Technical Report : 102

STATUS OF VARTHUR LAKE: OPPORTUNITIES FOR RESTORATION AND SUSTAINABLE MANAGEMENT

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SUMMARY

Lake ecosystems vital functions such as recycling of nutrients, purification of water, recharge of groundwater, augmenting and maintenance of stream flow and habitat provision for a wide variety of flora and fauna along with their recreation values necessitates their sustainable management through appropriate conservation mechanisms. Failure to restore these ecosystems will result in extinction of species or ecosystem types and cause permanent ecological damage.

In Bangalore, lakes have played a prominent role serving the needs of agriculture and drinking water. But the burgeoning population accompanied by unplanned development has led to the drastic reduction in their numbers (from 262 in 1976 to 81 at present). The existing water bodies are contaminated by residential, agricultural, commercial and industrial wastes/effluents.

Varthur lake is situated in the south taluk of Bangalore district. It has a large surface area and is the main irrigation source to the nearby agricultural fields and supports a wide variety of flora and fauna. The main aim of undertaking the present study was to evaluate the ecological status of the Varthur lake, the results of which would help in restoration efforts.

The study consisted of three parts (i) Morphometric survey – to provide the information on the depth, surface area, width, etc of the lake; (ii) Water quality survey – to elucidate the quality of lake water and the nearby groundwater; (iii) Socio-economic survey – to assess the dependency of the nearby residents on the lake ecosystem.

The morphometric survey consisting of depth profiling, contour mapping, volumetric calculations and other general parameters (surface area, shoreline, maximum length, maximum width, and mean width) were estimated by field studies supplemented with GIS software and statistical calculations. Several physico-chemical parameters of both the lake and nearby groundwater were analysed according to standard methods of APHA. A random socio-economic survey was conducted in the nearby villages of Varthur, Baligere and Ramagondanahalli using a standard questionnaire.

The results of the above studies revealed the following:

(i) The morphometric survey showed that the lake occupies an area of 1 478 000 m^2 with a mean depth of 1.05m. The morphometric results emphasise the fact that the whole of Varthur Lake is shallow in relation to its surface area.

(ii) The results of the water quality analysis show that the lake is eutrophic with high concentrations of phosphorous and organic matter. All the parameters analysed were above the standards prescribed for surface waters. The lake was also subjected to faecal contamination. The groundwater analysis did not reveal any contamination by lake water, but further analysis has to be undertaken to rule out the possibility of groundwater pollution.

(iii) The socio-economic aspects of Varthur lake showed that local residents continue to rely heavily on the lake for cattle fodder and irrigation of crops.

The total land irrigated by the lake water amounts to 1537 acres. Various crops like paddy, arecanut, bananas, greens, vegetables, flowers and coconuts are grown using the lake water. There is a possibility that contamination of water supplies is having a negative effect on the quality and quantity of crops produced using the lake water. This poses a threat to the primary source of income for people living near the lake and warrants further investigation.

The results reveal the need and importance for the restoration and management of the Varthur lake. Restoration can be brought about in many ways, the important ones being pollution abatement, desilting of the tank and educating the stakeholders and the local population on the importance for restoring the lake ecosystem. All the conservation measures should have a holistic approach with watershed management practices.

1. Introduction

Though, the majority of our planet is covered by water, only a very small proportion is associated with the continental areas to which humans are primarily confined. Of the water associated with the continents, a large amount (more than 99%) is in the form of ice or groundwater and is difficult for humans to use. Human interactions with water most often involve fresh streams, marshes, lakes and shallow ground waters; thus completely relying on a relatively scarce and rare commodity.

Lake ecosystems are one of the most productive ecosystems in the biosphere and play a significant role in the ecological sustainability of the region. They constitute an essential component of human civilization, meeting crucial needs to sustain life on earth, such as water (agriculture, drinking, etc.), food (protein production, fodder, etc), biodiversity (diverse flora and fauna), energy (fuel wood, etc), recreation (tourism), transport, water purification, flood control, pollutant sink and climate stabilisers. The values of wetlands though overlapping (like cultural, economic and ecological factors) are inseparable. The geomorphological, climatic, hydrological and biotic diversity aspects have contributed to wetland diversity.

Anthropogenic activities including deforestation, agriculture, and watershed development are known to affect the input rates of nutrients and organic matter into lakes, often increasing the overall productivity of lake biota. Lakes are under increasing threat due to the separate, but often combined impact of identifiable point sources such as municipal and industrial wastewater, and non-point degradation like urban and agricultural run-off within a lake's watershed. Major degrading factors include excessive eutrophication due to nutrient and organic matter loading; siltation due to inadequate erosion control in agriculture, construction, logging and mining activities; introduction of exotic species; acidification from atmospheric sources and acid mine drainage; and contamination by toxic (or potentially toxic) metals such as mercury and organic compounds such as poly-chlorinated biphenyls (PCBs) and pesticides. In addition, physical changes at the land-lake interface (eg. draining of riparian wetlands) and hydrologic manipulations (eg. Damming outlets to stabilise water levels) have major impacts on the structure and functioning of these ecosystems.

Lakes have played a major role in the history of Bangalore serving as an important drinking and irrigation source. They occupy about 4.8% of the city's geographical area (640 sq. km) covering both urban and non-urban areas. Bangalore has many man-made wetlands but has no natural wetlands. They were built for various hydrological purposes and mainly to serve the needs of irrigated agriculture. The spatial mapping of water bodies in the district revealed the number of waterbodies to have decreased from 379 (138 in north and 241 in south) in 1973 to 246 (96-north and 150-south) in 1996 and 81 at present. This overall decrease of 35% was attributed to urbanisation and industrialisation (Deepa et.al., 1997). The tanks were reclaimed for various purposes such as residential layouts, commercial establishments, sport complexes, etc. Only 30% of the lakes are used for irrigation at present. Fishing is carried out in 25% of the lakes surveyed, cattle grazing in 35%, agriculture in 21%, mud-lifting in 30%, drinking in 3%, washing in 36% and brick-making in 38%. This highlights the need for appropriate conservation, restoration and management measures.

The following Table 1provides the distribution of tanks by taluks in Bangalore.

TABLE 1: TALUKWISE DISTRIBUTION OF TANKS

S no	**Name of the Taluk**	**No. of tanks**
1	Bangalore North	61
2	Bangalore South	98
3	Hoskote	23
4	Anekal	44
5	Magadi	11
6	Nelamangala	13
7	Devanahalli	12

1.1 Background

Varthur Lake is an artificial lake, or *tank*, located in the Bangalore South taluk of the Bangalore District in Karnataka. This lake has played an important role in maintaining water resources for irrigation since its construction during the Ganga Empire over 1,000 years ago (Karnataka State Gazetteer, 1990). Over the centuries, it has developed into a complex ecosystem that provides habitat for a variety of plant and animal species, including resident and migratory waterfowl. The lake also endows the local community with a pleasant microclimate and considerable aesthetic appeal.

The lake is surrounded by small farms that grow rice, raggi, coconut, flowers, and a variety of fruits and vegetables. The largest town in the immediate area is Varthur, which had a population of 5,431 as per 1981 census (Census of India, 1981). Several smaller villages are also located near the periphery of the lake. Figure 1.1 presents a view of southeastern Bangalore and Varthur Lake's catchment area as surveyed in 1970 to 1974. Human settlements and the roadways are marked in red; the outskirts of Bangalore city proper can be seen in the upper left-hand corner.

Figure 1.1 Varthur Lake and Surrounding Area

Source: Survey of India, 1980. Bangalore District. 1st Edition No. 57 H/9.

Varthur Lake is part of a system of interconnected tanks and canals that receive virtually all the surface runoff, wastewater, and sewage from the Bangalore South taluk. Rapid development and population expansion, both within Bangalore and in the surrounding towns and villages, have taken a heavy toll on many of the tanks in the area, and Varthur is no exception. The Bangalore South taluk alone has experienced a surge in its population from 2,84,556 to 4,45,581 between 1971 and 1981 (Census of India, 1981). Pollution loading has exceeded the lake's ability to assimilate contaminants, leading to visible degradation of the quality of water in the lake. Examining the current ecological status and economic value of the lake is crucial for developing appropriate remediation strategies. Figure 1.2 presents the interconnectivity of lakes as per the satellite image.

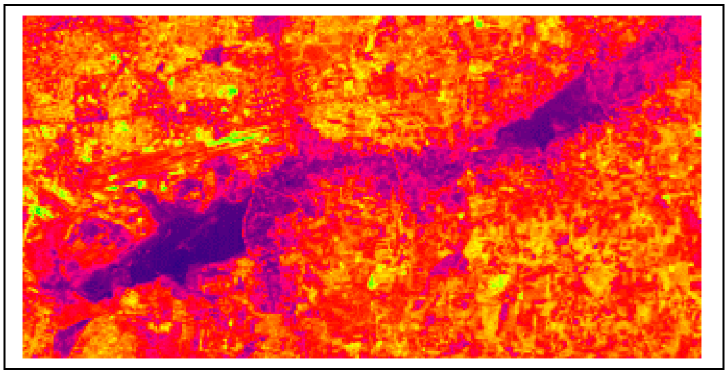


Figure 1.2: Interconnected lakes

1.2 Objective

The purpose of the study was to identify the most immediate threats to the ecological status of the Varthur Lake and to evaluate the necessity of undertaking restoration efforts in order to maintain the benefits provided by this tank. The results of this study will also provide a base for future analysis of the ecology of the lake and its importance to local residents.

1.3 Scope

The study was composed of the following components:

- **Morphometric Survey of Varthur Lake**, including depth profiling and calculation of volume, to evaluate the risks posed by sedimentation and to provide general morphometric information for future analysis of Varthur Lake.

- **Water Quality Survey** of lake water to determine the extent of the pollution in Varthur Lake during the post-monsoon and dry winter seasons and analysis of groundwater to detect potential contamination from lake seepage.

- **Socio-Economic Survey** of the stakeholders living in close proximity to Varthur Lake to determine their dependency on the lake, how their use of the lake has changed over time, and their willingness to support restoration efforts.

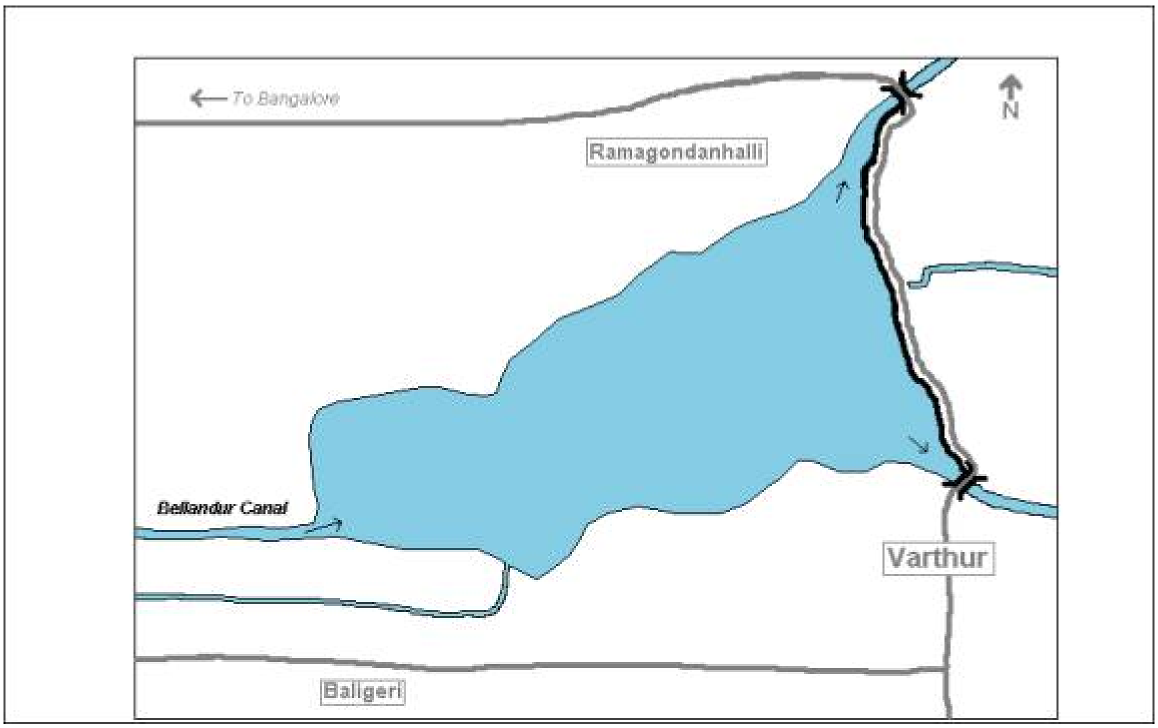
2. Morphometric Survey

2.1 Methodology

Verification of the Shoreline

A 1:50,000 scale map of Varthur Lake published by the Survey of India (SI) in 1980 was scanned, georeferenced, and digitised using MapInfo Professional 5.0. The digitised shoreline of the lake was then overlapped with a geometrically-restored LISS II satellite image of the lake from 1998 using Idrisi 32 software (Eastman, J. Ronald. 1999). From the image, it is seen that the general shape and surface area of the lake is virtually the same in 1998 as it was between 1971 and 1974, when the SI map was completed. The SI map was used as a reasonable approximation of the current shoreline of the lake for the remainder of the study under the assumption that the outline of the lake has not changed significantly since 1998.

Figure 2.1 LISS image and SI map



Depth Sampling

The depth of the lake was measured at randomly distributed points around the lake. The location of these points was recorded using a handheld GPS (Geographic Positioning System). The depth of the lake was sampled on two occasions, November, 2001, and February, 2002, corresponding to the post-monsoon and dry seasons, respectively. The position of the GPS points taken in the field were rectified to fit the map of the lake by comparing the GPS coordinates for two landmarks (the bridge over the northeast outlet and the main irrigation canal) to previously established coordinates published by the Survey of India, 1980.

The November depth samples were measured with a weighted line and measuring tape. A total of 31 sample points were recorded using this method. February samples were taken from a coracle boat using a graduated aluminum pole with a flat disc attached to the bottom. A total of 46 sample points were recorded with this method. The data collected during the February sampling is presented in Appendix A.

Contour Mapping

The depth data collected in February were converted into data points on the georeferenced map of Varthur Lake using MapInfo Professional 5.0 software. The initial bathymetric map was hand contoured using a 0.25 meter contour interval. The shoreline contour was truncated at the spillovers that transect the two primary outlets. All lines were drawn using the polyline tool incorporated in the software.

Volumetric Calculations

Estimations of the February volume of Varthur Lake were made using two methods, (A and B), based on the data used in the calculations. Method A was a simple manual calculation based on surface area slices at the .25 meter intervals used on the initial digitized map. Method B was a more accurate computer-assisted analysis that used a grid file of the lake extrapolated from the original data points and the contour map.

Method A:

This method subjected data from the contour map to two separate volume computations labeled formulas 1 and 2, respectively (Mutreja, K. N. 1986). The maximum depth of the lake is represented by the 2.0 m contour. Table 2.1 summarizes the application of formula 1. This procedure involved finding the volume of each layer between the contours (Vol. 1) and subtracting the volume of each layer that is lost due to the slope of the bottom of the lake (Vol. 2). Vol. 2 assumes a slope factor of 0.5.

Table 2.1 Volume Calculation Using Method A: Formula 1

Cont. ID	Area (m^2)	Depth (m^3)	Vol. 1 (m^3) (Depth of prev. cont.-Depth of cont.)*Area of cont.	Vol. 2 (m^3) (Area of cont.-Area of prev. cont.)*0.5	Vol. 1-Vol. 2	Comment
1	11,680	2.00	0	0	0	Vol. interval assumes 2 m contour represents max. depth
2	166,900	1.75	41,725	19,403	22,323	normal interval slope calculation
3	382,200	1.50	95,550	26,913	68,638	normal interval slope calculation
4	644,100	1.25	161,025	32,738	128,288	normal interval slope calculation
5	862,000	1.00	215,500	27,238	188,263	normal interval slope calculation
6	1,025,000	0.75	256,250	20,375	235,875	normal interval slope calculation
7	1,134,000	0.50	283,500	13,625	269,875	normal interval slope calculation
8	1,253,000	0.25	313,250	14,875	298,375	normal interval slope calculation
9	1,478,000	0.00	369,500	28,125	341,375	normal interval slope calculation

		total:	1,736,300	183,290	1,553,010	est. total volume of lake is 1,540,589 m^3

$$V = \frac{50 * \max.depth * \sqrt{\pi}}{\sqrt{A}}$$

Formula 2 (presented below) involves the summation of truncated irregular cones delineated by the contour lines on the map. Max. *depth* represents the maximum estimated depth of the lake and *A* represents the surface area of the lake.

Method B:

The second method for calculating the volume of the lake used the same data points and contour map incorporated into Method A to create a computer-generated model of the lake. Volume calculations were based on this second model. Data points were expressed as UTM coordinates the digitized data was created with MapInfo Professional 5.0. The gridding calculations, contouring, and graphics were completed using Surfer 7 contouring software.

The first step involved digitizing the hand contoured map of Varthur Lake, thus converting each contour into a data file composed of a series of points expressed as X, Y, and Z (east, north, and depth) coordinates. The data points from the February field sampling were also entered directly into the data file. All data points were referenced using coordinates taken from the 1980 SI map of Varthur Lake. The resulting data was treated using the Kriging formula option, which analyses the given data and extrapolates information for areas where no data is available. This analysis produced a grid file of the lake with data points spaced at 5-meter intervals. The resulting grid file was then subjected to a blanking file representing the shoreline of the lake in order to reduce any data that the Kriging program had extrapolated outside the boundary of the lake to a nil value. All volume calculations were derived using options incorporated into the software, including computations based on the Trapezoidal Rule, Simpson's Rule, and Simpson's 3/8 Rule.

General Parameters

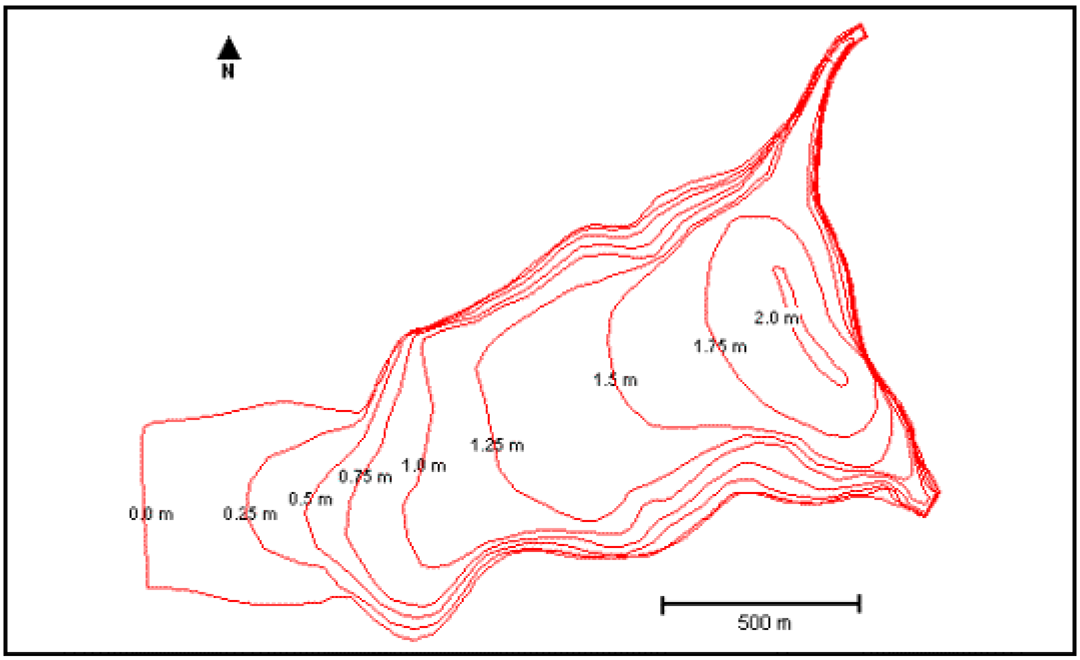
Surface area (area), shoreline, maximum length, maximum width, and mean width of the lake were estimated using a geo-referenced image of Varthur Lake from the SI map and MapInfo Professional 5.0 software. For details on the calculation of mean depth, relative depth, mean width, and shoreline development, see the glossary provided near the end of this document.

2.2 Results

Varthur is an extremely shallow lake, with a very large surface area in relation to its depth. The total area of the lake is estimated to be 1,478,000m^2.The shoreline of Varthur Lake does not appear to have changed considerably between the early 1970's and present day, unlike many other tanks in the district that have decreased drastically in size due to encroachment.

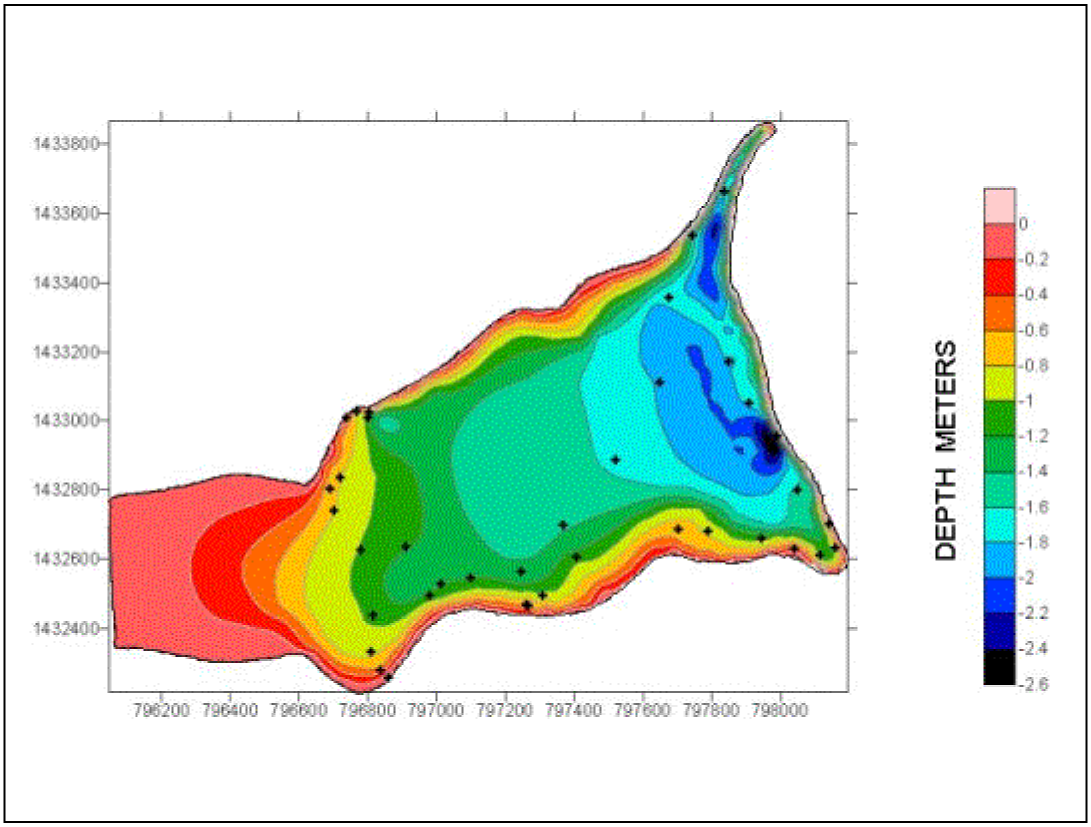
Two methods were used to calculate the volume of the lake. Method A employed standard formulas for calculating the volume of a reservoir using data from the contour map presented in Figure 2.2. Figure 2.2 is a bathymetric map of Varthur Lake and shows the lake has an estimated maximum depth of approximately 2.0 meters. The mean depth is estimated to be 1.05 m and the lake bottom exhibits a very gradual downward slope from west to east, with maximum observed depth occurring near the dam wall. These results are consistent with sedimentation patterns common to dammed reservoirs.

Figure 2.2 Bathymetric Map of Varthur Lake, February 2002



Method B involved software-assisted volumetric analysis incorporating the same contour map as well as the actual data points collected in the field to extrapolate a depth profile of the lake in grid form. This profile produced a maximum estimated depth of 2.55 m, which is 0.55 m greater that that of the previous contour map. The following figure presents a visually enhanced image of the depth profile produced using method B.

Figure 2.2 Gridded Depth Profile of Varthur Lake, February 2002



Three standard calculus-based formulas were applied to the above profile, resulting in three separate but highly similar estimates of the volume. The results of these calculations are summarized below in Table 2.2.

Table 2.2 Results of Volume Calculations: February 2002

Method	Information Source	Application	Estimated Volume
A	Contour map	Formula 1	1 553 010 m^3
		Formula 2	1 667 588 m^3

B	Depth profile in grid form	**Trapezoidal Rule**	1 574 494 m^3
		Simpson's Rule	1 574 473 m^3
		Simpson's $^3/_8$ Rule	1 574 519 m^3

The widest variation in volume estimates lies between the two formulas used in method A. This is likely due to the large horizontal intervals found between the contour lines. The values calculated using method B fall in between those derived using method A. The mean average of method B values is 1,574,495 m^3, with a standard deviation of 19 m^3. These values are more consistent, in part because the depth profile provides more detail than the contour map.

The remainder of the morphometric parameters for Varthur Lake is listed on Table 2.3. These results emphasize the fact that the whole of Varthur Lake is shallow in relation to its surface area. The lake exhibits low shoreline development consistent with the lack of topographical diversity in the region; this factor contributes to the regularity of the sedimentation patterns within the lake as there are few formations to interfere with the water currents.

Table 2.3 Morphometric Parameters of Varthur Lake, February 2002

Parameter	Values from Contour and SI Map	Alternate Values from Depth Profile in Grid Form
Area	1 478 000 m^2	1 477 196 m^2
Maximum observed depth	1.85 m	
Maximum estimated depth	2.0 m	2.55 m
Mean depth	1.05 m	1.07 m
Relative depth	0.15%	0.19%
Shoreline	6 560 m	
Shoreline development	1.52	
Maximum length	1 810 m	
Maximum width	1 040 m	
Mean width	117 m	

2.3 Observations

As silt and sediment-laden water enters Varthur Lake from the Bellandur Canal, the velocity and turbidity of the water decreases considerably due to the increase in cross-sectional area and the presence of large mats of water hyacinth. At this point, the water no longer contains sufficient energy to displace or carry larger suspended particles. These particles are deposited on the lake bottom near the inlet, forming a delta. Smaller suspended particles are deposited further away from the inlet where the velocity and turbulence decrease further. This forms a gradual downward-slope along the length of the reservoir, with the deepest section occurring near the dam. The velocity of the water increases as its approaches the northeast and southeast outlets, and these areas appear to accumulate less sediment that the main body of the lake.

Varthur may have a slightly less silt than the other tanks in the area due to desilting performed by local residents around the edges of the lake. This activity was observed in several areas along the northern shoreline while conducting field sampling. Varthur Lake has a catchment area of 1.8 km^2, the second largest in the Bangalore South taluk (Govt. of Karnataka, 1990). This catchment area contains a substantial human population engaged in agriculture and various industries and, therefore, the potential for accelerated sedimentation due to anthropogenic causes is substantial. Without previous depth profiles of the lake, it is difficult to estimate the rate of sedimentation. However, even if the historical depth of Varthur is very shallow, its lack of depth makes it highly susceptible to increases in sediment loading caused by human development within the catchment area.

Loss of depth and volume would reduce the water supply available to local farmers who continue to use Varthur as a primary water source. It would also have a detrimental effect on the quality of water in the reservoir and degrade habitat for fisheries and wildlife. The ability of the lake to moderate the local climate would be reduced, as the amount of energy absorbed and released by the lake would decline along with its depth and volume. Accumulation and impaction of silt on the lake bottom also has the potential to impede the infiltration of rainwater into the aquifers below. This infiltration is the main water source of groundwater recharging in the Bangalore area. Varthur Lake represents a major local reservoir of rainwater and a reduction in the permeability of its benthic layers would decrease the water resources available from local open and bore wells. These wells are the primary source of domestic, potable, and agricultural water, and their decline would be detrimental to the people living in the area. The method of volume calculation based on hand-drawn contour maps and formula 1 yielded results very similar to those obtained using sophisticated software programs and is a more practical approach for volume estimation when the resources employed in method B are not available.

2.4 Conclusions and Recommendations

Varthur Lake is a shallow, artificial reservoir with a mean depth of approximately 1.1 m as of February 2002. The pattern of sedimentation in the lake is consistent with that of a typical dammed reservoir. The western portion of Varthur located near the primary inlet is extremely shallow. The depth gradually increases moving towards the eastern portion of the lake, reaching maximum depth, estimated from 2.0 to 2.55 m, near the dam wall. Varthur Lake, like many tanks in the Bangalore area, is suffering from rapid sedimentation that poses a threat to the ecology and very existence of the lake. In order to gauge the rate at which it is filling in, studies measuring the sediment loading of the reservoir should be undertaken. Comparing the amount of suspended solids present in the inflow and outflow would not yield an accurate estimate of the amount of sediment actually settling in Varthur because much of the sediment is organic debris from autotrophic organisms living in the lake itself. The feasibility of using sediment traps as an alternate means of measuring sediment loading of the lake should be investigated. Analysis of the composition and permeability of the underlying sediment through core sampling would be very useful in determining the impact of sedimentation on the recharging of groundwater supplies. Removal of accumulated sediment has historically been a regular aspect of tank maintenance. Records referring to the desilting of Bangalore tanks date back to the early 16^{th} century. Some form of desilting will eventually have to take place in Varthur in order to retain the water-holding capacity of this reservoir.

Monitoring of the morphology and sedimentation patterns is an important, but often neglected, aspect of the limnological analysis of Bangalore's tanks. In order to preserve and enhance the substantial benefits provided by Varthur Lake, information regarding these parameters should be expanded and employed to prevent the unnecessary loss of this valuable resource.

3. Water Quality Survey

3.1 Methodology

Collection of samples

Water samples from Varthur Lake were collected on three occasions: October, November, and January 2002. October samples were collected from the shoreline nearest to the following locations: Bellandur Canal, the south-southwest portion of the lake, and the northeast and southeast outlets. Water samples were collected from 10 to 30 cm below the surface of the water during the morning hours. These samples were collected and stored in white, 500 ml polyethylene containers, with the exception of those collected in borosilicate glass bottles for dissolved oxygen analysis. No preservatives were added as the samples were transported to the laboratory within six hours and either refrigerated or analysed immediately.

Bore well water samples were collected in January from four locations closest to the southern shore of the lake. These samples were collected and stored in clean, white, 500 ml polyethylene containers that had not been used for lake sampling. No preservatives were added, as samples were taken to the lab and analysed immediately.

Analysis of Samples

On-site analysis of lake water included air and water temperature, transparency and, in the case of October and November sampling, dissolved oxygen. Laboratory analysis included: acidity, alkalinity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), chloride, chlorine residual, coliform bacteria, dissolve oxygen (DO), electrical conductivity (EC), fluoride, hardness, iron, nitrate, pH, phosphate, potassium, sodium, sulphate, solids (total, total dissolved, and total suspended) and turbidity.

The majority of lake water analyses followed standard procedures published by the Indian National Environmental Engineering Research Institute (NEERI, 1998) and the American Public Health Association (APHA, 1985). Ammonia, coliform bacteria, fluoride, iron, pH (in the field), phosphorus, residual chloride, and turbidity for October and November samples were tested using a Jal-Tara Water Quality Testing Kit produced by Development Alternatives in New Delhi (Development Alternatives 2000).

Bore well samples were tested for ammonia, chloride, coliform bacteria, EC, fluoride, nitrate, and pH. EC and pH were measured using an electrical conductivity meter and a pH meter, respectively. All other parameters were tested using a Jal-Tara Water Quality Testing Kit.

3.2 Results

3.2.1 Lake Water Samples

A complete set of results from analysis of October, November and January water samples is provided in Appendix B. The following is a brief summary of these findings.

General Parameters

Dissolved oxygen (DO) levels in Varthur Lake were extremely low. Water temperature ranged from 22 to 26°C prior to 9:00 AM on all sampling dates. The pH of the water was found to be slightly alkaline (approximately 7.5 to 8.0) for all water samples. November water samples exhibited a strong ability to neutralise acids in solution due to the presence of bicarbonate. The acidity of the samples was much less than their alkalinity. Total hardness showed little variation during the sampling period, indicating that the overall concentration of calcium and magnesium salts is fairly constant; hardness due to calcium carbonate ranged from 59 to 68% of total hardness for November and January samples.

In November, light was able to penetrate the upper 19 to 24 cm of the water column. Transparency was substantially reduced during January. Further examination of physical properties revealed high concentrations of suspended and dissolved solids. The concentration of total dissolved solids (TDS) showed substantial seasonal variability, increasing three-fold between November and winter sampling periods. This increase in TDS corresponds to a similar increase in electrical conductivity. Moderate to high concentrations of total suspended solids (TSS) were also present in January samples. Water from the middle of the lake exhibited the highest concentration of TSS by far.

Nutrients

Nitrate concentrations present in October samples were low, averaging only 0.24 mg/l. The average concentration of nitrate increased to 1.00 mg/l and 1.27 mg/l in November and January, respectively. Ammonium was estimated to be in excess of 3.0 mg/l for three of the four October samples. Phosphorus concentrations from January samples were very high, averaging 15.1 mg/l.

Organic Matter

The BOD of water samples was extremely high and nearly equivalent to COD.

Microbial Contaminants

Bacterial culturing confirmed the presence of the bacteria *E. coli* in the lake.

Inorganic Constituents

The concentration of chloride ions in November samples averaged 102 mg/l. In January samples, these values increased 60 to 70 percent. October lake water samples contained less than 0.2 mg/l of residual chlorine, which is the minimum detection level of the Jal-Tara kit. Sulfate concentrations in the lake were consistently low, however, a substantial decrease in sulfate occurred between November and January sampling dates. Sodium concentrations for November were only moderately high. Elevated levels of potassium were observed in November samples. January samples were well within standard range for unpolluted surface waters.

3.2.2 Groundwater Samples

Results from the groundwater survey are presented in Table 3.1. Two of the samples tested positive for minor concentrations of coliform bacteria. These well were located at opposite ends of the lake, approximately 250m and 750 m from the southeastern and southwestern shorelines, respectively.

Table 3.1 Groundwater Survey Results

Parameter	Site 1	Site 2	Site 3	Site 4
Ammonia (mg/l)	<0.2	<0.2	<0.2	<0.2
Coliform bacteria	negative	positive	positive	negative
Chloride (mg/L)	0.8	1.1	0.9	0.8
EC (μS/cm)	896	1120	928	832
Fluoride (mg/l)	0.6	0.6	0.6	0.6
Nitrate (mg/l)	<10.0	<10.0	<10.0	<10.0
PH	7.40	7.28	7.41	7.55

3.3 Observations

3.3.1 Lake Water Samples

Results of the analysis for samples taken near the northeast outlet during October, November and January are presented in Table 3.2. This table also includes standard values for unpolluted water bodies as well as regulations and guidelines.

Table 3.2 *Comparison of Water Quality Data and Various Pollution Standards*

Parameter	Results *from the* Northeast Outlet			Standard value for unpolluted surface waters[1]
Sampling Date	Oct-11	Nov-11	Jan-31	
General Parameters				
Acidity, total (mg/l)	n/a	92.0	n/a	
Alkalinity, total (mg/l)	n/a	332.0	n/a	
Alkalinity as HCO3 (mg/l)	n/a	332.0	n/a	
D.O. (mg/l)	2.0	3.0*	2.9	
EC (μS/cm)	460	474	1420	10-1000
Hardness, Total (mg/l)	213.6	209.3	232.5	
Hardness, $CaCO_3$ (mg/l)	132.0	124.0	158.1	
Hardness, $MgCO_3$ (mg/l)	n/a	77.6	62.7	
pH (*in situ*)	7.5-8.0	n/a	n/a	
pH (*ex situ*)	7.61	7.55	7.68	
Air Temperature (°C)	28.5	26.0	21.0	
Water Temperature (°C)	27.0	26.0	23.0	
Total Diss. Solids (mg/l)	332.4	370.8	1246	
Total Solids (mg/l)	n/a	n/a	1258	
Total Susp. Solids (mg/l)	n/a	n/a	12	
Transparency (cm)	n/a	27.0	11	
Turbidity (NTU)	50	50	25	
Nutrients				
Ammonia (mg/l)	>3.0	n/a	n/a	<3.0
Nitrate (mg/l)	nil	1.074	1.40	≤0.1
Phosphorus (mg/l)	n/a	>1.0	15.54	.005-.020
Organic Matter				
BOD (mg/l)	n/a	n/a	74.2	≤2.0
COD (mg/l)	n/a	n/a	82.2	≤20.0

Microbial Contaminants				
Coliform bacteria	positive	positive	n/a	
Inorganic Constituents				
Chloride (mg/l)	n/a	100.0	170.0	≤10.0
Chlorine, residual (mg/l)	<0.2	n/a	n/a	
Fluoride (mg/l)	<0.3	n/a	n/a	<0.1
Iron (mg/l)	~0.3	n/a	n/a	
Potassium (mg/l)	130*	20.2	2.2	<10.0
Sodium (mg/l)	907*	32.8	n/a	<50.0
Sulfate (mg/l)	n/a	14.5	8.48	2.0-80.0

* values subject to interference. See section 3.2

** total ammonia, depends on pH

[1,] UNESCO, WHO, UNEP 1996 Water Quality Assessments: A Guide to the Use of Biota, Sediments and Water in Environmental Monitoring. Second Edition. E & FN Spon, Madras.

The wide variation between TSS concentrations for various sampling sites could be due to the presence of organic floatables observed during collection of the samples. The presence of these clumps of matter could significantly increase the TSS value for a sample in comparison to a similar sample without clumps.

> Turbidity from organic and inorganic suspended matter in Varthur has the potential to impact the ecology of the lake in several ways. Many toxic contaminants, such as heavy metals and some pesticides, could potentially find their way into Varthur by adhering to solids in solution. Eventually, much of the suspended matter will settle in the bottom of the lake where they smother benthic organisms and contribute to siltation. Turbidity is also the most important factor in prolonging the survival of faecal coliform in water bodies because the particulate matter shelters bacteria from harmful solar radiation (DWI, 1995).

The bacterium *Escherica coli* is indigenous to the intestines of animals, including humans. Its presence in Varthur indicates that faecal matter contaminates the lake. Faecal contamination is often associated with other types of pathogenic bacteria and viruses found in untreated sewage. The turbidity of the lake water, along with its warm temperature, mildly alkaline pH, and low oxygen levels, could lead to prolonged survival of pathogenic bacteria for up to several days.

Varthur contains significant amounts of the macronutrients required by aquatic plants in large quantities in order to survive and grow, especially phosphate. Excess amounts of phosphorus could be the result of contamination from sewage and/or fertilisers. Both the population of Bangalore and the availability of fertilizers have increased in recent years. Eutrophication has resulted in large populations of algae to develop in Varthur, which imparts a green colour. This process has also assisted in the intrusion of Eichhornia crassipes *(water hyacinth). Although the amount of lake surface occupied by this plant fluctuated dramatically between sampling dates, the western portion of the lake was consistently covered with mats of hyacinth, as were the two main outlets. Overall, coverage by water hyacinth increased during the winter months.*

The concentration of nitrate was slightly higher than standard values for unpolluted waters in October samples, but increased substantially in November and January. The relatively low nitrate concentrations observed in Varthur could be a result of several biological processes. Loss of nitrate in Varthur could be the result of *ammonification*, the conversion of organic nitrogen to ammonium during the decomposition of organic matter. High concentrations of ammonia observed in October samples support this explanation. Under anoxic conditions, nitrate may also be converted to nitrite; it is likely that such conditions exist near the bottom sediments of Varthur lake, given the extremely low oxygen levels of the surface layers, and that this process may be partly responsible for the lower concentrations of nitrate in the water. Loss of nitrate also occurs through uptake by macrophytes and algae; during periods of high plant growth, this process may significantly reduce nitrate concentrations in the lake.

November ammonia concentrations in Varthur were high enough to be toxic to many forms of aquatic life. Given the warm temperature, alkaline pH of the water, and organic pollution present in Varthur, these concentrations may have been substantially greater than 3.0 mg/l, which is the maximum detection of the Jal-Tara kit. When water samples from January were viewed under a microscope, the most dominant zooplankton by far was Daphnia, a species that is highly tolerant of ammonia.

Potassium is also an essential element for plant growth. Elevated levels of potassium were observed in November samples, indicating potential contamination from industrial effluents or fertilizer. Potassium concentrations dropped substantially in January, possibly due to uptake by the increasing macrophyte population. A similar trend was observed for sulfate and could be caused by winter plant uptake as well.

The high BOD of the water samples indicates that decomposition of organic matter is one of the main factors leading to the low DO concentrations observed in the lake. Much of the remaining oxygen is likely consumed through nighttime respiration by aquatic plants. Eutrophic lakes similar to Varthur often experience a daily cycle of hyper- and hypo-oxygenation due to the high concentration of photosynthetic algae that produce oxygen during daylight hours and consume oxygen at night. However, the data collected is insufficient to confirm these diurnal-nocturnal fluctuations in DO.

The low DO content of Varthur limits diversity of animal life that can survive in the lake. Anoxic conditions also affect many other chemical processes within the lake that can be detrimental to organisms, such as the conversion of organic nitrate to toxic ammonia.

The high BOD values imply that virtually all of the organic matter contained in the samples was biologically degradable, and that the combined concentrations of sulphates, nitrates, ferrous iron, and other organic components that cannot be oxidized by bacteria are comparatively low. Based on these findings, only a small proportion of the organic pollution in Varthur could have its origin in industrial effluents. The majority of organic pollution likely comes from animal and plant sources, such as sewage and plant death within the lake. In addition to sewage, several aquaculture ponds are seasonally drained into the lake also have the potential to contribute substantial amounts of nutrient-rich organic debris.

Elevated chloride values could be due to many factors, including sewage, industrial effluents, and agricultural runoff. The seasonal variation may due to the fact that January concentrations were not diluted by monsoon rainwater.

The water sample taken from the Bellandur Canal in November was very similar in composition to those taken from Varthur Lake, and it is likely that many of the contaminants that enter Bellandur Lake from its own substantial catchment area eventually make their way to Varthur.

3.3.2 Groundwater samples

The following groundwater parameters were found to be within the limits set by the 1983 Indian Standards Specification for Drinking Water: ammonia, chloride, electrical conductivity, fluoride, nitrate, and pH. There is a possibility that coliform bacteria present in two if the sample could have originated from sewage effluent in the lake, however, these bacteria could also have been present on the pump itself due to human contact.

3.4 Conclusions

The water quality survey for Varthur Lake indicates that it is a eutrophic lake containing high concentrations of organic wastes and phosphorus. Nutrient enrichment has allowed substantial populations of water hyacinth and algae to develop in the lake. The decay of organic matter present in the lake, much of which comes from plant life growing in the lake itself, has resulted in extremely low concentrations of dissolved oxygen and elevated ammonia content.

The pollution entering Varthur Lake comes mainly from non-point sources that are, by nature, difficult to identify with certainty. The tank is part of a large network of interconnected canals and reservoirs, the largest of which is Bellandur Lake, which receives all of the overflow sewage and wastewater from central, eastern, and southeastern Bangalore city. A variety of industries, sewage outlets, urban wastewater, and agricultural runoff contribute to the current condition of these water bodies and it is, therefore, very difficult to determine the most significant sources of pollution. Any restoration efforts for Varthur Lake must address the interconnected nature of these sources contaminating the lake.

Pesticides have become readily available through government-sponsored programs in Bangalore area, increasing the potential for contamination of local water bodies.

4. Socioeconomic Survey

4.1 Methodology

Sample households from the town of Varthur and the villages of Baligeri and Ramagondanhalli were interviewed using a standard questionnaire. Questions were presented to the participants orally and answers were recorded onto a survey form. A copy of the original survey form is provided in Appendix C. Interviews were conducted from October 14th to November 10th. 22 households took part in the survey, representing a total of 217 people. The questions posed during the interviews were classified under the following headings:

- ✓ Demographic Information
- ✓ Domestic Water Usage
- ✓ Groundwater Recharge
- ✓ Irrigation
- ✓ Other Commercial Uses
- ✓ Water Usage for Livestock
- ✓ Livestock Fodder
- ✓ Family History
- ✓ Aesthetic Value & Recreation
- ✓ Fishing & Aquaculture
- ✓ Waterfowl
- ✓ Spiritual Value
- ✓ Health Effects
- ✓ Community Involvement in Restoration

Questions regarding domestic water usage, irrigation, other commercial uses, water usage for livestock, livestock fodder, and fishing and aquaculture attempted to quantify residents' direct economic reliance on lake and groundwater resources. Other direct uses, such as recreation and, in some cases, spiritual value, were investigated using qualitative questions regarding use of the lake. Any changes in lifestyle, such as a change in occupation, that may have been caused by deterioration in the quality of the lake were investigated in the family history section of the questionnaire.

The use of groundwater resources was included in the survey to identify trends in the overall reliance on lake resources compared to groundwater. Usage of groundwater may be indirectly associated with lake water resources as the Varthur lake could be responsible for recharging local aquifers. Questions regarding groundwater recharge were intended to detect changes in the local water table that could be the result of reliance on bore wells.

Questions pertaining to waterfowl and fish populations pertained to qualitative information about changes in the ecology of the lake, especially the biodiversity and abundance of wildlife. These topics, along with questions regarding aesthetic value, sought information on less tangible benefits provided by the lake that may be affected by a decline in its overall condition. Potential harm to the local population as a result of this deterioration was also investigated through questions regarding mosquito populations and incidents of insect and water-borne diseases.

The heritage value of the lake as well as family commitment to remaining in the area were investigated through questions regarding both family history and their desire to see future generations remain near Varthur. Determining residents' overall concern for the future of the lake was the motivation behind the question regarding support for future reclamations efforts.

4.2 Results

The survey revealed that the total land area irrigated using Varthur lake water is 1537 acres and the total number of farmers dependent on the lake water for irrigating their lands is 1159. In Varthur, Sorahumase and Valepura village, the land irrigated by the lake water amounts to 796, 551.27, 189.13 acres respectively. The type of crops grown in Varthur village and the area under each crop is as follows: Paddy – 771.31 acres, coconuts – 8.22 acres, bananas – 9.26 acres, Beetle leaf – 0.26 acres, arecanut – 0.10 acres and Floriculture – 5.31 acres. In Siddapur village the main crops grown are vegetables and floriculture whereas in the nearby Ramagondanahalli it is vegetables, greens and flowers.

All respondents used bore wells to meet their domestic water needs. 9 of the 22 households interviewed purify their drinking water with a filtration system, and one household boiled the water prior to drinking.

20 of the households, representing 83% of the survey population, relied on agriculture as their primary source of income. 12 of these households relied exclusively on lake water to irrigate their crops, and 2 more used both the lake and bore wells for this purpose. 10 of the houses that use the lake for irrigation reported a decline in both the quality and quantity of crops due to pollution of the lake water.

14 households raise cattle, primarily for milk. At least 11 of these farms rely exclusively on plants growing on and around Varthur Lake to feed their cattle. 9 of these 11 farms rely on the sale of dairy products for part of their income; the percentage of total income derived from dairy products for these farms ranged from 1 to 74%, with mean and median averages of 32% and 40%, respectively.

None of the households were involved in fishing the lake, however, one was actively engaged in aquaculture of carps in lake-water-filled dugouts near the shore. Another respondent indicated a desire to start a similar operation.

86% of the respondents indicated that they had noticed deterioration in the quality of the lake. Although estimates of when this deterioration began varied widely, (from 6 to 40 years), over half of the estimates ranged from 15 to 20 years ago. 10 of the farms reported a reduction in the quality and quantity of their crops as a consequence of polluted lake water. 18 of the respondents indicated that the mosquito population around Varthur has increased in recent years. One respondent indicated that family members had suffered from malaria and dermatitis. Another household that did not filter or boil their drinking water reported problems with viral fever. The smell given off by the lake in winter months was considered to be a nuisance by 16 of the households involved in the survey.

All of the residents surveyed indicated that their families had lived in the area for one generation or more. Duration of residency ranged from 30 years to more than 200 years and at least 60% of the families had lived in the area for over 100 years. 19 of the 22 households surveyed would actively support reclamation efforts for Varthur Lake. 16 of the 22 households visit the lake on an annual basis to submerge idols during Ganesh festival.

4.3 Observations

The effect of polluted lake water on crop production could very well be detrimental due to factors such as pathogens contained in the water (see section 3.4). It is unclear whether aquaculture has become popular because of a decline in the population of fish in the lake or because of its comparative convenience and increased yield. Several residents lamented the fact that fish stocks have declined and they are no longer able to enjoy this resource.

Water hyacinth is often classified as a nuisance species in Bangalore tanks. However, it provides a significant and inexpensive source of cattle fodder for farmers around Varthur as well as a source of income for residents who gather and sell the water hyacinth. The majority of households in the villages surveyed maintain dairy cattle to feed their families and, in most cases, to supplement their income. While estimates of income derived from dairy varied widely, this income would be reduced if farmers had to purchase fodder outside the lake area.

Many residents relied on bore wells or open wells for all their water needs, a trend that increases rapidly as distance from the lake increases. Reliance on bore wells does not necessarily negate their reliance on Varthur Lake, however, because Varthur could play an important role in recharging local aquifers in the area. 50% of the population represented in the survey does not filter well water prior to drinking. This makes them more susceptible to potential contamination of groundwater supplies by pollutants in the lake water.

Contaminated water in Varthur lake has led to the increase in mosquito populations reported by local residents, including consistently warm water temperatures and large populations of water hyacinth that provide breeding habitat for these insects (see section 3.3). Mosquitoes constitute both a nuisance and a public health risk in the vicinity of the lake, as they are carriers of diseases such as malaria, encephalitis, and dengue fever.

Few of the people living near Varthur have direct contact with the lake either for annual submersion of Ganesha idols or recreation. Many respondents were generally unaware of changes in the ecology of the lake unless they pertained to sight, smell, or mosquito populations. Some respondents were unable to provide information on wildlife populations, especially fish. Despite these observations, most respondents indicated a willingness to support efforts aimed at restoring Varthur Lake to a less polluted state and hoped that their children would remain in the area around the lake to raise their families.

4.4 Conclusions and Recommendations

It is obvious from the survey that local residents continue to rely heavily on the lake for cattle fodder and irrigation of crops. There is a possibility that contamination of water supplies is having a negative affect on the quality and quantity of crops produced using lake water. This poses a threat to the primary source of income for people living near the lake and warrants further investigation.

The degradation of the lake has affected residents in several ways. The smell emanating from the lake during winter months and increased mosquito populations pose a considerable nuisance to those living in the vicinity of the lake. Mosquitoes are also a potential health risk as they accommodate the transmission of many tropical diseases. Contamination of groundwater by pollutants originating from the lake poses a substantial risk to people living near Varthur. Loss of potable water supplies would be grossly detrimental to the economic well being of the community and efforts should be made to continue monitoring drinking water supplies for local towns and villages.

The degradation of Varthur Lake has lead to the loss of both direct and indirect benefits from the lake. However, a strong majority of residents are committed to remaining in the area and are willing to support community-based lake rehabilitation. In order to reclaim lost benefits and enhance the existing use of lake resources, efforts should be undertaken to improve the water quality and ecological health of Varthur Lake while keeping in mind the primary uses of the lake resources.

5. General Summary

The current shallow depth of Varthur is of primary concern, as loss of depth will eventually jeopardize the very existence of the reservoir. Further analysis and monitoring is necessary to determine the rate at which Varthur is filling with sediments. Eventually, desilting must take place in order to maintain the water-holding capacity of the reservoir. In order to do this, the Jala Samvardhane programme needs to be undertaken immediately. Beyond desilting, efforts must be made to reduce the amount of sediment entering the reservoir as well as the amount organic sediments accumulating due to a cycle of nutrient enrichment, plant growth, and plant decay.

Nutrient enrichment is largely responsible for the poor quality of water in the reservoir. Varthur Lake displays many features common to eutrophic water bodies, such as low dissolved oxygen levels and high ammonia content, which result in a reduction in the diversity and number of animal species that can inhabit a lake. Nutrient and organic pollution is likely exacerbating problems like plant overgrowth, pathogenic bacteria, increased mosquito populations, and unappealing smell. The most significant source of this pollution remains unknown due to the complex nature of the catchment area and the limited water quality parameters incorporated in this study. However, results of this study consistently indicated that sewage, wastewater, and agricultural runoff are the most likely sources of contamination.

It is obvious that Varthur Lake continues to provide substantial economic benefits to the local population, despite the tendency of some locals to avoid direct contact with the lake due to the previously mentioned health risks and aesthetic concerns. Factors that elude quantification through a socio-economic surveying, such as microclimate regulation, biodiversity, and the rich heritage associated with the lake, add to the value of this resource. All of these benefits are being eroded by contamination of the lake and, therefore, lake restoration must take place in order to maintain and, perhaps, improve the quality of life currently available to residents of the Varthur Lake area. A majority of residents in the area recognize the importance of the lake and are willing to offer their support for such efforts.

6. Opportunities and Initiatives for Restoration

Efforts towards Lake Restoration and conservation in Bangalore are piecemeal and reactive, as evidenced by the state of Varthur lake water. Conservation efforts could be far more effective if we could avoid habitat degradation. This approach would require an ability to predict the elements of the lake biota that are most vulnerable to extinction and to identify their ecological attributes (bird migration, fish diversity, etc.). A related point is the need to assess the health of the lake community and to monitor changes in it over time.

The preliminary step that has to be implemented in restoring lake for their long-term sustenance includes:

Pollution impediment:

Wastewater, solid and semi solid wastes entering in to the lake from external sources must be stopped before any restoration work is implemented.

Harvesting of Macrophytes:

Water hyacinth and other nuisance vegetation present in the lake, causing eutrophication, must be removed manually or mechanically. Weed infestation can also be controlled by applying chemicals like methyl-chlora-phenoxy-acetic acid, hexazinore, etc., and biological control by means of introducing *Pila globosa* (trophical snail), Chinese grass carp (fast growing fish) etc. that feed on many aquatic plants.

Desiltation:

Dredging of the sediments in the lake to improve the soil permeability, water holding capacity and ground water recharge. Recent technological developments do permit wet dredging. Studies in Kolar district reveal that desilting of waterbodies helps in lowering fluorosis in borewell water (ground water).

Rain water harvesting:

The lake can also be used as rainwater harvesting structure. After desiltation or dredging, the storage capacity i.e., the water holding capacity of the lake would increase and as Varthur lake has a large catchment area, it would prove to be an effective rainwater harvesting structure. The bunds surrounding the lake can be strengthened and fencing should be provided around the lake. A draw well can be constructed at one end of the tank with an underground filter media connecting the well and tank bed to fetch clear water.

Watershed Management:

Watershed management is the rational utilization of land and water resources for the optimum production with minimum hazard to natural resources. As an extension of the restoration programme, watershed management practices are essential for proper land use, protecting land against all forms of deterioration, conserving water for farm use, proper management of local water for drainage, flood protection and sediment reduction and increasing productivity from all land uses.

Best Management Practices:

The restoration programmes with an ecosystem approach through Best Management Practices (BMPs) helps in correcting point and non-point sources of pollution.

Key steps for best management practices include:

- Pollution alleviation practices to reduce the engendering of non-point source of pollution (mainly agricultural and storm runoff) through source reduction, waste minimisation and process control.
- Promoting public education programmes regarding proper use and disposal of agricultural hazardous waste materials and regular monitoring of lakes, which are rudimentary. The local schools can undertake the periodic monitoring of water bodies and educating the stakeholders on the importance of restoration and maintenance of the Varthur lake. The education programmes are already underway (funded by the Commonwealth of Learning, Canada), the students of KK English High School periodically monitor the lake water quality along with the soil quality of the catchment area. The Energy and Wetlands Research Group, Centre for Ecological Sciences teach the 8^{th} and 9^{th} standard students on various aspects of the lake ecosystem and help in the water quality analysis.
- Afforestation with native species in desolate areas around the wetland (catchment area) to control the entry of silt from run off.
- The shorelines of the lakes should be lined with bricks or stones to control shoreline erosion.
- Constructed wetlands for the purpose of stormwater management and pollutant removal from the surface water flows.
- Infiltration trenches for reducing the storm water sediment loads to downstream areas by temporarily storing the runoff.

- Extended detention dry basins for removing pollutants primarily through the settling of suspended solids.

- Gyration of crops rather than monocultures to reduce the need for N and assist with pest control and help in aeration of soil.

These restoration goals require profound planning, authority and funding along with financial resources and active involvement from all levels of organisation (Governmental and Non-Governmental Organisations (NGOs), research organisations, media, etc.) through interagency and intergovernmental processes all made favourable in innovating and inaugurating the restoration programs. Network of educational institutions, researchers, NGO's and the local people are suggested to help restore the fast perishing Varthur Lake ecosystem and conserve it by formulating viable plans and management strategies.

7.0 Acknowledgement

We thank the Commonwealth of Learning, Canada and the Ministry of Environment and Forests, Government of India for the financial support. We are grateful to Mr.M.A. Khan for actively involved in the environmental education programme. Ms.Kruthi, Ms.Mala Archana and Ms. Sushma took part in the field investigations.

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9.0 Glossary

BOD – (biochemical oxygen demand) the amount of oxygen required by microorganisms to oxidize all the biologically degradable organic matter present in a sample to an inorganic form. High BOD values indicate large concentrations of organic matter that is susceptible to bacterial degradation.

COD – (chemical oxygen demand) the amount of oxygen consumed while oxidizing biologically and non-biologically degradable organic matter in a sample using a strong chemical oxidant. High COD values indicate large concentrations of organic matter.

Digitization – converting an existing paper map into a digital form that can be stored as a database. This process normally involves scanning the original map and then tracing the desired features using digitizing software.

Geometric restoration – correcting distortions found in a satellite image by correlating points on the image with control points of specified locations using a series of polynomial equations.

Georeferencing – defining the location of an image using an established coordinate referencing system. This process normally requires the user to specify a coordinate system (eg., latitude/longitude), the reference units (eg., degrees), and the positions of the edges of the image.

Hardness – an expression of the total concentration of dissolved calcium and magnesium salts present in a body of water.

Mean depth – defined as the volume of a lake divided by its surface area.

Mean width – defined as the surface area of a lake divided by the maximum length of open water between shorelines.

Relative depth – a term that expresses the maximum depth of a lake or reservoir as a percentage of the average (mean) diameter.

relative depth =

$$\frac{50 * \max depth * \sqrt{\pi}}{\sqrt{area}}$$

Shoreline development ratio – the ratio of the shoreline the circumference of a circle whose area is equal to that of the lake. High values indicate an irregular shoreline that deviates substantially from a smooth circular shape.

$$2\sqrt{\pi * area}$$

shoreline development ratio = <u>length of shore line</u>

Transparency – the distance to which light can penetrate a body of water.

Turbidity – describes the degree to which incident light is scattered by particulate matter suspended in a body of water. As turbidity increases, transparency decreases.

UTM – (Universal Transverse Mercator) a grid coordinate system that employs metric units of distance. UTM grid coordinates are expressed as distance in meters to the north, referred to as the "northing", and distance in meters to the east, referred to as the "easting".

Bathymetry – The analysis of depth profile of the lake.

Watershed - All land and water areas that drain toward a river or lake, also called drainage basin or water basin.

Morphometry - Relating to the shape of lake basin; includes parameters needed to describe the shape of the lake such as volume, surface area, mean depth, maximum depth, maximum length and width, depth versus volume etc.

Eutrophic lake - A very biologically productive lake due to relatively high rates of nutrient input.

Eutrophication - The process by which lakes and streams are enriched by nutrients (usually phosphorous and nitrogen) which leads to excessive plant growth – algae in the open water, periphyton (attached algae) along the shoreline and the higher plants in the near shore.

Dissolved oxygen (DO) - The concentration of molecular oxygen (gas) dissolved in water; usually expressed in milligrams/litre or parts per million. Adequate concentration of dissolved oxygen is essential for fish and other aquatic organisms. DO levels are considered the most important and commonly employed measurement of water quality and indicator of a water body's ability to support desirable aquatic life.

Appendix A – Bathymetric Data Points: Febr uary 2002

Reference Points	GPS Coordinates		Map Coordinates	
	Latitude	Longitude	Latitude	Longitude
NE Bridge	77.74564	12.95691	77.74564	12.95691
Irrigation Canal	77.74429	12.95458	77.74559	12.9527
Data Points	GPS Coordinates		Corrected Coordinates	
Depth (cm)	**Latitude**	**Longitude**	**Latitude**	**Longitude**
72	77.74243	12.94627	77.74369	12.94533
85	77.74323	12.94619	77.74449	12.94525
100	77.74472	12.94599	77.74598	12.94505
13	77.74565	12.94571	77.74691	12.94477
98	77.74629	12.94548	77.74755	12.94454
84	77.7467	12.94569	77.74796	12.94475
64	77.74655	12.94637	77.74781	12.94543
0	77.74655	12.9464	77.74781	12.94546
156	77.74568	12.94734	77.74694	12.9464
185	77.74514	12.9488	77.7464	12.94786
175	77.74431	12.94968	77.74557	12.94874
182	77.7438	12.95088	77.74506	12.94994
163	77.37437	12.99547	77.37563	12.99453
148	77.743	12.95396	77.74426	12.95302
175	77.7424	12.95227	77.74366	12.95133
82	77.74193	12.95025	77.74319	12.94931
166	77.74086	12.94824	77.74212	12.9473
143	77.73938	12.94644	77.74064	12.9455
90	77.73886	12.94447	77.74012	12.94353
64	77.73884	12.73884	77.7401	12.7379
59	77.73839	12.94423	77.73965	12.94329
41	77.73839	12.94423	77.73965	12.94329
38	77.73839	12.94423	77.73965	12.94329
118	77.73535	12.94587	77.73661	12.94493
113	77.7343	12.94926	77.73556	12.94832
88	77.7343	12.9493	77.73556	12.94836
76	77.73432	12.94942	77.73558	12.94848
92	77.73402	12.94943	77.73528	12.94849
58	77.73372	12.94923	77.73498	12.94829
78	77.73353	12.9478	77.73479	12.94686
73	77.73328	12.94748	77.73454	12.94654
80	77.73334	12.94688	77.7346	12.94594
105	77.73407	12.94581	77.73533	12.94487

102	77.73423	12.94402	77.73549	12.94308
80	77.73418	12.94302	77.73544	12.94208
34	77.73448	12.94257	77.73574	12.94163
0	77.73448	12.94255	77.73574	12.94161
108	77.73484	12.73484	77.7361	12.7339
118	77.73581	12.94456	77.73707	12.94362
118	77.73612	12.94489	77.73738	12.94395
121	77.73694	12.94507	77.7382	12.94413
130	77.73824	12.94519	77.7395	12.94425
115	77.73975	12.94557	77.74101	12.94463

Appendix B – Water Quality Survey Data

Collection Info												
Date of Sampling	**Oct 11**	**Oct-11**	**Oct-11**	**Oct-11**	**Nov-11**	**Nov-11**	**Nov-11**	**Nov-11**	**Jan-31**	**Jan-31**	**Jan-31**	**Jan-31**
Time of collection	AM	AM	AM	9:00 AM	~12:00 PM	10:24 AM	9:40 AM	8:37 AM	8:15 AM	8:45 AM	9:15 AM	10:00 AM
Order of collection	3	2	4	1	4	3	2	1	S1	S2	S3	S4
Location	Bellandur Canal	Main Inlet	NE Outlet	SE Outlet	Main Inlet	Center	NE Outlet	SE Outlet	Center	NE Outlet	SE Outlet	NE Irrigation Canal
Sampling depth (approx.)	< 15 cm	< 15 cm	< 15 cm	< 15 cm	30 cm	30 cm	30 cm	30 cm	30 cm	30 cm	30 cm	30 cm
Comments	sampled from shore. grassy.	sampled from shore, s.side. muddy.	sampled from shore	sampled from shore	sampled from boat	sampled from boat	sampled from boat	sampled from boat	sample from boat	from boat, 50 ft from hyacinth	from boat, clear from weeds	from boat, hyacynth present
Parameters (in situ)												
D.O. (ppm)	2.8	3.4	2.0	2.8	6.3*	5.2*	3*	5.5*	1.8	2.9	2.2	1.8
Air Temperature (C)	30.0	26.0	28.5	30.0	32.5	26.0	26.0	21.0	21.0	21.0	23.0	na
Water Temperature (C)	26.0	26.0	27.0	26.0	21.0	24.0	26.0	23.0	22.0	23.0	22.0	na
Transparency (cm)	n/a	n/a	n/a	n/a	19	n/a	27	25	10	11	10	12
Apparent color (estimated)	green	Brown	brown	green	green	green	green	green	dark green	dark green	dark green	green
PH	8.0	7.5-8.0	7.5-8.0	8.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	N/a
Parameters (ex situ)												
Acidity, total (mg/l)	n/a	n/a	n/a	n/a	64.0	64.0	92.0	140.0	n/a	n/a	n/a	N/a
Alkalinity, total (mg/l)	n/a	n/a	n/a	n/a	336.0	336.0	332.0	348.0	n/a	n/a	n/a	N/a
Alkalinity as HCO3 (mg/l)	n/a	n/a	n/a	n/a	336.0	336.0	332.0	348.0	n/a	n/a	n/a	N/a
Ammonia (mg/l)	>3.0	1.0-3.0	>3.0	>3.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	N/a
BOD (mg/l)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	76.4	74.2	74.2	74.2

Chloride (mg/l)	n/a	n/a	n/a	n/a	108.0	104.0	100.0	96.0	160.0	170.0	170.0	170.0
Chlorine, residual (mg/l)	<0.2	<0.2	<0.2	<0.2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	N/a
Coliform bacteria	positive	positive	positive	positive	positive	positive	positive	positive	n/a	n/a	n/a	N/a
EC (microseimens/cm)	480	470	460	460	493	490	474	474	1460	1420	1470	1480
Flouride (mg/l)	<0.3	<0.3	<0.3	<0.3	n/a	n/a	n/a	n/a	n/a	n/a	n/a	N/a
Hardness, Total (mg/l)	209.3	405.5*	213.6	383.7*	209.3	213.6	209.3	218.4	251.1	232.5	251.1	241.8
Date of Sampling	**Oct-11-01**	**Oct-11-01**	**Oct-11-01**	**Oct-11-01**	**Nov-11-01**	**Nov-11-01**	**Nov-11-01**	**Nov-11-01**	**Jan-31-02**	**Jan-31-02**	**Jan-31-02**	**Jan-31-02**
Location	Bellandur Canal	Main Inlet	NE Outlet	SE Outlet	Main Inlet	Center	NE Outlet	SE Outlet	Center	NE Outlet	SE Outlet	NE Irrigation Canal
Hardness, CaCO3 (mg/l)	136.0	136.0	132.0	132.0	128.0	136.0	124.0	140.0	148.8	158.1	158.1	158.1
Hardness, MgCO3 (mg/l)	n/a	n/a	n/a	n/a	78.4	85.3	77.6	81.3	78.4	62.7	78.4	70.6
Iron (mg/l)	~0.3	~0.3	~0.3	~0.3	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Nitrate (mg/l)	0.11	0.63	nil	0.21	0.25	2.40	1.07	0.30	1.26	1.40	1.30	1.12
pH	7.71	7.64	7.61	7.68	7.70	8.18	7.55	7.64	7.74	7.68	7.70	7.64
Phosphate (mg/l)	n/a	n/a	n/a	n/a	>1.0	>1.0	>1.0	>1.0	1.5	1.5	15.06	14.74
Potassium (mg/l)	118*	125*	130*	115*	21.4	21.0	20.2	21.4	2.2	2.2	1.8	1.9
Sodium (mg/l)	1055*	1053*	907*	1046*	51.0	69.2	32.8	18.9	n/a	9	n/a	n/a
Sulphate (mg/l)	n/a	n/a	n/a	n/a	20.6	18.4	14.5	16.8	3.28	8.48	2.12	2.54
Total Diss. Solids (ppm)	355	349	332	335	347	365	371	358	1076	1246	1204	1178
Total Solids (ppm)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1148	1258	1218	1196
Total Susp. Solids (ppm)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	72	12	14	18
Turbidity (NTU)	50	25	50	n/a	50	50	25	50	27	25	24	25

* = possible interference/analytical error

Appendix C – Socio-Economic Survey Form

SOCIO-ECONOMIC STUDY OF VARTHUR LAKE AREA Primary Surveyor:

NAME OF RESPONDENT:____________________________ AGE:_____ M/F DATE:___________

VILLAGE/ ACREAGE/ RURAL NAME:_________________ VILLAGE TALUK:_______________

DEMOGRAPHIC INFORMATION

TOTAL NUMBER OF PERSONS IN HOUSEHOLD: ___
AGE 0-15 YEARS: ___ AGE 16-25 YEARS: ___ AGE 26-50 YEARS: ___ AGE 50+ YEARS: ___
OCCUPATION(S) OF HOUSEHOLD MEMBERS:
TOTAL HOUSEHOLD INCOME (Rs./yr):

DOMESTIC WATER USAGE (drinking, cooking, washing, bathing)

SOURCE:	BOREWELL	SPRING	LAKE	OTHER ________
QUANTITY USED				
WATER FILTER USED? YES/NO				

GROUND WATER RECHARGE

USE OF WATER	IS WELL COMMUNAL?	AGE OF WELL	DEPTH (m)	RE-DRILLED/ YEAR
DOMESTIC				
AGRICULTURE				

IRRIGATION

WATER SOURCE	CROP	AREA	PUMP CAPACITY	**HOURS OF USE/DAY**	**YIELD**	INCOME (Rs.)

HAS THE QUALITY OR QUANTITY OF CROPS CHANGED OVER THE YEARS? YES/ NO/ DON'T KNOW

AFFECTED CROP	QUAL	QUAN	YEAR 1	YIELD 1	YEAR 2	YIELD 2	YEAR 3	YIELD 3

OTHER COMMERCIAL USES (Cottage Industries)

ACTIVITY	WATER SOURCE	WATER USAGE	INCOME (Rs.)

WATER USAGE FOR LIVESTOCK

WATER SOURCE:	**TYPE OF ANIMAL**	**QTY OF ANIMALS**	**WATER CONSUMED**	**USE OF ANIMAL**	INCOME (Rs./Mo)
BOREWELL ___	COW/BUFFALO				
LAKE ___	SHEEP				
OTHER _______	POULTRY				
	OTHER _______				

LIVESTOCK FODDER

TYPE OF FODDER	**WATER SOURCE** (borewell, lake, spring, rain)	**QTY. OF FODDER (Kg/DAY)**
CUT / DRY GRASS		
HUSK (purchased)	**N/A**	
FRESH GRASS / PASTURE		
DUCKWEED		
HYACINTH		

FAMILY HISTORY

HOW LONG HAVE YOU/YOUR FAMILY LIVED IN THIS AREA? __________ YEARS

HAVE YOU WITNESSED THE QUALITY OF THE WATER IN THE LAKE CHANGE? YES/ NO FOR HOW LONG? ______

IF YES, HOW HAS THIS AFFECTED YOUR LIFESTYLE?

HAS THE PRIMARY OCCUPATION OF YOUR FAMILY CHANGED IN THE PAST 30 YEARS? YES/ NO

IF YES, HOW?

AESTHETIC VALUE / RECREATION

ARE YOU CONCERNED ABOUT A DECLINE IN AESTHETIC VALUE OF THE LAKE (SIGHT/SMELL)? YES/ NO

HAS THIS DECLINE PREVENTED YOU FROM ENJOYING TRADITIONAL ACTIVITIES AROUND THE LAKE (eg. picnics)? YES/ NO

FISHING/ AQUACULTURE

GROWN OR CAUGHT	SPECIES	WATER SOURCE (IF GROWN) (lake, borewell, spring, surface)	YEILD	INCOME

HAVE YOU NOTICED A CHANGE IN THE NUMBER OR SIZE OF FARMED/ LAKE FISH?

NUMBER: (DECLINE/ INCREASE/ SAME/ DON'T KNOW) SIZE: (DECLINE/ INCREASE/ SAME/ DON'T KNOW)

HAVE DIFFERENT TYPES OF LAKE FISH BECOME MORE/LESS COMMON? (YES/ NO/ DON'T KNOW)

IF SO, WHICH TYPE?

WATERFOWL

HAVE YOU NOTICED ANY CHANGE IN THE OVERALL NUMBER OF BIRDS? (DECLINE/ INCREASE/ SAME/ DON'T KNOW)

HAVE DIFFERENT TYPES OF BIRDS BECOME MORE/LESS COMMON? (YES/ NO/ DON'T KNOW) IF SO, WHAT TYPE?

SPIRITUAL VALUE

DOES THE LAKE PLAY A ROLE IN RELIGIOUS PRACTICES? (YES/ NO/ DON'T KNOW)

SUBMERSION OF IDOLS (eg. Ganesh)? (YES/ NO/ DON'T KNOW)

HEALTH EFFECTS

HAS THE NUMBER OF MOSQUITOS CHANGED OVER THE YEARS THAT YOU HAVE LIVED HERE?

(INCREASE/ DECREASE/ SAME/ DON'T KNOW)

DOES YOUR FAMILY SUFFER FROM ANY DISEASES (RELATED TO WATER QUALITY)? (YES/ NO/ DON'T KNOW)

IF YES, PLEASE LIST:

COMMUNITY INVOLVEMENT IN RESTORATION

WOULD YOU LIKE YOUR CHILDREN TO REMAIN HERE AND CONTINUE USING THE LAKE? (YES/ NO/ DON'T KNOW)

WOULD YOU BE WILLING TO ASSIST WITH A PLAN TO REHABILITATE THE LAKE? (YES/ NO/ DON'T KNOW)