nutrient influx in to the lake. For many years in the past there used to be a small area covered by water hyacinth, but none took notice. By December 2013, the lake was fully covered by water hyacinth. The lake, which used to look beautiful, became an ugly site and local people wanted the weed to be removed.

A series of meetings were held between community, TARU and Indore Municipality to remove the weeds so that further restoration works can be taken up. Meanwhile in March 2014, the water hyacinth leaves browned up due to some unknown problem.

A single plant under ideal conditions can produce 3000 plants in 50 days and can cover an area of 600 sqm in a year. *Therefore cleaning the water hyacinth before it spreads is cheaper than removal over the whole lake. In this case, the urban local body could not address the challenge soon enough due to lection code of conduct related delays.*

If it was not addressed, there is risk of blockage of outlet (pipes) due to clogging by water hyacinth, which can potentially result in overflowing lake and breach of the main bund and possible catastrophic failure of the lake itself. Lake breach scenarios helped in understanding the seriousness of the issue. Just before the monsoons season (May end), the Indore Municipal Corporation started the removal process.

3.3.4 Aeration Systems

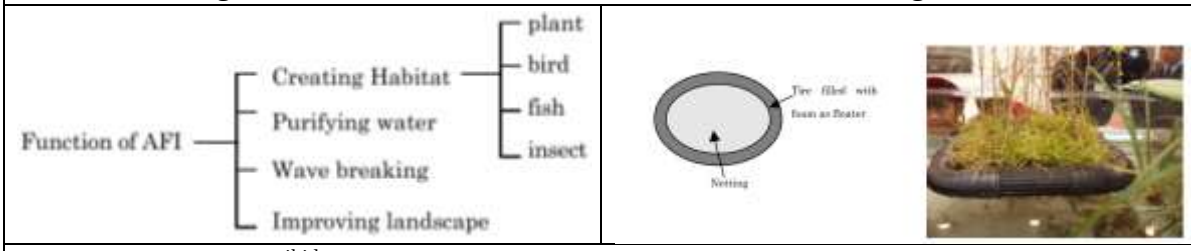
Aeration may be necessary to reduce the biological oxygen demand as well as nutrient load in the Lake. Aeration increases dissolved oxygen in lake water and speeds up aerobic

decomposition of organic matter, controls blue green algae, prevents fish kills, liberates dissolved gases into the air instead of allowing them to build harmful levels in the pond (Ammonia, carbon dioxide, hydrogen sulphide and methane). Several types of aerators are available in the market but the aeration systems are to be designed based on the size of the Lake, nutrient inflow and lake chemistry. Since aerators require energy, use of aerator capacities should be carefully worked out to reduce electricity consumption.

3.3.5 Artificial floating islands

The Artificial Floating Island (AFI) is a floating structure on which aquatic vegetation such as reed grows. The main purpose is to create habitats, purify water, improve landscape, and preserve lakeshore by wave absorption he AFI creates artificial nearshore mini-ecosystem through utilization of water surface instead of occupying the shoreline space. Since the AFI uses floating platforms to support vegetation, it can move up and down with the fluctuation of water level, and also can be move from place to place[17].The main functions of AFI are presented in the following Figure 23.

Figure 23: Illustration and Functions of Artificial floating Islands



Source: Zhen, 2001 [ibid]

Several versions of AFIs are available. One of the earlier generation system was designed by Living Technologies, USA and was named as Lake Restorer. It consists of a floating base, solar panel, a small pump to circulate water, aerator from the bottom of the lake, substrata for growing plants and few selected plants to remove nutrients. A variety of ZFIs can be built to suit the local situations. In perennial keas they can be anchored in deeper parts of the lake so that the risk of theft can be minimized.

3.3.6 Sewage Treatment Plants by intercepting drains (STP)

Sewage treatment plants are common interventions taken by urban local bodies. They are costly to maintain unless there is sufficient income generation possible from recreation activities or the urban local body has sufficient resources to maintain the sewage treatment plants. Only in case of a single inflow point STP's are feasible, otherwise the other drainage lines have to be intercepted and diverted to the sewage treatment plant. When commissioning sewage treatment plants, it is necessary to work out operational costs and repayment mechanisms. Options like decentralized wastewater treatment plants requiring minimal energy and maintenance can be used in case of small lakes of preferably less than 5 ha. These plants can be built totally underground, but they would require large land area. Availability of government land along the drainage line is essential for building such decentralized wastewater treatment plants. Such plants typically have treatment capacity in the range of <10 to 100 cu.m/day. With average of 10 mm of evaporation and percolation loss each 1 hectare water spread area will lose about 10 cu.m/day.

[17] http://www.globalrestorationnetwork.org/uploads/files/LiteratureAttachments/98_ecological-engineering-techniques-for-lake-restoration-in-japan.pdf

Restoration of Hussain Sagar Lake, Hyderabad

Hussain Sagar Lake is an artificial lake in the center of Hyderabad, the state capital of Andhra Pradesh. In recent years, sewage and industrial waste water have increased due to urbanization, giving rise to problems such as algae and bad odor. Hyderabad Urban Development Authority (HUDA) requested Japan Bank for International Cooperation (JBIC) through Government of India in 2004 to assist in improving water quality of the Lake and sanitary conditions of people in the catchment area of the lake and in the area surrounding the lake.

The Hussain Sagar Lake Restoration and Management Project also conducted the capacity building programmers for personnel of Hyderabad Urban Development Authority (HUDA) to implement water quality improvement measures for the lake. The Hussain Sagar Lake of Hyderabad was restored through desiltation and release of treated water from the 30 MLD STP. Over years additional STPs were built and ring sewers were installed to intercept other drains. This Lake also is provided with the aeration systems. Also, systems segregate the religious materials and idols were installed. The water quality has significantly improved.

The Save our lakes representation note to Hyderabad Metropolitan Development Authority stated that "The nutrient levels are very high and the lake is in an advanced state of eutrophication. Anaerobic conditions prevail at the bottom of the lake, indication near absence of dissolved oxygen. The consequent presence of hydrogen sulphide with bad odors is noticeable"[18].

3.3.7 Shore line Restoration

Shore lines of urban lakes are often used to dump solid wastes as well as religious materials, resulting in deterioration of the surrounding environment. Many urban local bodies have developed ring roads and parks along the lake banks to prevent encroachment, as well as providing social spaces. These are often engineered structures, which prevent shoreline vegetation to form. As far as possible, such hard surfaces should be avoided and suitable species of local water tolerant plants may be selected for providing soft vegetative cover along the shoreline. Maintaining such ecotones[19] is important, but also a challenge due to unmanaged dumping of solid wastes. Ecological restoration methods may be used if hard surfaces are created along the shore.

3.3.8 Ecological Restoration

The technical solutions are often costly and will have high operational and maintenance costs. Applying ecological principles can reduce these investments by allowing the nature to provide several ecological functions like nutrient removal, providing sufficient shade, reducing pollution. The ecological restoration the effective at the catchment as to less in the Lake itself. The ecohydrological framework provides options for deriving double benefits.

The process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed is called ecological restoration or eco-restoration. Eco-restoration involves recovery of original normalcy of function, structure, potential, service and process of eco system. Eco-restoration focuses on rectification of four basic component of ecosystem[20]:

[18] http://www.soulhyd.org/H_S-lake-1.html (Report dated in November 2012)

[19] An **ecotone** is a transition area between two biomes It is where two communities meet and integrate It may be narrow or wide, and it may be local (the zone between a lake and land)

[20] http://www.fes.org.in/source-book/ecological-restoration-source-book.pdf?file=ZG93bmxvYWQvd3AxOS5wZGY=?file=ZG93bmxvYWQvd3AxOS5wZGY

1. Mineral cycle,
2. Water cycle,
3. Energy flow and
4. Succession.

Bio-remediation is an ecological treatment process that uses naturally occurring microorganisms (Yeast, fungi or bacteria, diatoms) to breakdown or degrades hazardous substances in to less toxic or non-toxic substances. Typically, the components of a lake bioremediation projects execution involve physical cleaning, aeration and bio augmentation Most of the bioremediation is done by dosing of microbial consortium (multiple symbiotic microbes) to ensure multiple stage of nutrient removal. Several commercial organizations market microbial cultures and enzyme products for lake restoration. Some of the products use both microbial consortium as well as enzymes. It may be necessary to conduct pilot tests before particular product is chosen for remediation.

Lake Restoration of Powai Lake, Mumbai

The Powai Lake was built in 1891. The catchment area of the lake is about 600 hectares. Over the years, real estate development around the lake and erosion from the adjacent hills has reduced the total area of water spread and the water depth. Domestic sewage from nearby settlements, particularly slums entered the lake directly and solid wastes are dumped on its shores. Aquatic weeds such as Ipomoea and water hyacinth grow luxuriantly over the lake causing a serious problem). BMC has used bioremediation technique to restore the water quality, in which they were quite successful. Bioremediation was along with physical restoration. Ooty and Kodaikanal lakes in Tamil Nadu, and Mirik Lake in West Bengal are also best examples of successful restoration using bioremediation technique[21].

Fish constitute very important biotic community in a lake. They harvest nutrients and live biomass, reduce disease vector larvae in the lakes. While fishing can be a remunerative livelihood activity, concerns of bio-magnification needs to be addressed, especially in lakes with industries in their catchments. Some of the heavy metals and persistent organic compounds (e.g. Polychlorinated Biphenyls, pesticides) may get concentrated in the fish and can cause health impacts on people consuming the fish. However they can reduce the mosquito menace, common in most of the urban lakes. Larvivorous fish are preferred in urban lakes along with other local species. It may be necessary to conduct experiments to check symbiosis between different fish species before introducing them into urban lakes.

3.4 Institutional options

The urban lakes need management systems to survive, especially in highly human-modified environments. With increase in solid and sewage dumping, social as well as financial mechanisms are necessary to maintain them. The urban lakes are owned by the government

[21] http://moef.gov.in/report/0708/chap05.pdf

agencies, but in rapidly urbanizing environments their priorities are providing basic services to citizens. Community and private sector demands often catalyze action, therefore creating demands from the communities civil society groups is often necessary to ensure lake restoration.

3.4.1 Local management

As the lakes are absorbed by the new townships, and decay of the lake ecosystems, the local communities face the challenges of frequent floods in the catchments as well as foul smells and mosquitoes. While there are many options to generate incomes and to set up social management systems, organizing communities around the lake restoration requires identifying common purposes on which the communities can organize to take up lake conservation/restoration. Common issues like mosquito menace, foul smell and other problems can be catalysts for organizing communities for lake restoration. Several community based efforts have been reported from various cities across India.

Bangalore lakes: Community Based Initiatives

Kaikondrahalli Lake in Bangalore is an example which was restored using a socially inclusive model that also balanced the interest of local stakeholders. A group of citizens including original inhabitants of villages around the lake and resident welfare associations from wealthier apartment complexes have worked with the municipal corporation to design an ecologically meaningful, socially sustainable lake-restoration programme. Like the other lakes in the city, Kaikondrahalli was also a marshland until 2009. Some of the nearby residents approached the BBMP regarding the lake about 5 years ago and formed "Mahadevapura Parisara Samrakshane Mattu Abhivrudhi Samiti" (MAPSAS) to formally manage the lake. As a result, the lake that was once on the verge of extinction has been ultimately restored with clean water flowing in and over 1,000 trees planted. Around 37 bird species, including migrant birds, have been spotted at the lake. Provision is also made for local residents to wash cattle[22].

Before restoration in 2009

After restoration in 2011

Tree plantation Drive

Similarly other lakes also have been restored by community efforts. Community based Lake improvement organization have been formed to manage ***Puttenahalli lake****, which also has a website[23], to provide inspiration to other such efforts.*

*Citizens of Hyderabad have formed an advocacy group called "****Save our lakes[24]****". Such efforts are getting attention and also are able to focus the debate on lake restoration.*

Community leadership from middle and upper socio economic groups often emerges spontaneously since the land prices are high and they often are concerned about the environment and have capacity and resources to influence the urban local bodies.

Catchments with predominantly poor communities, the community context analysis results can form the basis for initiating the debate in the community on lake restoration, which can catalyse further action. It may be necessary to create platforms to voice their concerns with

[22] http://www.thealternative.in/society/kaikondrahalli-lake-serves-as-a-model-feat/
[23] http://www.puttenahallilake.in/
[24] http://www.soulhyd.org/

the urban local bodies. While these communities may be able to provide support in maintenance of the lake, external investments will be necessary for undertaking capital works. In lakes where fishing and other communities with lake dependent livelihoods still exist, involving these stakeholders is essential.

3.4.2 ULB-Community partnerships

The ULBs have resources and capacity to take up capital works, but often face challenges in maintaining the multiple decentralized assets created by lake restoration investments. Maintenance of these assets requires day-to-day care as well as prevention of misuse. Unless the communities form and enforce rules and set up local institutions for managing these resources, restoration assets may become defunct over time. Also, unless the communities take responsibility for prevention of solid waste dumping and misuse of assets, the restoration efforts can get neutralized. Monitoring the water quality and assessing the need for timely action is another important issue that can be addressed by the local communities. Local community based organizations are necessary to take up these functions. Identifying the local leadership, formation & sustaining of community-based organizations as well as creating a platform for exchange of information are essential. The following activities are required to sustain lake conservation groups:

- Awareness generation about need for lake conservation, linkage between lake health and direct and indirect impacts on the community.
- Identification of local leadership and formation of community-based organizations.
- Identification of clear roles and responsibilities of the community.
- Delineating rules and obligations of the community in conserving lake
- Designing and implementation of monitoring and reporting mechanisms
- formation of a platform for exchange of information between the CBO and ULB

Some of the urban local bodies have taken initiatives in lake restoration under urban renewal programmes. These efforts also need strong community involvement for ensuring sustainability. The lake development authorities are often more proactive in engaging with the communities since they have clear mandates and responsibilities.

3.4.3 Private sector engagement

Lake is a common property and benefits the neighboring business, industries and the communities. A well conserved lake is an asset especially to the hotel and other service sector businesses. Also the land value increases if the lake is able to provide better ambience. Many high-value hotels and residential properties are located along the lake banks. Involving real estate, and hotel and industrial sector can significantly improve the quality of restoration as well as sustainability of interventions.

The private sector can be involved in conservation activity, which can significantly reduce the costs of managing the lake. The role of private sector can include in providing investments, adopting a Lake and developing it further, bearing the O&M costs, funding for desilting and plantation etc. Most of the activities can be implemented under Corporate Social Responsibility (CSR) funds. With the emergence of lake view housing projects, real estate sector is a potential stakeholder. The Public private partnership models have been explored in Bangalore. The Karnataka government has started leasing lakes to private entities since 2004. The effort of lake conservation is taken over by the Private Institutions like Siemens as a part of Corporate Social Responsibility; Hebbal Lake was leased over to Oberoi hotel Groups, and they are planning to develop the lake with a hotel on its banks. In order to generate revenue to manage the costs, institutions are able to leverage the lake view

advantage. While their involvement can ensure sustainability, issues of public access need to be addressed. There were also plans for developing lakes as entertainment or amusement parks which need to be carefully planned since increasing number of visitors will require special arrangements and additional lake management costs. Involving civil society groups in decision-making and negotiations may be necessary to avoid conflicts and public interest litigations. The Environment Support Group in Bangalore has been campaigning against privatization of lakes.

Banjara Lake restoration: Public Private Partnership

Banjara lake is an 80 year old small manmade lake with an area of 4.17 ha and maximum depth of 5m. It is located on the west of Banjara hills in Hyderabad. Taj Banjara Hotel is located on the bank of the lake; Also, there are several apartments and commercial complexes on the banks of the lake. It receives about 1.5 mld sewage discharged by upstream colonies. The upstream part of the lake is clogged by water hyacinth and garbage. Evidently, the lake water had very low dissolved oxygen but high TSS, BOD, COD and ammonia contents.

The Andhra Pradesh tourism development corporation Ltd (APTDC) in association with Taj GVK, the owner of the hotel, has developed a conservation and management plan. The conservation measures include: Prevention of further pollution by treating the sewage entering the lake, and lake aeration for improving the water quality. Other activities aimed at improving the aesthetics include the removal of encroachments and provision for public access.

Source: Conservation and management of Lakes – An Indian Perspective, MOEF, 2010

3.5 Sustainability

The restored urban lakes require continued operation and maintenance work as well as prevention of encroachments and solid waste dumping and misuse of water. The sewage treatment as well as aeration requires energy. Also, operations staff is required to maintain these facilities. Some of the bioremediation measures require continued dosing of microbial cultures. These operation and maintenance costs cannot be sustained unless the lakes are able to generate incomes from recreation and other activities.

3.5.1 Income sources

Identification of income generation opportunities and creating institutions to sustain these activities is necessary before the restoration efforts are taken up. It is possible to lease out the lake for recreational and other uses and user fee system can be implemented. In Hyderabad, food courts and boating activities provide some income that is supplemented by government funds for O&M. Such steady income options may not be available in many urban lakes due to availability of land, size and other constraints. Private sector engagement and their CSR activities can supplement the funds required to meet the O&M expenses.

In case of small lakes, the shore communities can take up some of the O&M activities through CBOs and voluntary contributions. Fees for idol immersion and other religious activities can provide some incomes, especially in case of small lakes. It is necessary to design O&M arrangements in consultation with local community groups at the lake management planning stage.

3.5.2 Monitoring mechanisms

After the restoration, the urban lakes need to be monitored regularly especially since the changes in catchment hydrology as well as inflow water quality are quite dynamic. Also, the encroachments and other changes in the lake and the shore to be monitored to prevent reduction in effective water spread area. While these changes can be monitored by urban local bodies in case of large lakes, community-based monitoring systems are cost-effective in case of small lakes. In case of local monitoring, the methods and tools should be simple enough for use by the community-based institutions. Bio indicators and simple cost-effective monitoring systems can be developed in association with local academic institutions and pollution control board. A close linkage between the community-based organizations and these institutions need to be established and trained during the baseline monitoring before taking up restoration activities.

The following parameters may be monitored regularly by the communities, preferably at least once in a month.

Table 6: Community-based monitoring systems

Type	Parameters	Remarks
Water quality, inflow outflow	Basic parameters like inflow, color transparency, pH, etc. using handheld equipment	Can be done by local residents, schools. Validation and fine tuning can be done by academic institutions by seasonal data collection
Biological monitoring	Lake specific Indicators, weed growth, insect vectors, and fish. mollusks etc.	Can be done by both CBOs and school/ colleges
Anthropogenic activities	Solid waste dumping, lake uses, encroachment	Reporting to the ULBs, preferably through photographs, Identity of reporters should be kept confidential or through mobile phone application software
Source: TARU Study		

It is necessary to establish linkages with the local universities and laboratories, which can conduct seasonal studies to correlate these ***low quality-high density*** data collected by the CBOs. These institutions can centrally manage the data analysis. The community-based monitoring data can be directly sent to the partner institutions through mobile-based applications. Triggers and alarm systems can be designed in the central server managed by the partner organization, so that timely action can be done, in case any abnormalities are noticed.

3.5.3 Management mechanisms

Most of the urban lakes are small, as described in earlier examples are mostly done through community level institutions or by private sector. Since most of the urban lakes are small, community-based organizations can manage individual lakes but centralized management at

the urban local body level is necessary to ensure timely action to manage the lakes across the city. A multi-stakeholder platform including CBOs, universities and the urban local body members need to be established for effective management of multiple lakes across the city.

Several successful management rules and mechanisms have evolved in India for management of large lakes. These are context specific and the lessons from them may need to be adapted to local conditions and institutional systems.

Shoreline management has been done in many urban lakes by banning construction activity to specific heights above the periphery of the lake (e.g. Hyderabad City lakes, Udaipur lakes). In many cases, the lake periphery has been declared as protected area or wild life sanctuary (e.g. Pong Dam Lake, Loktak lake). To prevent pollution from human wastes, community toilet facilities are provided around periphery of the lake (Udaipur lakes, Sasthamkotta, and Ashtamudi Lake). Solid waste management measures have been introduced (Bhoj Wetlands, Mirik Lake, etc). Demarcation of lake boundaries has been done by fencing around the lake periphery (Mysore city lakes, Bangalore city lakes, Kanjli Lake). Peripheral roads and green belts also have been created (Bhoj wetlands).

Ecotourism facilities have been undertaken, which have converted many lakes into tourist centers (Jalmahal and Jaisamand lakes in Rajasthan, Mirik Lake in West Bengal). In some cases, tourism has been controlled to prevent adverse effect on the biodiversity of the lake areas (Tsomoriri Lake). Restrictions and guidelines have been imposed on Idol immersions (Bhoj Wetlands, Bangalore, Mumbai and Hyderabad Lakes)

SPVs for Lake Management and conservation with a unified mandate have been set up. These are - the Bhoj Wetland Authority in Bhopal (Madhya Pradesh), the Chilika Development Authority (CDA) in Orissa, the Loktak Development Authority (LDA) in Manipur, Lake Development Authority in Bangalore (Karnataka), J&K Lakes and Waterways Development Authority in Jammu and Kashmir, Hyderabad Urban Development Authority in Andhra Pradesh, and Jal Vikas Samiti in Udaipur, Rajasthan[25]. More such organizations are being planned.

Lake restoration and management committee need to be constituted in order to facilitate the implementation of restoration and management activities as per scientific and technical designs and plans, administration financial flow, evaluation of the implementation activities, people's participation in regular maintenance of the lake[26]. Several context specific innovations are possible in monitoring and management of multiple small lakes in many cities across India. Use of Information technology, involvement of local communities and local research/academic institutions. Government departments and private sector are necessary to implement sustainable solutions.

[25] http://www.worldlakes.org/uploads/Management_of_lakes_in_India_10Mar04.pdf
[26] http://wldb.ilec.or.jp/data/ilec/wlc12/O%20-%20Social%20Cultural%20Aspects%20Participation%20for%20Management/O-1.pdf