Re-Eutrophication and Pathenogenic Contamination of Lake Chivero

Lessons for Sustaining Technological Interventions in Lake Basin Management

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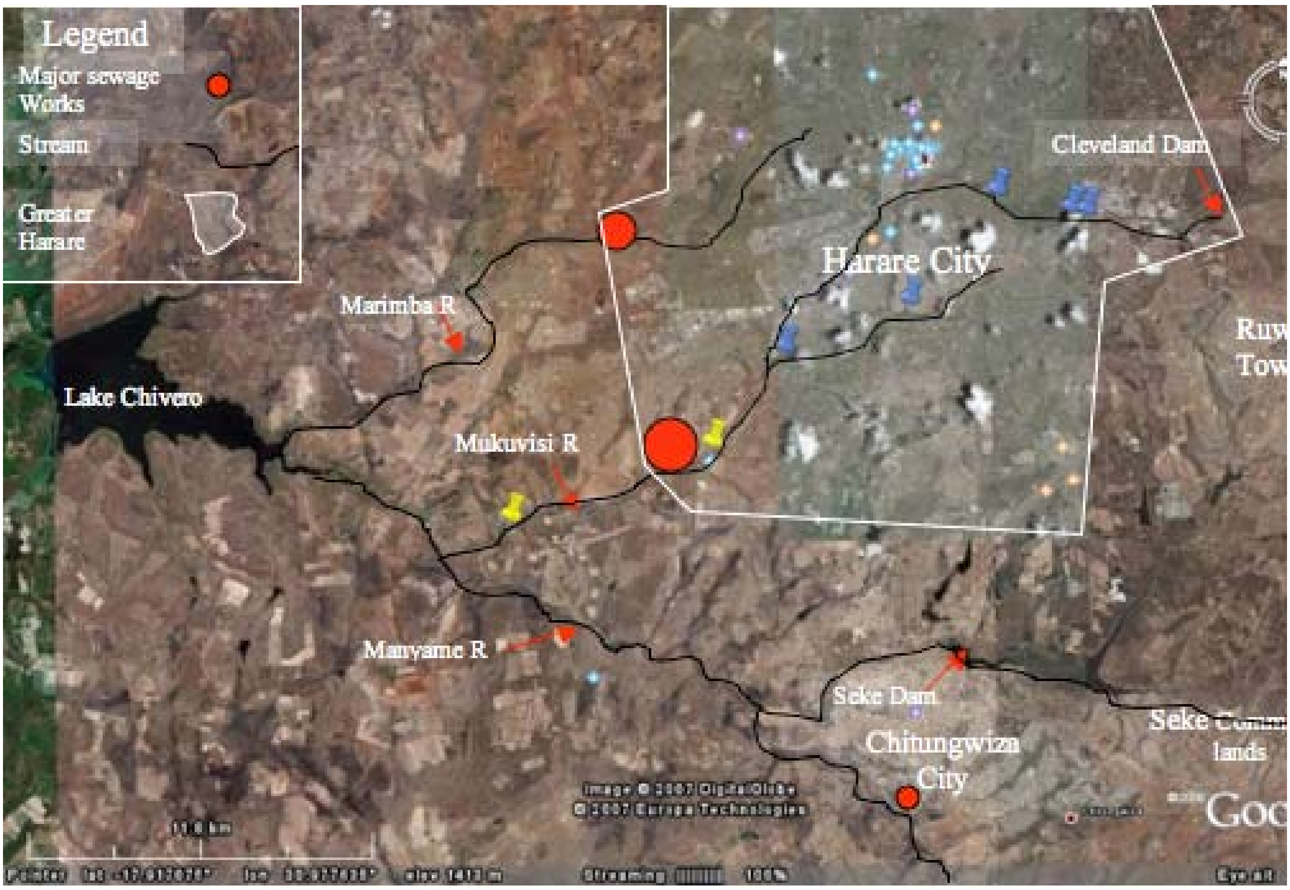
Abstract

Lake Chivero illustrates a number of lake management issues. The lake is downstream to the City of Harare and its satellite urban settlements. About fifteen years after its filling the lake became hypereutrophic. The restoration measures taken to restore it were based on scientific data. Good management and investment in infrastructure and nutrient removal wastewater treatment technology resulted in reducing the trophic state to mesotrophic state by the end of the 1970s. From 1980 onwards, there was a surge in urban population, with a doubling period of about 12.5 years. Watershed runoff diminished, resulting in reduction of the flushing rate.. As the population grew, the proportion of wastewater returns to precipitation runoff inflows increased to the extent that wastewater return is the main inflow into the lake during the dry season. These developments, in the context of inadequate investment in wastewater treatment facilities, poor infrastructure maintenance, low operating capital and poor governance, have resulted in the lake reverting to hypereutrophic state, which now poses a health risk.

Introduction

Lake Chivero is a Southern African tropical impoundment created in 1952 primarily to supply water to the City of Harare, then called Salisbury. It is located in Zimbabwe at longitude 17° 54'S and latitude 30°47'S. It is on the Manyame River with an upstream catchment of 2136 km^2.

Figure 1. Satellite view of Harare with relevant features



Its surface area is 26 km^2 with a mean depth of 9m at an elevation of some 1300m above sea level.

Figure 1 is an overlay of the Google earth image over part of Harare, showing some of the relevant features discussed below.

The city, now called Harare, began as a settler settlement, in 1890, established by the Pioneer Column, a band of opportunistic explorers lead by Cecil Rhodes. It was then called Fort Salisbury, and later simply became Salisbury. It became a municipality in 1897 and a city in 1935. It was established by a small stream now called the Mukuvisi River. A small impoundment, Cleveland Dam, was constructed upstream of the city, and supplied the city until the city outgrew the dams capacity to satisfy the city's needs. A bigger dam, Prince Edward, (now called Seke Dam) was constructed on the Manyame River, with a capacity of 3.38 ML. Later this was supplemented by Harahwa (Henry Harlem) Dam with a 9.03 ML capacity.

Historical context

Fig. 2 A&B show population growth of Harare City and surrounding urban settlements. By 1950, the city of Harare manufacturing sector was expanding. From Fig. 2B, the combined growth of Harare plus satellite settlements in the post-1975 period gives a doubling period of about 12.5 years. By the 1950s the water supply of the Harare city from the then existing Manyame River dams (Fig.1) was approaching the limits of their supply capacity. A bigger supply reservoir was needed. Up to this stage, wastewater was discharged into the Mukuvisi River and flowed away from the city and its supply reservoirs (Fig. 1).

To cater for the increased demand, a new dam, Lake Chivero (then called Lake McIlwaine) was constructed downstream of the city at an elevation some 200m lower than the city. Its location meant that waste water from the urban complex drained into the new lake.

Early impact of waste water on Lake Chivero

The planners of Lake Chivero thought that with its 250 ML capacity the lake would be able to cope with the incoming wastewater inflow by dilution, as well as the seasonal flushing of the lake during the rainy period.

By the mid 1960s, the lake was invaded by the water hyacinth, *Eichhornia crassipes.* This exotic invasive had been reported in Zimbabwe watersheds as early as the 1940s, but had not posed a management problem. Its sudden explosive growth in Lake Chivero was the first visible sign of eutrophication in the lake. It was then controlled by application of the herbicide 2,4-Dichlorophenoxyacetic acid (2,4-D). The eradication of water hyacinth was then followed by massive blooms of *Anabaenopsis sp.* which gave the lake a foetid smell. In the city, enteritis complaints increased (Marshall 1991).

Restoration

Following extensive research by the University of Zimbabwe in collaborating with the City Council appreciation of the role played by the waster water discharges lead to three significant measures:

- The promulgation of the 1975 Rhodesia Water Act, which set a dissolved phosphorus concentration of 1mg/L as the maximum permissible limit for discharge into public streams;
- The design and construction, by the Salisbury Municipality, of an activated sludge Biological Nutrient Removal (BNR) sewage treatment plant; and
- The establishment of irrigated pastures for the disposal sludge and any treated sewage that did not meet the statutory limitation for discharge to public streams.

Figure 2a. Population growth of Harare and satellite settlements

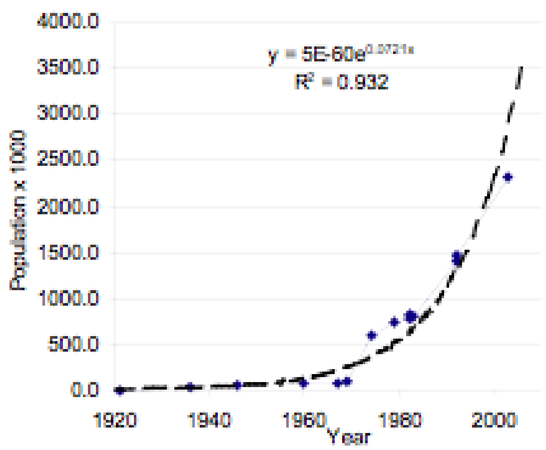


Figure 2b. Population growth of Harare and satellite settlements since 1975

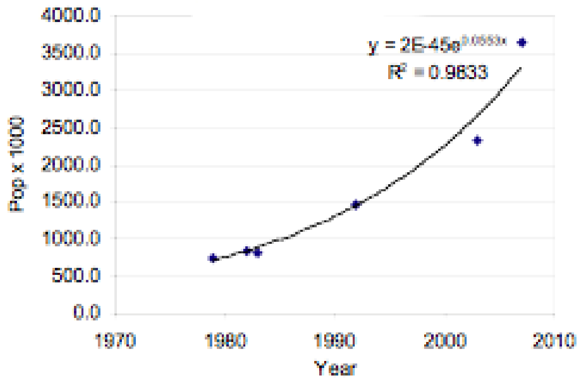
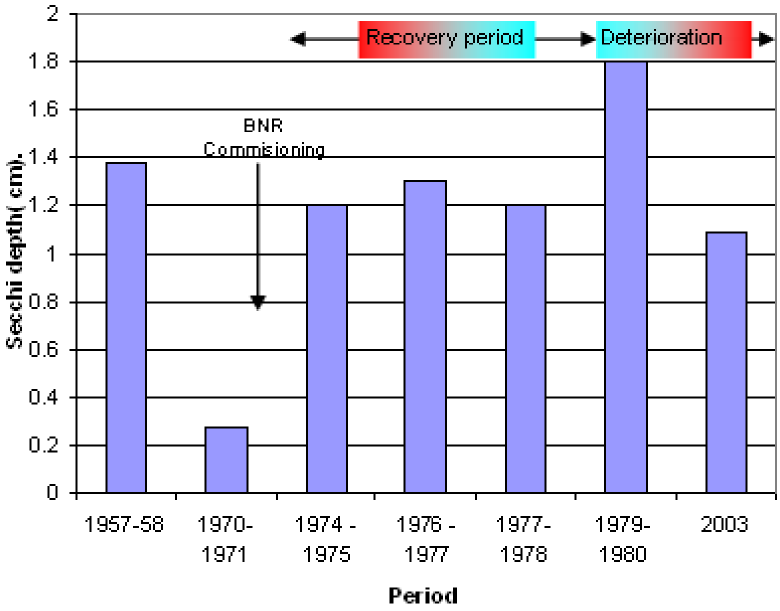


Table 1 shows changes in phosphorus loading to the lake following the remedial measures for the pre- and post-remediation period of 1968 and 1978. Fig. 3 shows changes in secchi disc transparency before and after the restoration measures. Considering that the BNR system was commissioned only early 1975, the lake's response to the measures was remarkably rapid.

These measures, and a constant surveillance to remove water hyacinth plants that appeared after the spray programme manually, allowed the lake to recover from a hypereutrophic state to a mesotrophic state (Thornton 1982). The total phosphorus load was reduced from nearly 300 tonnes per annum to less than 40 tonnes per annum. Secchi disc transparency increased to above one metre. The water sport (sailing, water skiing) tourist industry generally revived.

Figure 3. Secchi disc changes following restoration measures (data from Thornton 1982, Ndebele and Magadze 2006)



However, as part of the recovery evaluation process, Magadza (1994) warned that the lake was in a metastable condition and that unless stringent measures to control nutrient inflows were maintained it could rapidly revert to the previous eutrophic state. Nevertheless, this case study shows that a hypereutrophic tropical impoundment, which ranks among the class of large lakes of the world, could be restored by controlling nutrient loading into the lake.

The post 1980 era

The tragedy of Lake Chivero is what has happened from the post-1980 period up to now. Table 2 shows the status of some of the wastewater treatment plants in the Harare Municipality. As shown in Figure 2B the urban population of the Lake Chivero watershed is doubling every 12.5 years since 1975. The data include the population of the Chitungwiza city, established in the early 1960s. The sudden rise in the overall population in the mid 1970s shows the population surge in Chitungwiza. However, this city lacks an economic base, and thus has no revenue base, apart from household utility charges. Consequently, the

Table 1. Historical changes in phosphorus regime in L. Chivero (after Thornton, 1982, Magadza 1997).

Parameter	1967	1978	1996	2006 (Ndebele and Magadza 2006)
P-load (tonnes pa)	685 (27.4 g m^{-2})	39.6 (1.5 g m^{-2})	350 (14 g m^{-2})	
Mean P- conc. mgl^{-1}	2.8	0.13	1.8 (Manyame)	2.67 (2.42 - 3.18)
Conductivity μScm^{-1}	160	120	800	2124.5 μScm^{-1}

(Wet season values)

Table. 2. Waste water treatment capacity at some of the Manyame watershed sewage works.

Plant	Trickle filter	Year	Activated sludge (BNR)	Year	Ponds	Year	Total capacity	Present flow
Firle	36	1960	18	1982			144	250
			18	1974				
			72	1998				
Crowborough	36	1957	18	1982			54	120
Donnybrook					2.3	1953-1972	2.3	10
Marlborough					2	Post 1980	2	7
Total							202.3	387

city is unable to invest in public services works to manage, among other things, its wastewaters.

To summarise the major developments that have lead to the sorry state of the present Lake Chivero:

- The establishment, in the lake's watershed of a high density low income urban settlement, Chitungwiza, which has a very weak fiscal base to provide basic services.
- The rapid population growth, with a doubling period of only 12.5 years, of settlements in the lake's watershed, with a mismatch between population growth rate and investment in civic works.
- The progressive breakdown in infrastructure maintenance, leading to chronic sewer breaches that go unattended for long periods.
- The breakdown in city sanitation services which results in large heaps of uncollected refuse
- Central government interference with urban councils that results in incompetent politically appointed "commissions" to run city affairs.
- Development of a non-consultative style of governance in which ratepayers face ever escalating charges for substandard services.

Hydrology

From a hydrological point of view, there have been significant changes in the lake's watershed.

Run off and flushing rates

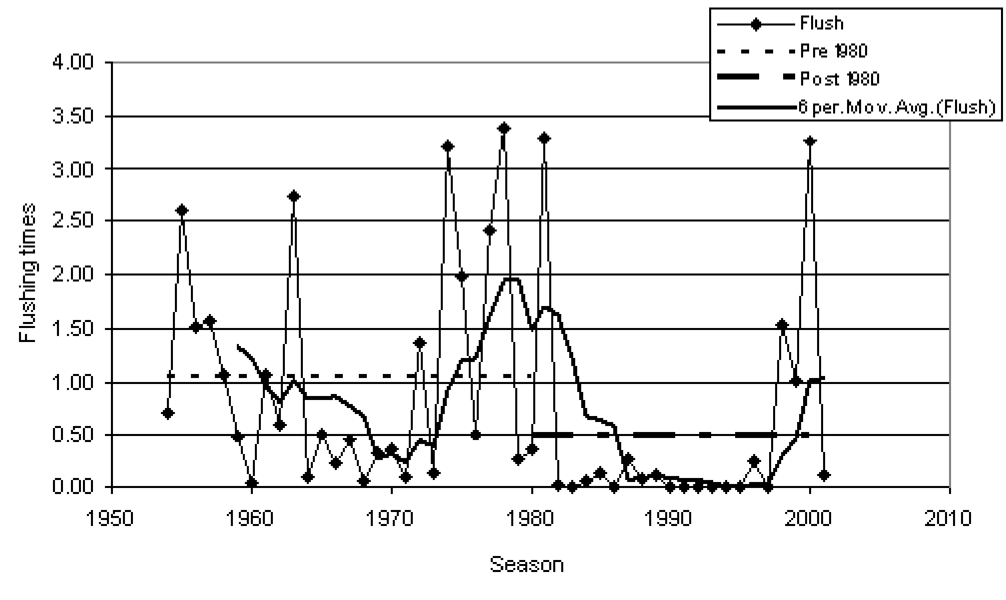
Fig. 4 shows the annual flushing rate, calculated as total runoff divided by lake volume. The data show high variability but overall the pre-1980 period had higher flushing rates, with the post-1980 era being on the average half of the pre1980 era. Thus, in the post-1980 period, the lake has received less runoff from the watershed and the water has stayed longer in the lake.

Constituent flows

The Manyame River has traditionally been regarded as the main inflow into Lake Chivero, with 92% of the lake's watershed drained by this river. Urban drainage is principally through the Marimba, Mukuvisi and Nyatsime rivers. These latter tributaries have increasingly become wastewater conveyances to the lake. For example the conductivity of the Mukuvisi River changes from an average of 50 _Scm^{-1} at Cleveland Dam, to over 2000 _Scm^{-1}, as it passes through the city and receives partially treated (and now frequently untreated) sewage from the sewage works.

The Chitungwiza City wastewater treatment plant was designed for BOD and TSS reduction, with a capacity of some 20 mega litres per day. The city, envisaged as a small periurban industrial township, has close to a million inhabitants discharging over 50 mega litres daily. As the effluent would not have met the nitrogen and phosphorus standards for discharging into L. Chivero, the effluent was to be piped out of the L. Chivero watershed into an adjacent watershed (Mufure), where it would initially be processes in pastureland, prior to draining into the L. Kariba watershed. However low pumping capacity and pump failures resulted in the effluent being discharged into the L. Chivero watershed via the Nyatsime River tributary of the Manyame River. To remedy this situation a BNR plant

Figure 4. Flush rate per annum



was constructed to process the Chitungwiza effluent. Poor census data resulted in under-design of this plant.

Figure 5 shows an increasing ratio of wastewater bearing inflows to the inflows of the major watershed runoff (not including the Nyatsime River). This is particularly conspicuous during drought periods when wastewater effluent can be as much as five times the run off inflows from precipitation in the watershed. Indeed, during the dry season Lake Chivero's inflow consists almost entirely of wastewater returns. Thus, increasingly the lake's water is being constituted mainly of urban waste waters.

Non point source inflows

The result of progressive breakdown in civic services by the Harare municipal authorities has been the accumulation of uncollected garbage and increase incidences of sewer breaches that go unattended for considerable periods. Magadza (2003) has estimated the no point source export of phosphorus and nitrogen from Harare suburbs. Thornton (1982) estimated phosphorus loads from "other sources" as 18 tonnes per annum. From the results given in Table 3 for the sub-watersheds that drain into Lake Chivero, it is clear the current no point source loadings have increased by at least fifteen times the 1978 value. It is thus clear that managing piped waste water from the urban areas through the wastewater treatment plants will still leave a considerable loading of nitrogen and phosphorus to the lake that is of the same magnitude as the pre-restoration period. This means that investing in high technology wastewater treatment plants will no longer solve the pollution problems of the lake, as it did in the mid to late 1970s, because sufficient loading from no point source nutrient loading will maintain the hyper-eutrophic state of the lake.

Status of eutrophication of L. Chivero.

Water Quality

The Lake Chivero pollution status has been discussed by Magadza (2003). Between March and April 2003 total phosphorus concentrations ranged between 1.98 mg/L and 2.99 mg/L at three sampling sites on the lake, with a mean of

Figure 5. Ratio of waste water carrying stream flows to Manyame River flow

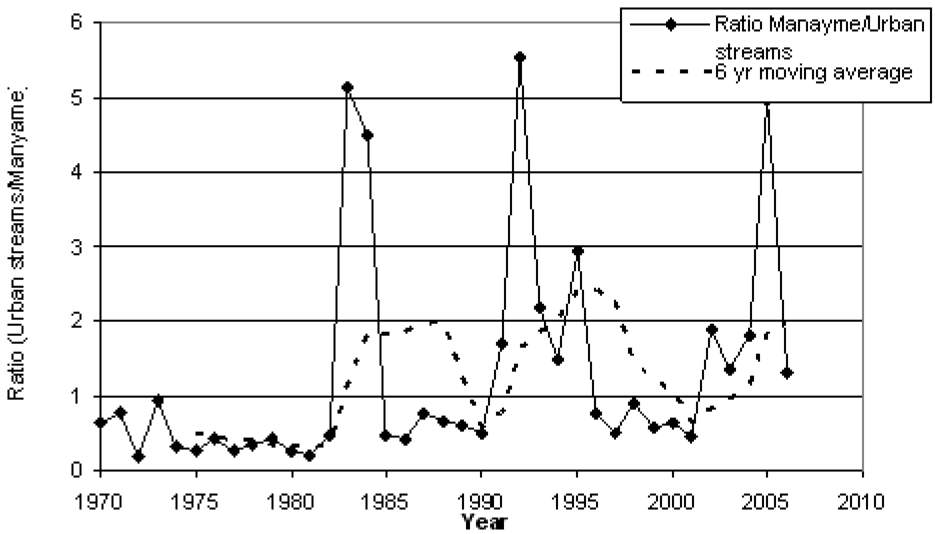


Table 3. Nutrient exports during wet season from Harare suburbs to L. Chivero (excluding Chitungwiza) (Adapted from Magadza 2003)

Catchment/ Suburb	Type	Phosphorus		Nitrogen		Total export		P/N ratio
		Tonne km^{-2}	Kg Capita^{-1}	Tonne km^{-2}	Kg Capita^{-1}	P tonne	N tonne	
Kuwadzana	High	0.08	0.17	0.47	0.96	2.88	16.75	5.81
Budiriro	High	2.30	0.23	13.77	1.35	22.08	132.17	5.99
Mukuvisi	High/ Industrial	10.28	1.00	39.98	3.89	98.99	385.04	3.89
Epworth	High	3.38	1.11	12.20	4.00	103.12	371.88	3.61
Glenview	High	0.30	0.39	1.09	1.44	30.23	111.39	3.68
Marimba	Mixed/ industrial	0.13	0.77	0.86	4.98	9.28	60.31	6.50
Mean or total		2.75	0.61	11.40	2.77	266.59	1077.53	4.91

2.24 mg/L (Ndebele and Magadza 2006). This is about three orders of magnitude higher than the 1967 value (0.04 mg/L), during which the lake was already hypereutrophic, and over 20,000 times the mean value during the recovery period (c.f. Table 1). Chloride levels ranged between 71.03 mg/L and 174.78 mg/L. Magadza (2003) showed the existence of thermohaline stratification and declining oxygen levels, to the extent that the lake suffers from frequent anoxia leading to fish kills (Moyo 1997.).

Nuisance invasive aquatic weeds (*Eichhornia crassipes* and *Hydrocotyl*) have become pervasive, with *Hydrocotyl* increasingly replacing *Eichhornia* whenever the latter is sprayed.

The cost of treating the L. Chivero water to potable standards has escalated, and in the context of an ailing economy, the water authority is no longer able to supply the urban

population with adequate water with several suburbs going without piped water supply for weeks and months, though the lake storage is high. Cholera cases have been reported in the media (Box 1).

Health implications

In evaluating health impacts of eutrophication and raw sewage pollution of Lake Chivero and its environments we recognise two caveats. Firstly, not all the residents of City of Harare obtain water from municipal supply system. Many obtain water from open sources such the Manyame River (Fig 7) which carries partially treated (and often understated) sewage from Chitungwiza, a well as from shallow wells. In the municipal supplied suburbs, the number of people who resort to unsafe supplies of surface water increases during periods of municipal water supply failure, which in some suburbs can last for several days to weeks.

The second caveat is that there is no liaison between the medical services and the environmental service to link malaises to environmental conditions. For example following the spillage of hundreds of thousands of litres of PCB in the Lake Chivero watershed in 1998, there was no attempt to investigate the health implications of the spills, even though considerable amounts of PCB were detected in mother's milk in all watersheds which suffered the spill. Some of the data presented here are results of opportunistic student research, attempting to make the linkage between lake conditions and human health.

Health impact from control of water hyacinth

Following the first large scale application of 2,4-D to control water hyacinth the City health records show an increase in the incidences of still births and malformed babies. There has been no study on the health effects of herbicide application in the current situation.

Possible link between cyanobacteria and health

Following the spraying of water hyacinth with 2-4.D Marshal (Marshall 1991), noted a significant increase in *Anabaenopsis sp.* The increase in this cyanobacterium was coincident with a surge in enteritis in City of Harare. In a study on microcystin concentrations in L. Chivero (Ndebele and Magadza 2006), the data showed that the average concentration of microcystin-RL was 19.9 μgl^{-1}. The recommended level of microcystin in lake water for potable water supply is 1 μg/L. Microcystin has been linked to incidence of liver cancer (Lepisto et al 1992). Figures 7 and 8 show respectively the growth of intestinal enteritis and lever cancer incidences in Harare. There is, however, no time trace of the growth of microcystin in the lake to associate these diseases with cyanobacteria in L. Chivero. The data however strongly suggest that there is urgent need to couple the environmental condition of L. Chivero and city health.

Risk of water borne parasitic infections

The discharge of raw or partially treated sewage exposes the Greater Harare population to a variety of water borne parasites, namely

- Protozoa (e.g. *Endamoeba, Trichomonas, Giardia*).

Figure 6. *Hydrocotyl* in Manyame

Figure 7. Women collecting water from polluted Manyame River

- These are generally less than 10μ in size and can thus pass through sand filtration.
- Their cysts are resistant to chlorination.

- Various nematode parasites which are also discharged as cysts (e.g. *Strongiloides sp*)
- Trematoda (e.g. *Clonorchis*, transmitted by ingestion of inadequately cooked fish)
- Schistosomes transmitted by making contact with water containing cercaria e.g. during fishing, or waster sport. Surveys generally show a parasitaemia of about 60% in under 18 year olds in urban Harare

Although this brief survey of health issues concerned with L. Chivero presented a limited number of observations, the extent of the impact of L. Chivero on the health of the city of Harare needs a wider investigation on a number of pollutants that could pose health risks, such as dioxins, heavy metals, pesticides and industrial effluents. Although PCB levels in mothers' milk were investigated at various localities in Zimbabwe, that study did not include Harare, where there were ostensibly the heaviest spillages.

Impacts of plant failures

The supply of potable water to city of Harare is now beset with major problems

- Frequent power outages
- Lack of funds to procure adequate supplies of water purification chemicals
- Aging equipment
- Depletion of technical staff

The power outage and plant break down result in failure to process sewage, resulting in discharge of untreated sewage into the lake. Further as Table 2 indicates all wastewater treatment plants are now grossly overloaded, and in the best circumstances can only treat a fraction of the incoming sewage, resulting in the now constant discharge of inadequately treated waste water.

Power outages, and or lack of water treatment chemicals leads to waterworks shut downs, or delivery of insufficiently treated potable water supply. Enteric diseases are now widely reported in the city suburbs. Figure 9 shows suspended matter deposits from municipal water supplies settled in a bath tub.

Figure 8. Enteritis deaths per thousand infected

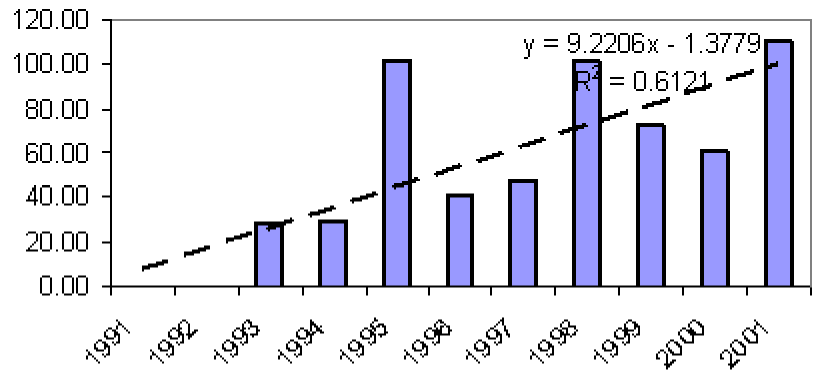
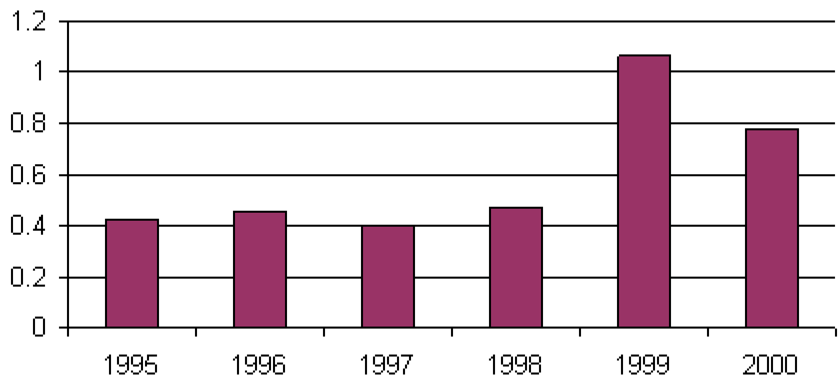


Figure 9. Liver cancer: incidence/1000



Although the economic downturn contributes to the state of affair in the Lake Chivero case, high-handed interference by central government is also a significant contributor. The Zimbabwe Water Act provided for the creation of a national water authority, the Zimbabwe Water Authority (ZINWA). Its role, as described in Schedule (Section 9) of the Zimbabwe Water Act 1998, is regulatory in the management of water resources, such as authorising dam constructions, licensing water abstractions and water quality emissions monitoring and control. However to control urban councils politically the state imposed an ill-prepared ZINWA on urban councils in the day-to-day running of water supply and waste management. Being a parastatal organisation which should raise its own revenue the authority emphasised its revenue collection rather than service delivery. Thus, even though ZINWA fails to supply water and run wastewater treatment plants, residents are legally bound to pay for services not delivered.

Figure 10. Particulate matter in municipal water supply settled in a bath tub

Ironically, ZINWA is now the largest polluter of Lake Chivero. At the rivers confluence with the lake the rivers have grey colour typical of sewage effluent and have strong smell of hydrogen sulphide (Fig. 10). Several visitors to the lake have reported seeing faecal matter. Thus ZINWA, the authority to safeguard the nation against water pollution, now risks adding the inhabitants of greater Harare, Chitungwiza and Norton, with a total population of some five million inhabitants, to the world population of people with no safe drinking water. This is equivalent to endangering the water supply of more than the whole of New Zealand or Denmark or 35% of Zimbabwe population.

Box 1 is a media portrayal of the health risks that the waters of L. Chivero now pose. Magadza (2002) noted the rise in bloody diarrhoea incidences among five year olds in Harare during the rainy season. This is explained by the mingling of rain water runoff with breached sewer

Table 4. Evaluation of the management of Lake Chivero against World Lake Vision Committee (2003) Seven Principles (International Lake Environment Committee (IEC)/ United Nations Environment Programme-International Environmental Technology Centre (UNEP-IETC).

Principle		Compliance status	Comment
1.	A harmonious relationship between humans and nature is essential for the sustainable use of lakes	Conflicts between nature and human	Poor compliance of policy and legal provisions by society, industry and state institutions
2.	A lake drainage basin is the logical starting point for planning and management actions for sustainable lake use	Principle not applied	No linkages between various jurisdictions and management authorities in the drainage basin, in spite of institutional structures (watershed councils) set up to facilitate this.
3.	A long-term, preventative approach directed to preventing the causes of lake degradation is essential	No evident long-term plan	Management strategies now consist of responding to crises, through aid assistance requests.
4.	Policy development and decision making for lake management should be based on sound science and the best available information	Poor application of scientific approach.	In initial planning of the lake scientific knowledge on function of aquatic systems was limited, but subsequent research by independent researchers has built up a good knowledge base which can be used for management of the lake.
5.	The management of lakes for their sustainable use requires the resolution of conflicts among competing use of lake resources, taking into account the needs of present and future generations and of nature	No attempt to resolve conflicts	The major conflict is the use of the lake for potable water supply, recreation and fisheries and as a wastewater receptacle at the same time.
6.	Citizens and other stakeholders should be encouraged to participate meaningfully in identifying and resolving critical lake problems.	Principle not adhered to	The state system has very little room for inclusive participation by non state entities. There is no intension by managers to consult with rate payers, or consult other technical expert groups, such as universities and the Zimbabwe Academy of Sciences
7.	Good governance, based on fairness, transparency and empowerment of all stakeholders, is essential for sustainable lake use.	Poor, but punitive governance.	Although the national water authority was set up in the spirit of this principle, it has turned out to be principally a revenue collector for little services in return. Breached sewers go unattended for weeks or months. On the part of the municipality, refuse collection is infrequent.

outflows, rendering children who play in the puddles susceptible gastroenteritis infections.

Table 4 is an evaluation of the management of Lake Chivero against the Seven Principles developed by the World Lake Vision Committee (2003). Clearly, the management of Lake Chivero falls far short of the recommendations of the World Lake Vision.

What can be done?

The current management strategy is to seek more funds to construct more wastewater treatment works. A total of 255 ML capacity expansion at a cost of approximately US$353 million is planned. This is indeed a priority, but such funding is unlikely to be available from local resources in the present economic circumstances. Nevertheless, we have shown earlier that the no point source of phosphorus and nitrogen can maintain the lake in a hypereutrophic state given that the sum total of this source of nutrients exceeds the 1967 levels when the lake was hypereutrophic (Tables 3 above). Thus, the high technology wastewater treatment strategy now needs to be complemented by other strategies. One strategy is the implementation of the Seven Principles recommended by World Lake Vision Committee (2003). This requires a major mind shift on the part of the management authorities on the rights and obligations of stakeholders. In Laguna, de Bay it has been amply shown that involvement of citizens, at the lowest level, can yield very satisfactory results, which could not have been achieved by a top down management style. On the part of the citizens it requires a sustained educational and awareness programme to educate them in how they affects their water resources.

The other strategy is use of ecological methods for runoff water quality control. Studies on the Mukuvisi River, one of the major nutrient contributors to the lake, have shown that the wetlands associated with this river have considerable water quality restoration (self purification) capacity (Machena 1997). Prior to 1980 urban wetlands were left undeveloped as "ecological lungs" to the city, but now these wetlands are being increasingly converted for property development. It is recommended here that the State develop a clear policy and implementation strategy for wetlands conservation. Within the urban areas of Harare and surrounding urban settlements, we recommend that the authorities develop and implement an extensive programme of wetlands management, such as constructed wetlands. In this respect, it should be pointed out that The United Nations Environmental Programme-International Environmental Technology Centre (UNEP-IETC) has case studies of ecological technologies for sound environmental management of water resources, e.g. *Planning and Management of Lakes and Reservoirs: an integrated approach to eutrophication*. (UNEP-ITEC 1999), (see also Jørgensen 2000)

Box 1

As a result, the incidence of waterborne diseases such as dysentery, diarrhoea and cholera has increased to such an extent that the Harare City Council (HCC) is obliged to offer free treatment. The city's health department last month warned of an imminent disaster in the capital if the water situation was not addressed.

The Cape Argus (SA), 8 October, cited in ZWNEWS 09/10/07 http://www.zwnews.com/

Planning personnel in the water resource management have indicated to the author that a major development project cycle, from the initial decision to commissioning is often more than ten years. With a doubling period of 12.5 years, it means such a planning near-term cycle scenario can never be up to date with the growth of services demand. This means that the planned utility life span for the service being developed must be at least two to four times the demand doubling period. This implies some ingenious financing strategy in which the unborn pay for their anticipated services well in advance.

Figure 11. Marimba waters entering Lake

Figure 12. Effluent from breached sewer

Lessons learned

- Population growth in L. Chivero urban areas is doubling every 12.5 years.

- Wastewater management development has lagged well behind wastewater processing capacity needs.

- Out of an estimated total daily wastewater flow of 387 Ml per day from greater Harare only, total wastewater processing capacity is only 202 Ml per day, leaving a deficit of 185 Ml per day.

- In addition non point source effluent contributes more than 300 tonne phosphorus and 1000 tonnes nitrogen, sufficient to maintain the lake in a hypereutrophic state. Thus developing capacity to manage piped wastewater effluent without parallel capabilities in non point source pollution control will not solve the L. Chivero eutrophication problems.

- Microcystin levels in the lake now exceed recommended health limits by a factor of 20.

- Combination of inadequate wastewater processing capacity and frequent failures at wastewater processing facilities have now rendered the Lake Chivero water supplies a health risk to an urban pollution of some 5 million people.

- Liver cancer and enteric diseases are on the rise.

- Poor governance leading to inadequate funding for development and maintenance of wastewater treatment facilities is a major contributing factor.

- That given adequate flushing rates and stringent control of nutrient loading reservoirs of the size of Lake Chivero can recover from hypereutrophic state in periods of less than a decade.

- The situation calls for innovative technical and ecological methods in urban wastewater management in a developing country.

Conclusion

The lake Chivero case is a typical example of how poor governance, hydrological changes, probably linked to climate change, urban population growth and lack of anticipatory management can lead to an environmental crisis. Prior to 1980, professional and technical experts made the technical management decisions. However, since the 1980s political considerations have frustrated sound management. This, added to burgeoning population pressures, and thus more wastewater output, has now developed into a major crisis with regard to the management of lake Chivero and the goods and services it is supposed to provide. However, it has been demonstrated before that application of sound scientific principles and good management and governance can result in restoration of a hypereutrophic lake. With foresight this possibility still remains.

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