CHAPTER 1

1. INTRODUCTION

1.1 FRESHWATER SHORTAGE

In the past freshwater was considered an infinite resource and its exploitation was assumed a god-given right. Modern scientists have now concluded that this type of management of an important resource such as water is very costly. In developing nations demand is usually greater than availability, a situation that is exacerbated by the high rate of growth of populations, (Chenje et al., 1996).

Of the total water found on the earth's surface oceans hold 97%, but unfortunately this water is too salty for drinking and irrigation purposes (Leopold, 1974) as cited by Moss (1988). Of all the water that is found on earth only two percent is freshwater, (World Lake Vision Committee, 2003). About 2.15% is held in glaciers and ice caps and 0.625% is soil and groundwater (Leopold, 1974) as cited by Moss (1988), and these two sources although usable by humans may be inaccessible for human consumption. Only less than 0.5% is found readily available for human use (World Lake Vision Committee, 2003).

Streams and rivers are our major sources of freshwater, which are characterized by a linear and unidirectional flow as well as temporal and spatial fluctuations in discharge. These features call for the need to store water through the construction of dams. The dams and rivers have been subjected to pollution, particularly those that have urban and rural catchments thus reducing the amount of portable water. In the Dominican Republic about 80% of all drinking water comes from surface sources which all contain pollutants from erosion, human and animal waste, petroleum products, inorganic fertilizers, pesticides, herbicides and raw sewage (Witter et. al., 1996).

The changes in land use patterns such as the clearance of vegetation for urban development and agricultural use is causing extensive soil erosion and subsequent siltation of rivers, streams and dams/ lakes, which reduces the water storage capacity of dams (World Lake Vision Committee, 2003). Cultivation of soil loosens the soil, consequently increasing the rate of leaching of nutrients into rivers and lakes. In Zimbabwe, afforestation with Eucalyptus trees was contributing towards the lowering of the water table, because of their deep roots and persistent foliage (WRMS Technical Secretariat, 1995).

Payet & Obura (2004) identified freshwater shortage as a major concern in the East African region, citing annual internal renewable water resources per capita in the year 2000 as averaging 6202m^3 for the region compared to 12000m^3 in South East Asia and Latin America. The shortage was attributed to the semi arid climate, human impacts such as population growth, land use change and changing rainfall patterns in the region as well as the small land area in the Indian Ocean Islands. They predicted that this freshwater shortage would undermine food security and economic growth in the coastal areas resulting in conflicts among freshwater users at both national and international levels.

The issue of climate change exacerbates the problem of water shortage. Global climate change is resulting in increasing frequency and severity of droughts, particularly in Sub-

Saharan Africa, thus reducing the amount of freshwater available for use by humans. The droughts are also causing the failure of dams to spill, which leads to an increasing rate of accumulation of pollutants (Bailey, Kajese & Koro, 1996). According to Hansen et. al. (2002) global surface air temperatures have risen by 0.5^0C in the past 25 years and by 0.75^0C in the past century, a scenario that could increase the rate of evaporation thus impacting negatively on fresh water sources.

Southern Africa is a water stressed region (Thornton and Nduku, 1981). The water shortage is worsened by the increasing frequency of droughts in the region throughout history in the periods: 1964-66, 1982-83, 1986-88, 1991-92, 1994-95, (Chenje et al., 1996), thus necessitating the proper management of water systems in the region. The frequent droughts increase the water residence time, a situation, which worsens the problem of eutrophication in dams that have urban catchments that dump sewage water into dams.

1.2 POLLUTION

1.2.1 Chemical pollution

The cleansing action of water has caused dams and rivers to become dumping grounds for wastewater from the sewers and storm drains (Magadza, 2003). Mason (1996) identified point and diffuse sources as the two major sources of pollution. He defined point sources as those discharges known to authorities and as such could be controlled or stopped e.g. sewage effluent. A GIWA assessment in the East African region by Payet & Obura (2004) identified sedimentation that was worsened by overgrazing and solid wastes as the major pollution concerns, with sewage from growing urban centres increasingly becoming a problem.

The problem of sewage discharge into water bodies is worldwide. At one time the Thames River in England was referred to as ‘The Sewer of Europe’ (Mason, 1996) because of the nasty odour and colour of the water caused by sewage dumped into it. During the dry season the flow of some rivers consists entirely of effluents, with contamination being greatest in urban, commercial agricultural and rural areas.

(Mason, 1996) defined diffuse sources as those that enter watercourses from storm drainage as well as runoff and land drainage containing fertilizers and pesticides applied to crops. Studies by Nduku and Thornton (1981) showed that diffuse runoff had a large impact on the pollution of water bodies and maintenance of eutrophic conditions in Zimbabwean impoundments. Jarawaza (1997), Mathuthu et. al. (1997) and Magadza (2003) concurred.

Mason (1996) also referred to chronic pollution, which he claimed could be controlled since a watercourse received continuous discharge. He however referred to episodic events like the deliberate discharge of wastes, such as occurred in England, 1994, when there was the spillage of lime slurry by a gas company, cyanide from a railway engineers, and raw sewage from a water company and caustic soda from a dairy farm, all of which resulted in a large-scale loss of aquatic life. Such episodic events should be of great concern to water managers since a single event can destroy years of careful management of pollution (Mason, 1996). A disastrous consequence of chemical pollution that is affecting most freshwater bodies is eutrophication.

1.2.2 Microbiological pollution

According to Mason (1996), about 25 000 people die each day worldwide from water borne diseases like cholera, dysentery and gastroenteritis due to poisons in dirty water. In India about 73 million working days, costing US $600 million in productivity and health care are lost each year because of water related diseases (Mason 1996). About 36% of people treated at clinics in the Dominican Republic in 1991 were treated for water borne diseases (Witter et. al., 1996).

Odada et. al. (2004) identified municipal untreated water, runoff, storm water and animal waste as immediate causes of microbiological pollution in the Lake Victoria basin of East Africa. Runoff and storm water carried animal, plant and human waste from both point and diffuse sources into rivers and dams, thus creating an environment that supports the growth microbiological pathogens. Payet & Obura (2004) also referred to the prevalence of pollution of surface waters with human waste due to inadequate sewage disposal facilities, causing high incidences of cholera and dysentery in Madagascar and Tanzania because most people obtained drinking water from shallow wells, boreholes or poorly treated supplies.

1.3 EUTROPHICATION

Eutrophication is the aging of water bodies such as oceans, lakes, dams, estuaries and slow moving streams (Weld, 2002) due to increased nutrient concentrations in the water causing them to become more productive over thousands of years. The nutrients nitrogen and phosphorus have been found to be the primary regulators of eutrophication (Ryding & Forsberg, 1976, Marshall & Falconer, 1973 on Lake Chivero, Mason, 1996 and Magadza, 1997). Robarts (1981) found out that the most important nutrients needed for the growth of phytoplankton are nitrogen and phosphorus though carbon might be important.

The phytoplankton blooms reduce or prevent the penetration of light into the water, causing underwater vegetation to die. The underwater vegetation provides food, shelter, and spawning as well as nursery habitat to many aquatic organisms, which may die. The growth of rooted plants in the littoral zone e.g. reeds also increases thus increasing the rate of sedimentation.

Eutrophication also causes dense blooms of blue-green algae. Carmichael (1994) reported that about 12 different species of cyanobacteria had been shown to produce toxins, each species being capable of producing several different toxins. The major toxic genera of cyanobacteria include *Anabaena, Aphanizomenon, Nodularia, Oscillatoria and Micicrocystis* (Carmichael, 1994). Many blue-green algae species produce toxins, which might cause gastroenteritis (Zilberg, 1966) as cited by Marshall (1997) and are associated with liver and nervous system damage in both humans and livestock as well as death in severe cases (NYS Algal information, 2000). Some of the toxins are precursors of trihalomethanes, chemicals that could be carcinogenic (World Lake Vision Committee, 2003). The blue-green algae also cause undesirable tastes and odours to the water (World Lake Vision Committee, 2003), which demands the use of more flocculants and more activated charcoal in the treatment of water (Marshall, 1997).

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The death of the large submerged aquatic vegetation and algae increase the organic matter content in the water resulting in increased BOD. Prolonged exposure of aquatic living organisms to oxygen levels below 5-6mg/L might not kill the aquatic organisms, but may increase the susceptibility of the organisms to environmental stresses like high ammonia levels, extreme Ph levels and toxins from herbicides and pesticides from farms (Gower, 1980). Exposure to oxygen levels less than 2mg/ L for one to four days may kill most of the biota (Gower, 1980) like fish, crabs, tadpoles, shrimps, crayfish, copepods, beetles, water scorpions, midge larvae and water-boatman in a system. Lake Chivero in Zimbabwe is renowned for its high levels of eutrophication, which resulted in the famous fish deaths of March / April 1996, (Moyo, 1997).

1.3.1 Nitrogen

Nitrogen occurs in water as dissolved organic and inorganic nitrogen and as nitrogen locked up in organic compounds in sediments and living organisms. The inorganic nitrogen occurs in the form of ammonia, nitrates and nitrites. This inorganic nitrogen is the form, which is used by plants. The most prevalent form of nitrogen in freshwaters is nitrates (Kalkhoff, 2001 and Walk, 2004). The organic nitrogen is in the form of proteins, peptides, nucleic acids, amino acids and other carbon containing compounds found in living organisms.

Nitrogen gets into water bodies through various ways. Because of their negative charge, which repels the negative charge on clay particles nitrates are highly soluble in water and are not adsorbed to soil particles such that they can quickly leach through soil. The nitrites and ammonia also leach into water but not as fast as nitrates. They are oxidised to nitrates in the soil by nitrifying bacteria. Inorganic nitrogen can also get to dams by seepage or sub-surface flow. Some nitrates, and nitrites, ammonia and soluble organic nitrogen enters reservoirs dissolved in rainwater (Paerl & Whitall, 1999).

Nitrogen only becomes a limiting nutrient when the ratio of nitrate and ammonia to reactive phosphorus is less than 10:1 (Walk, 2004). If nitrates or ammonium ions exceed 0.3mg/L in spring there will be sufficient nitrogen to support algal blooms (Walk, 2004). Nitrate- nitrogen levels between 0.5 and 1.5mg/L are considered to make a water body eutrophic (Walk, 2004). In the late 1960's to late seventies researchers like Talling, (1966), and Moss (1979) found nitrogen to be a limiting factor in many African lakes e.g. lakes Victoria, George, Uganda and Malawi. However, recent studies have shown that nitrogen levels have increased around the edges of Lake Victoria since the1960's (Rabi, 1996 and Talling & Lemoalle, 1996)

Robarts (1981) suggested that P: N ratios in the range of 1: 4 to 1: 5 and 1: 2 in North American and Zimbabwean sewage effluent respectively would produce systems that were nitrogen limited. This limitation could however be overcome by large populations of nitrogen – fixing blue green algae, such as *Cylindrospermopsis raciborskii*, which occurs in a wide range of lakes reservoirs and tropical rivers (Isvanovics et. al., 2000). These blue green algae would dominate in waters where nitrogen is a limiting factor.

However, if sewage addition continued the nitrogen levels would become too high, thus inhibiting nitrogen fixation and allowing growth of other algal species.

Algal bioassay studies by Robarts & co-workers (1974 and 1975) at the University of Zimbabwe using pure cultures of *Selenastrum capricornutum*, an alga not found in Lake Chivero and natural communities, mainly of *Microcystis aeruginosa*, led Robarts & co-workers (1974 and 1975) to conclude that nitrogen could be the potential primary limitation to algal growth whilst phosphorus could have been a secondary limiting factor.

1.3.2 Phosphorus

Phosphorus is a natural element found in rocks, soils and organic material. It clings tightly to soil particles and so its concentration in clean waters is generally very low making it a limiting factor for the growth of aquatic plants in such waters. However, phosphorus is used extensively in fertilizers and other chemicals like detergents and insecticides resulting in it being found in high concentrations in the soils of areas of intense human activity like urban areas and rural areas.

Phosphorus exists in water in solid form in the form of living and dead plankton and nekton, precipitates, phosphorus adsorbed to particles or amorphous phosphorus. It also exists in solution as organic or inorganic phosphates (PO_4^{-3}). The organic phosphates are bound to compounds in plant, animal tissue or organic pesticides. The inorganic phosphates are in the form of orthophosphates i.e. reactive phosphates, the form used by plants which is common in sewage and polyphosphates i.e. metaphosphates and condensed phosphates which are strong complexing agents for some metal ions.

Polyphosphates are used for treating boiler waters and in detergents and are unstable in aqueous solution eventually converting to orthophosphates. The acidification of soils and the water body enhances the conversion of polyphosphates to orthophosphate, particularly through acid rain (Bindler et al., 2002).

According to Sharpley et. al. (2003) the intensification of livestock and crop production has resulted in a build up of phosphorus levels in soils and because the phosphorus levels are above the needs of crops, surface run off is fed with a lot of phosphorus. Irrigation on these farms accelerates leaching of nutrients into water bodies. Phosphorus is exported to streams and water reservoirs mainly through surface runoff and to a limited extent through subsurface flow in most watersheds. Loss through leaching and subsurface flow can however be quite high in areas with sandy, acidic, organic or peaty soils (Schindler, 2003).

Studies in the Experimental Lakes Area (ELA) in Ontario in Canada (1973) showed that phosphorus is the major cause of eutrophication in fresh water bodies since aquatic organisms can get enough carbon from diffusion of carbon dioxide into the water from the atmosphere. Mason (1981) suggested that phosphorus is a limiting nutrient for the growth of plants in most freshwater systems and so inputs of phosphorus in the form of phosphate ions result in an increase in biological activity. Yin & Harrison (2004) reported that low phosphorus levels were responsible for controlling eutrophication in the Pearl River Estuary in spite of the high nitrogen loads.

Marshall & Falconer (1973) identified phosphorus as the major nutrient responsible for eutrophication in lake Chivero and Robarts & Southal (1977) concurred. Reactive phosphorus concentrations followed the order of the trophic states of lake Chivero and Darwendale Dam (Thornton, 1980) signifying the crucial role of phosphorus in eutrophication. Robarts (1981) noted that P: N ratios in the range of 1:15 to 1:30 measured in North American aquatic ecosystems would lead to algal growth being limited by phosphorus availability. According to Magadza (2003) Lake Chivero, based on total phosphorus levels, and compared to South African standards for reservoirs had been in a hyper eutrophic state from 1988 to 2002.

Phosphates are not toxic to humans and animals unless present in high concentrations, which might cause digestive problems. Phosphate levels greater than 1.0 mg/L may interfere with flocculation in water treatment plants resulting in organic particles that harbour microorganisms not being completely removed during treatment of water (Murphy, 2002). The EPA has made the following recommendations to enable the control of eutrophication due to phosphorus: total reactive phosphate should not exceed 0.05 mg/L in a stream at a point where it enters a lake or reservoir, and should not exceed 0.1 mg/L in streams that do not discharge directly into lakes or reservoirs (Muller and Helsel, 1999). According to Muller and Helsel (1999) some scientists have classified the trophic status of water bodies according to phosphorus concentration. Lakes with total phosphorus concentrations less than 0.010 mg/L are classified as oligotrophic, those with phosphorus concentrations between 0.010 and 0.020 mg/L are classified as mesotrophic lakes, and eutrophic lakes have phosphorus concentrations exceeding 0.020 mg/L.

1.4 PHOSPHORUS AND NITROGEN LOADINGS

Sources of phosphorous and nitrogen are domestic sewage, industrial wastes and storm drainage (Marshall & Falconer 1973). Thornton and Nduku (1981), Mason (1996}, Magadza (1997 and 2003), Odada et. al. (2004), Mathuthu et. al. (1997) and Zaranyika (1997) reported high levels of phosphorus and nitrogen from sewage water dumped into rivers entering Lake Chivero. Marshall & Falconer (1973) identified municipal wastewater and soil leachates from landfills as the main sources of phosphorus in Lake Chivero.

Nduku ((1976) suggested that the organic matter that was accumulating in Lake Chivero was coming from sewage effluent, phytoplankton, zooplankton and dead worms as well as terrestrial litter washed into the lake by rainstorms or blown by the wind in autumn. Litter and garbage dumped onto streets by urban dwellers in the form of fruit peels and seeds, mealie cob leaves and cobs, papers, cigarette stubs, pieces of cloth, debris left after chewing sugar cane, vegetable wastes and rotting food. Some humans in urban areas urinate along roadsides, on the road and on tree bases. Dogs deposit their faeces anywhere. Oils from vehicles spilt on road surfaces or repair and backyard workshops are also washed into storm drains. A survey of 100 storm drains in Santiago showed that there was hardly $1m^2$ along the Yaque del Norte River in the Dominican Republic that did not contain at least 10 pieces of plastic paper, animal waste, cans, rotting vegetation, oil cans, and petroleum containers (Witter, 1994) as cited by Witter and Carrasco (1996).

During the rainy season these materials are washed into storm drains and finally into water reservoirs, thus increasing phosphorus, nitrogen and carbon loadings into dams (Thornton & Nduku, 1981). In urban areas the effect of washing nutrients into dams by running water is worsened by the fact that most urban centres are upstream of the dams that they abstract their water from and therefore the water in such dams is heavily polluted e.g. Lake Chivero in Zimbabwe (Magadza, 2003).

Studies by Thornton and Nduku (1981) revealed ratios of total P: N in storm water in the ranges of 1:6 to 1:35, which were lower than those of sewage water. Their studies also showed that industrial catchments released water with higher nutrient concentrations than residential and commercial ones in both Zimbabwe and outside the country. Runoff from urban and industrial catchments in Southern Africa and the U.S.A. in 1981, contained higher SRP and total N levels than in the U.K., but the U.K. had higher ratios of P: N than the former because the U.K water was heavily influenced by domestic waste water.

Jarawaza (1997) identified industrial pollution as a major concern in the deterioration of water quality in the Manyame basin, Zimbabwe. Zaranyika (1997) reported that studies by Mathuthu et al. (1993) had shown that the ZIMPHOS fertiliser plant in Zimbabwe was a source of pollutants such as nitrates, phosphates, chlorides, potassium, calcium and trace heavy metals like Pb, Cr, Cu, Zn, Ni, Co and Fe. Some air pollutants from the fertilizer companies, burning fossil fuels, metal production and exhaust gases from vehicles such as SO_2 and NO_2 (Bindler et al., 2002) form acid rain. The acid rain falls onto soils and increases the solubility of cations such as Ca^{2+}, Mg^{2+}, K^+ and Na^+ as well as phosphates and nitrates, thus increasing their movement into water bodies through leaching and resulting in the release of phosphorus from sediments.

Food processing industries and soap making industries release organic wastes that increase B.O.D. in water. Breweries and sugar factories have been found to contribute a lot of organic matter in Uganda's water systems (Centre For Environment Information and Knowledge in Africa, 1996). Abattoirs and the pulp and paper industries are another major source of organic nutrients.

Thornton and Nduku (1981) found out that industrial and urban areas released water with higher nutrient concentrations than undeveloped areas with pristine forests and that fertilizer applications by commercial and rural farmers resulted in higher loads of N and P. Thornton (1980) suggested that the expansion of Chitungwiza urban area had caused a increase in total nitrogen and phosphorus of Lake Chivero through increased loading from diffuse sources.

A substantial amount of nutrients is derived from run-off from farming areas and recreational parks (Nduku, 1976). According to Havens et al. (1996) cattle and dairy farms imported over 5400 tonnes of P yr^{-1} into the watershed of Lake Okeechobee, Florida USA, as feed and fertilizer, exported 1400 tonnes of P yr^{-1} in the form of milk, timber, cattle and other agricultural products with 500 tonnes of P yr^{-1} entering the lake and the rest accumulating in the watershed. The dung of cattle, sheep and goats contains organic matter and their urine is rich in nitrogenous compounds like ammonia and urea.

Water used to clean pigsties is rich in organic matter and urine that end up in rivers. Chicken droppings are rich in phosphorus and nitrogenous compounds and these materials can be carried into water bodies through run-off and seepage. According to Ingerstad (1977) most of the nutrients added as fertiliser are in soluble form and the excess nutrients leach into watercourses and reservoirs, particularly in humid areas Irrigation on these farms accelerates leaching of nutrients into water bodies.

Farmers use pesticides in the form of organochlorides, carbamates and organophosphates. The organochlorides are toxic, persistent and bioaccumulate. The organophosphates are insecticides, which are rapidly degraded (Allan, 1991) and release phosphorus (Murphy, 2002), which also gets into water bodies through agricultural runoff. The carbamates are organic compounds that decompose quickly in both soil and the water. The decomposition of both organochlorides and carbamates requires oxygen. Some of the pesticides and herbicides enter water bodies mixed with rainwater, since during spraying some of them find their way into the atmosphere. Thornton (1979) showed that summer phosphorus loadings into Lake Chivero accounted for over 80% of the annual loading. Vollenweider (1974) as cited by Water on Web. Student Lessons (2004) proposed that the deeper a lake is the less eutrophic it will be. He also plotted loading rates of hundreds of temperate lakes against their mean depths and then visually drew lines to separate the lakes into oligotrophic, mesotrophic and eutrophic as shown in Fig.2.

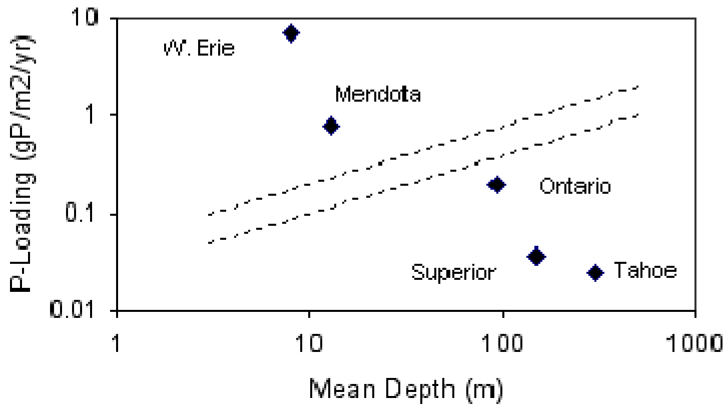


Fig 1: Vollenweider plot for temperate lakes
Adapted from Water on Web

According to Thornton (1980), Toerien (1977) produced a modified Vollenweider plot to several Southern African impoundments. Thornton suggested that when comparing loadings, it might be better to use phosphorus loading per unit area of lake as proposed by Vollenweider & Dillon (1974) or phosphorus loading per unit volume of lake as these expressions took the morphology of a lake into consideration.

1.5 FATE OF NUTRIENTS IN LAKES/ DAMS

Marshall & Falconer (1973) found out that about 54 metric tonnes of phosphorus were removed from solution in the water body from lake Chivero and they suggested that algal blooms might be responsible for phosphorus removal from water, but this biological removal was minimum compared to abiological removal (precipitation). Studies on phosphorus loadings into Lake Chivero and Darwendale Dam, downstream of Lake Chivero by Thornton (1980) showed that 46% of phosphorus entering Lake Chivero was retained whilst 82% from the lake was going into

Darwendale Dam. Nduku (1976) concluded that sediments were acting as a sink for phosphorus, nitrogen and organic matter in Darwendale Dam.

Nduku (1976) suggested that low oxygen levels and a low Ph at the mud – water interface led to a tremendous release of NH_4- N and PO_4 -P from sediments. According to (Elder & Robertson, 1999) the resolubilisation of orthophosphate from phosphate bound to sediments in water bodies takes place by the reduction of insoluble ferric ions. Nduku (1976) further suggested that when the NH_4- N and PO_4 –P reached oxygenated waters the NH_4- N was oxidized to NH_3- N whilst the PO_4 –P combined with Fe^{3+}, Mn^{2+}, $Ca^{2+}$and clay particles that formed insoluble precipitates.

Water residence time i.e. the average length of time that a water molecule will remain in a reservoir (Bice, 2004) is calculated using the formula; amount of water in reservoir/ inflow rate or outflow rate. According to this equation the higher the inflow or outflow rate the lower the residence time.

Schaffner & Oglesby (1977) cited by Thornton (1980) reported that 30 to 40% of phosphorus retention occurred in temperate lakes with a water residence time of less than one year and 75 to 90% retention occurred when water residence time was more than one year. Dillon (1975) cited by Thornton (1980) suggested that lakes with a water residence time of less than 0.5 years had a washout of phosphorus. Thornton (1980) concurred with the above-mentioned workers and concluded that John Mack

Lake had low phosphorus retention of 11%, because of a low residence time due to high inflow or high outflow rates that resulted in wash outs of phosphorus.

1.6 THE ROLE OF TURNOVER ON NUTRIENT DYNAMICS IN LAKES/DAMS

Nduku (1976) suggested that turnover caused the tremendous release of the nutrients NH_4- N and PO_4 –P from the hypolimnion into the epilimnion. However the high oxygen levels in the epilimnion would cause the oxidation of NH_4- N to NO_3- N and the precipitation of PO_4 –P, which would sink into the sediments in the hypolimnion. These reactions explain the presence of high levels of NO_3- N in the euphotic zone where NO_3- N would be expected to be low due to uptake by phytoplankton.

1.7 CURRENT SCOPE OF RESEARCH ON ZIMBABWEAN LAKES/ DAMS

A lot of research has been done on large lakes like Chivero, which supplies water to Harare, the capital city of Zimbabwe, by Nduku, Thornton, Magadza, Marshall, Moyo, Zaranyika (1997) and many others. A lot of work has also been done on Lake Kariba, the third largest man made lake in Africa through the Lake Kariba Research Station. Some work has been done on the Mazoe and Mwenje Dams (Marshal et al., 1971) as cited by Marshall & Falconer (1973) and Darwendale and John Mack Dams

(Thornton, 1980). Most research on dams seems to have been done on the large dams in Zimbabwe. Literature on studies done on small dams, constructed after independence to serve small towns and growth points could not be found.

1.8 FACTORS AGGRAVATING THE PROBLEMS OF WATER SHORTAGE AND POLLUTION.

Generally the root causes of the problems of water shortage and pollution are mainly institutional failure, poverty, population growth, habitat modification, overexploitation of land, particularly in rural areas, lack of investment planning and priorities, lack of adequate facilities for collection of wastes and sewage treatment and the lack of education and awareness (Belausteguigoitia (2004) as well as overcrowding in communal areas (WRMS technical Secretariat, 1995).

The fluid nature of water creates problems of ownership. As a result the old belief was that water was common property and this resulted in water resources falling prey to the "tragedy of the commons" (Hardin, 1968). Poverty has been a major catalyst in the escalation of the problems of overexploitation of natural resources such as land through stream bank cultivation in urban areas, illegal clearance of forests for fuel wood and gold panning along rivers, thus fuelling siltation of both rivers and dams in Zimbabwe.

The ever-increasing population growth in urban areas (Table 1) has not been matched with improvements and growth in wastewater treatment facilities that has forced municipalities to dump raw sewage into streams due to bursting of the overloaded pipes. The large population growth has seen an increase in garbage that is seen piled up in the streets because the municipalities cannot cope and this garbage is carried to water bodies by storm drainage during the rainy season.

The population growth has lead to habitat modification through clearance of vegetation to create land for construction of housing and industrial development and illegal cultivation, harvesting of trees for use as building materials, furniture crafting and fuel wood.

Table 1. Zimbabwe Urban demographic data for 1982, 1992& 2004 (10^3)

Place	Pop. 1982 (10^3)	Pop. 1992 (10^3)	Pop. 2004 (10^3)
Harare	656. 0	1189. 1	1976. 4
Bulawayo	413.8	621. 7	1003. 7
Chitungwiza	172.6	274. 9	423. 8
Mutare	69.6	131. 4	195. 3
Gweru	78. 9	128. 0	157. 5
Kadoma	44. 6	67. 8	110. 3
Masvingo	30.5	51. 7	83. 3
Kwekwe	47 .6	75. 4	81. 5
Marondera	19. 8	39. 4	102.869
Karoi	8. 7	14. 8	20. 9

Pop = population *Adapted from The world Gazetteer (2004).*

1.9 PAMOLARE SOFTWARE PACKAGE AS A MODELLING TOOL FOR THE MANAGEMENT OF EUTROPHICATION

The acronym PAMOLARE is derived from the phrase Planning and Management of Lakes and Reservoirs focusing on Eutrophication. The software package PAMOLARE was developed for use in management of eutrophication in lakes and reservoirs in developing countries and countries with economies in transition like Zimbabwe. The package consists of (a) a 1-layer model with four state variables namely; phosphorus/nitrogen (i) in water, (ii) in sediments, (iii) loading and (iv) release, and several additional parameters, (b) a 2-layer model which is a medium complex model with more state variables than the 1-layer model, (c) a Structurally Dynamic 2-layer model (SDM) that uses energy to simulate the structural dynamics of zooplankton and phytoplankton and (d) a loading model that requires data on daily temperatures, precipitation and light intensity, municipal waste water, industrial waste water, rural area fertilizer use, and concentrations of phosphorus and nitrogen in rainwater.

The choice of the model depends on the information available and the experience of the decision maker. Inexperienced decision makers are advised to start with the 1-layer model and then the 2- layer model. The models in PAMOLARE however have some limitations, such as inability to predict the position of the thermocline, the impractical assumption that inflow and outflow volumes remain constant and inability of the models to handle further hydrodynamic analyses of the reservoirs (PAMOLARE Help section).

A mathematical model in the environmental sciences consists of external variables, state variables, mathematical equations, parameters and universal constants. The inputs of nutrients, especially phosphorus and nitrogen are the external variables in the modelling of eutrophication. The model in PAMOLARE uses equations, which describe the relationships between the control variables and the state variables. The state variables are the concentrations of nutrients and phytoplankton, and these are predicted by changing the external variables.

Modelling with PAMOLARE has not been done on Zimbabwean dams.

1.10 THE STUDY SITE

1. 10. 1 General description

Rufaro dam is a small dam, which is part of the upper watershed of the Mazowe catchment. It is located along the Nyambuya River, about 5.5 km north of Marondera town (fig.1). Rufaro dam supplies water to the growing Marondera town, whose population has grown from 19 800 in 1982 to 102 869 2004 (The World Gazetteer& Marondera Municipality, 2004). Marondera draws water from two other small dams, but the Rufaro dam source is the cheapest in terms of pumping because it is the nearest.

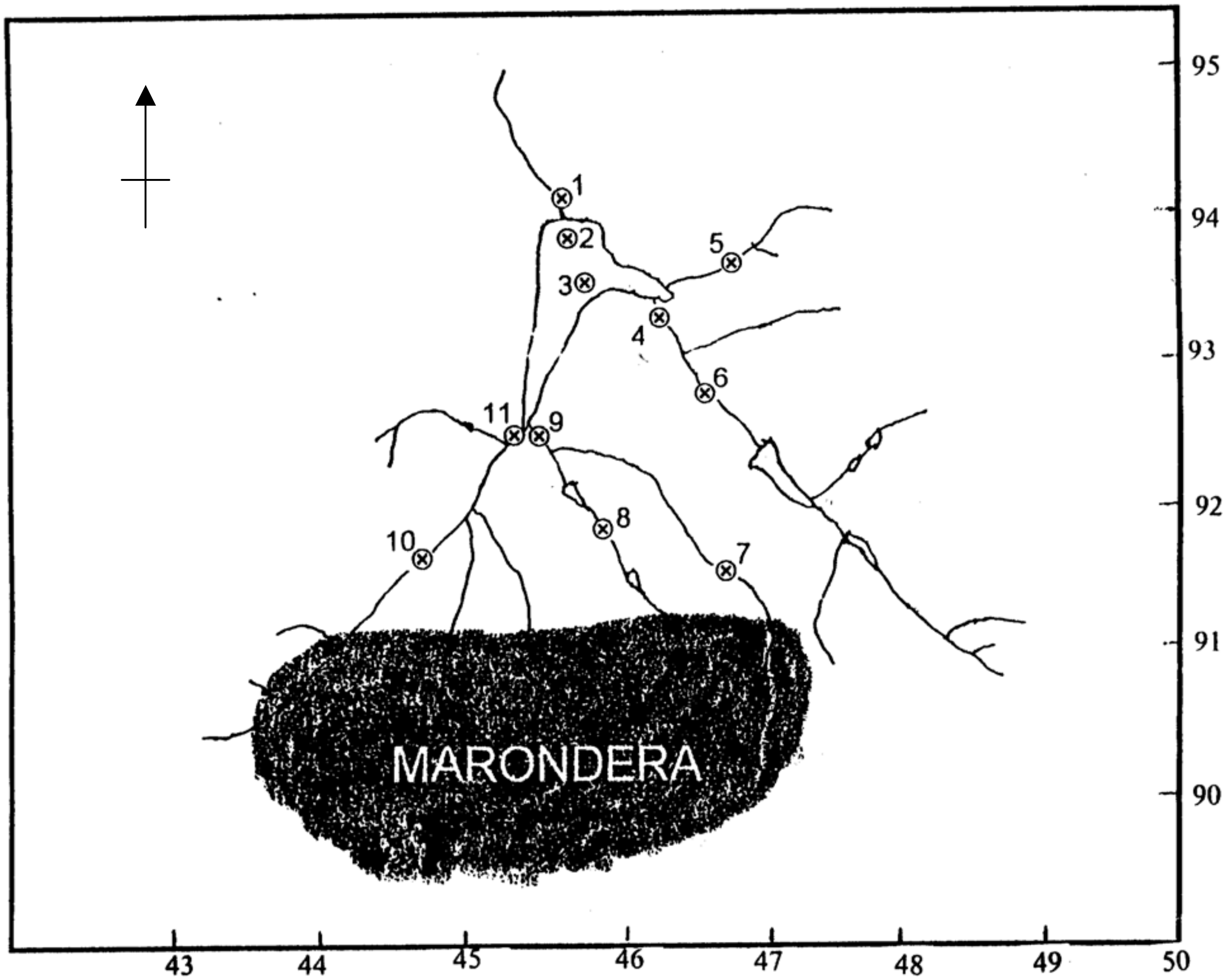
The dam is also a recreational area where families, friends and business executives go picnicking. Couples also have wedding photos taken there. It is also a habitat for birds such as the red and black storks, in November and December, if the rainy season delays as well as water ducks. Locals catch fish from the dam and these are a rich source of protein.

Rufaro dam receives water from (1) Nyambuya River, whose catchment is mainly commercial farming land, (2) storm drainage from the town centre, industrial area which is composed hardware shops, municipal water works, C.ME.D depot, general wholesalers, a few small scale soap and floor polish making industries, motor vehicle repairs, Chibuku breweries, the Cold Storage Commission abattoir, which closed in 1995 and reopened in June 2004 and the Dombotombo high density suburb, and (3) sewage ponds. During the dry season most of the inflow to the dam comprises of episodic flow from the sewage ponds and storm drain water from the waterworks, residential areas and industries with very little flow from Nyambuya River because of smaller dams upstream, which are used by commercial farmers. In November/ December, 2003 the funnel shaped spillway was not spilling and was exposed, lying on a dry bed, a sign of looming severe water shortage, if it does not rain. No fish deaths or weed problems have been reported so far, but a survey of the dam is needed in order to implement sound management policies.

1.10.2 Hydrological data for Rufaro Dam, Marondera

Table 2: Selected Hydrological Data for Rufaro Dam, Marondera

Location (lat)	18^0 S
(Long)	31^0 N
Year constructed	1985
Catchment Geology	Granite
Catchment land use	urban and commercial farming
Catchment area (10^6 m^2)	30.65
Surface area [Full supply level] (10^6 m^2)	0.81
Total capacity [Full supply level] (10^6 m^3)	5.25
Dead storage (10^6 m^3)	0.71
Live storage(10^6 m^3)	5.179
Maximum depth of water (m^3)	21
Net yield at 10% risk (m^3)	0.063
Net yield at 4% risk (m^3)	0.052
Mean annual rainfall for catchment (mm)	919.5



SCALE. 1: 50 000

Fig 2: Dam site and sampling sites
1= outlet, 2= dam wall, 3= intake tower, 4= Nyambuya river downstream, 5= Nyambuya river tributary, 6= Nyambuya river upstream, 7= Dombotombo storm drain, 8= CSC stream, 9= Main storm drain down stream, 10= sewage stream upstream, 11= sewage stream upstream

1.11 JUSTIFICATION OF STUDY

A study of Rufaro dam is essential because:

1. It is the major source of drinking water for the population of Marondera town, which is about 102.869 (The World Gazetteer 2004).

2. It supplies irrigation water to five farms around Marondera.

3. The dam used to supply water to the Cold Storage Commission Abattoir, which used to export beef to the European Union

4. The dam is part of the upstream catchment of the Mazoe Dam.

5. Since 1999 there have been epidemics of diarrhoeal diseases, especially soon after the first rains, which the residents suspected were linked to the drinking water quality. Complaints from residents of Marondera suggest that the water from the dam itself could be heavily polluted, because of (a) the brownish colour, (b) brown sediments and (c) the undesirable smell and colour of the tap water.

6. So far no detailed study has been done on small dams with both urban and rural catchments, constructed after independence to serve small towns and growth points and so information from this study could be used as an indicator of what could be happening in small dams with similar catchments.

CHAPTER 2

2 MATERIALS AND METHODS

2.1 RESEARCH QUESTIONS

The study attempted to answer the following questions:

Is Rufaro dam eutrophic?

If it is eutrophic, what are the major sources of nutrients?

What changes are expected to occur in the dam in the next 20 years if current conditions persist?

What would be the impact of doubling the population on the trophic status of the dam?

What impact would global climate change have on the trophic status of the dam?

Which practical management options may be implemented in order to improve the situation in the dam, considering the current macroclimate?

2.2 WORKING HYPOTHESES

1. H_o = There are no differences in the physical and chemical features of water in the different inflows and the dam.
2. H_o = The dumping of sewage effluent into the dam has no effect on the trophic status of the dam.
3. H_o = The dates of taking water samples have no effect on the physico-chemical characteristics of water in both the dam and the inflows.
4. H_o = Doubling the population and a decrease in precipitation due to global climate change would have no effect on the trophic status of the dam.

2.3 SAMPLING

2.3.1 Sampling times and methods

Three samples were collected per site per month at the beginning of November and December in 2003 and January, February, March and April in 2004. This would cater for replication. The randomisation was intrinsic to water because of its high fluidity and in the collection points, which were within 10m radius from the entry point of the streams into the dam and were selected depending on accessibility.

Water and mud samples from the river and stream were collected manually and water samples from the dam were collected using a water sampler whilst mud samples were collected using a mud grabber. From the dam samples were collected from the surface up to the deepest point at 1m intervals to capture as much information as possible. The samples at different depths were then mixed to produce an integrated sample whose parameters would be used for modelling purposes.

2.3.2 Sampling sites

Fig. 2 shows the location of the sampling sites. Samples of water and mud were collected from:

(i) where the main river and each of the two streams enters the dam (site No.'s 4, 9, & 11) within a distance of 10m from the dam because the fast flow of water does not cause a significant change in water quality over 10m,

(ii) the deepest part of the main dam i.e. near the dam wall site (No. 2) (maximum depth 15 m before the current rainy season and 21m at full capacity) and the intake tower site (No. 3) (maximum depth 6 m before the current rainy season and 8m at full capacity),

(iii) the outlet valve site (No. 1) that lets out water from the deepest part of the dam for irrigation, with no samples being collected from the spillway because the dam never spilled,

(iv) other samples were collected within 10m from (a) the sewage ponds (site No. 10, fig 1) since this is a point source off nutrients (b) where the stream from storm drains leaves Dombotombo township (site No. 7, fig 1) (c) the stream from the industrial area which passes through the Cold storage Commission abattoir that was closed in, 1995 (site No. 8, fig 1) and (d) where the Nyambuya river leaves the first small impoundment upstream of the dam (site No. 6, Fig. 1) and these areas were sampled during the rainy season i.e. January to April, when flow rates and the capacity of the river and the streams to carry nutrients would be high and

(v) the control samples that were taken from the tributary of the Nyambuya River (site No. 5).

2.4 CHEMICAL ANALYSES

2.4.1 Water Analyses

Chemical analyses of water samples were done at the University of Zimbabwe Hydrobiology Laboratory in the Biological Sciences Department using the DR Spectrophotometer Procedural Manual.

Reactive phosphorous was analysed by the Ascorbic acid method and the total phosphorous by the Acid Persulfate digestion method. Total nitrogen was determined by the Acid Persulfate digestion method.

Dissolved oxygen, conductivity, temperature, turbidity, pH, total dissolved solids (TDS), nitrates, chlorides, calcium and ORP were measured on site, using the Horiba U23 water quality monitoring instrument.

Flow rates were obtained from the ZNWA flow gauges on the streams.

The loadings were calculated using the formula; flow rate in (L per month)* concentration of nutrient/surface area of dam.

2.4.2 Sediment analyses

Sediments were dried in an oven maintained at temperatures between 30 and 45^{0}C to prevent loss of NH_4-N (Nduku, 1976). They were analysed for total nitrogen and total phosphorus at Grasslands Research Station in Marondera using the ammonium molybdate-ascorbic acid method for total P and the Kjeldahl method for total N (Nduku, 1976).

2.5 Statistical Analyses

The statistical analyses done on the data collected were (a) one-way ANOVA for sites and time (b) sample t- tests to compare (i) conductivity, DO, reactive phosphorus, total nitrogen and phosphorus between the dam wall and the outlet, (ii) the nitrate concentrations in the storm drains and the rivers (c) Principal Component Analysis of all sites including the control site to find out which sites have almost similar characteristics and (d) Discriminant Analysis to confirm the PCA groups and as an aid to the management of eutrophication.

2.6 MODELLING

Modelling with program PAMOLARE described in the introduction chapter 1.9, using the one- layer model of the dam was done to predict the situation in the dam over the next 20 years (a) under the current conditions (b) with the population doubled (c) with the precipitation reduced by 6.2% as predicted using the model SCENGEN and scenario SRES 1980 AI, (d) with the BNR installed as this is being constructed in the town and (e) with the storm drain water diverted to the BNR.The modelling would help in finding the most suitable solutions to managing eutrophication within the dam.

The formulae used to calculate the variables required for modelling were taken from the help section of the programme PAMOLARE. Default values were used for the values of a, P + N release, P + N bound and denitrification.

It was assumed that if the precipitation had changed by -6.2% the water residence time would increase by +6.2%.

If use of the BNR was effected it was assumed that the nutrient level would be reduced by about 50% i. e. 85% efficiency of the BNR (Mosby, 1995) subtract the 35% of sewage ponds since the sewage effluent is currently passing through stabilization ponds, which are assumed to reduce nutrient concentration by 35% (Mosby, 1995).

CHAPTER 3

3 RESULTS

3.1 MORPHOMETRIC AND CHEMICAL PARAMETERS

The minimum depth at the intake tower was 6m in December and the maximum depth was 8m in April. The minimum depth at the dam wall site was 15m in December and the maximum depth was 20m in April, which was 1m less than the depth at maximum capacity. The minimum secchi depth at both sites was 0.5m in November and December and the maximum secchi depth was 0.75m in April and both values were below the EPA value of 1.23m, implying a very low light penetration.

The dam water was on average alkaline at the intake tower (8.15) and acidic at the dam wall (6.66). The DO at the dam wall site (Fig 4) was much lower than that at the intake tower over the whole sampling period (Fig 3) ($t = 8.6$, $p= 0$). The conductivity at the intake tower was also higher than that at the dam wall site ($t = -10.8$, $p = 0$). The average ratio of total N to total P in the water was 1:2.

At the intake tower where domestic water is extracted from the Ph, temperature, nitrate and chloride levels were within EPA standards for reservoirs (Appendix E), but the turbidity, total nitrogen and phosphorus levels were above EPA standards for reservoirs. At the dam wall the DO was below the recommended EPA levels and the turbidity, chloride, total nitrogen and phosphorus levels were above the EPA recommended levels for reservoirs. Turbidity presented the highest variation with the TDS levels showing the least variation (Tables 3 and 4).

Table 3: Results for samples taken from the Intake tower- con = conductivity, Turb = turbidity, Tot = total, Orth P = reactive phosphorus

Parameter	09-12-03	08-01-04	09-02-04	12-03-04	15-04-04	Mean	St Dev	SE Mean
Con (µS/cm)	276.80	223.30	210.00	191.40	176.7	215.64	2.59	0.67
Ph	8.75	7.47	7.97	8.57	7.97	8.15	0.37	0.09
DO (mg/L)	4.77	6.45	7.76	10.51	11.56	8.21	2.34	0.61
Temp (^{0}C)	23.13	24.00	23.18	22.21	20.24	22.55	1.36	0.35
Turb (mg/L)	2.88	10.00	6.67	1.29	815.56	160.10	320.00	82.9
TDS (g/L)	0.18	0.15	0.14	0.12	0.11	0.14	0.02	0.01
ORP (mV)	22.38	4.83	24.67	70.86	95.11	32.69	40.60	10.50
Cl (mg/L)	3.71	101.03	57.27	146.00	0.38	61.68	58.10	15.00
NO_3 (mg/L)	15.36	16.93	3.35	0.15	3.62	7.88	7.04	1.82
Ca (g/L)	0.00	4.14	7.92	0.61	0.06	2.55	2.50	0.65
Tot N (mg/L)	0.83	3.23	3.40	0.67	1.07	1.84	1.26	0.33
Orth P (mg/L)	0.08	0.22	0.48	0.30	0.28	0.27	0.84	0.31
Tot P (mg/L)	5.60	2.97	0.40	2.20	1.11	2.46	1.94	0.50

Table 4: Results for samples taken from the Dam wall site (deepest point)- con = conductivity, Turb = turbidity, Tot = total, Orth P = reactive phosphorus

Parameter	03-11-03	09-12-03	08-01-04	09-02-04	12-03-04	15-04-04	Mean	St Dev	SE Mean
Con (µS/cm)	232.00	248.20	317.10	258.30	288.0	324.00	277.93	5.00	1.18
Ph	7.80	5.88	6.91	6.59	6.23	6.57	6.66	0.59	0.14
DO (mg/L)	2.20	1.84	2.54	2.82	4.35	6.32	3.35	2.70	0.64
Temp (^{0}C)	21.85	24.12	19.30	20.38	19.54	19.01	20.70	2.00	0.47
Turb (mg/L)	0.11	0.11	48.40	274.85	0.00	56.93	63.36	173.4	40.9
TDS (g/L)	0.07	0.08	0.23	0.22	0.23	0.13	0.16	0.06	0.01
ORP (mV)	48.00	31.50	157.60	61.00	70.93	22.07	49.18	88.00	20.70
Cl (mg/L)	227.50	556.80	216.10	104.60	396.00	0.87	250.31	220.10	1.12
NO_3 (mg/L)	0.86	1.19	14.23	3.50	1.24	3.72	4.12	4.76	1.12
Ca (g/L)	0.69	223.60	13.77	0.10	0.02	0.13	39.72	106.90	25.20
Tot N (mg/L)	2.30	1.97	3.90	3.70	1.87	0.65	2.40	1.15	0.27
Orth P (mg/L)	1.58	1.26	0.31	1.22	0.08	0.05	0.75	0.50	0.08
Tot P(mg/L)	0.91	5.60	2.87	0.91	0.68	0.94	1.99	2.76	0.52

3.2 DEPTH PROFILES OF THE DAM

Generally DO, Ph, and ORP decreased with depth, whilst conductivity increased with depth (Figs 5, 6, 8,11 and 12). At the intake tower (Fig 15), NO_3 levels were uniform in February, March and April, but in December and January they were highest at 0-1m depth.

The temperature depth profiles showed stratification within the dam in December, January and February, which broke down in March up to a depth of 14m Figs (3 & 4). The thermocline was rather unstable and ill defined. The dam wall area displayed NO_3 stratification in January only (Fig.16). There was an unusual kink of cooler, more oxygenated water with lower Ph and chloride levels around 1-2m depth in December (Figs . The kink of higher DO persisted in January and February (Figs 5& 6). In January, February and April the 1-2 m depth column presented kinks of higher Ph (Figs7 & 8) and around 6m depth (Figs 11, 12,13& 14) there was a kink of higher ORP and Cl.

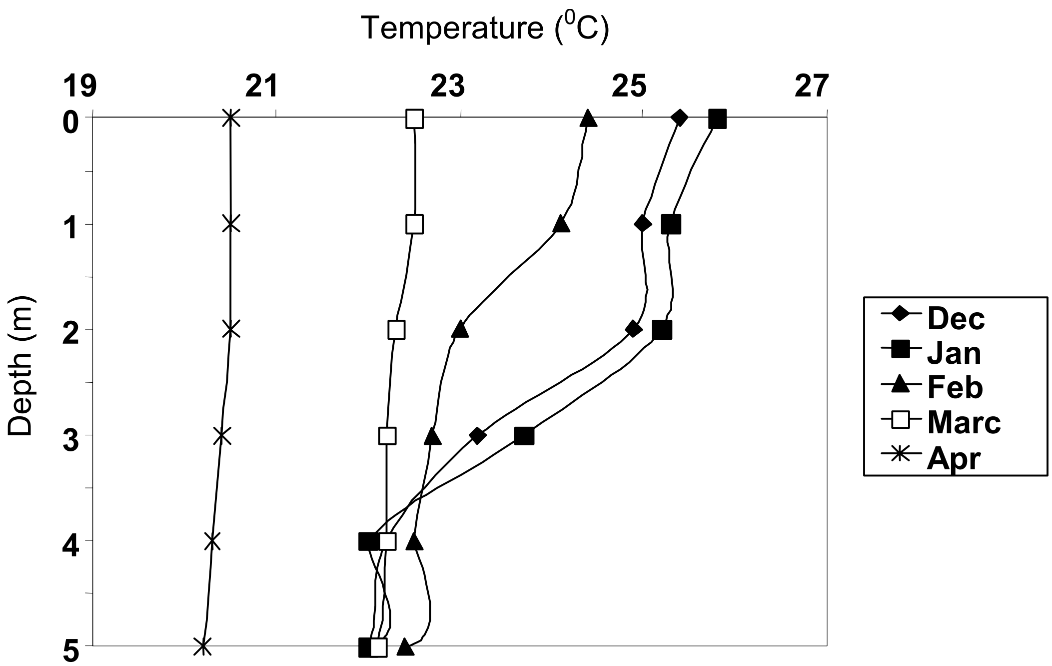


Fig. 3: Temperature profiles at the intake tower

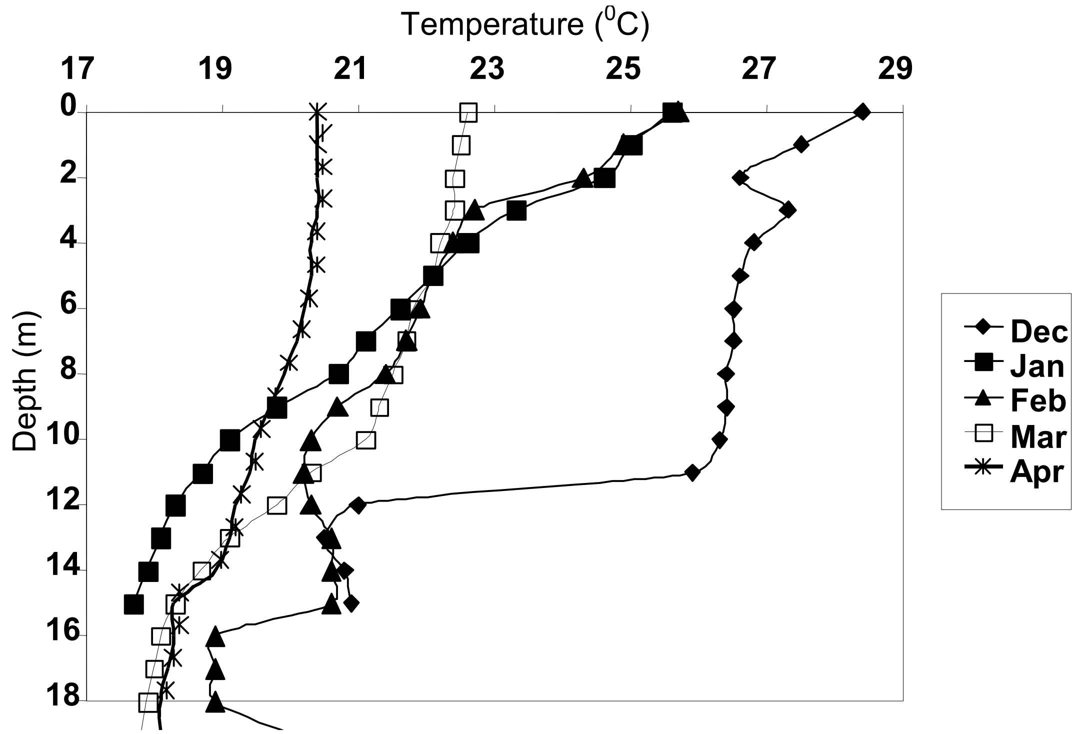


Fig. 4: Temperature profiles at the dam wall

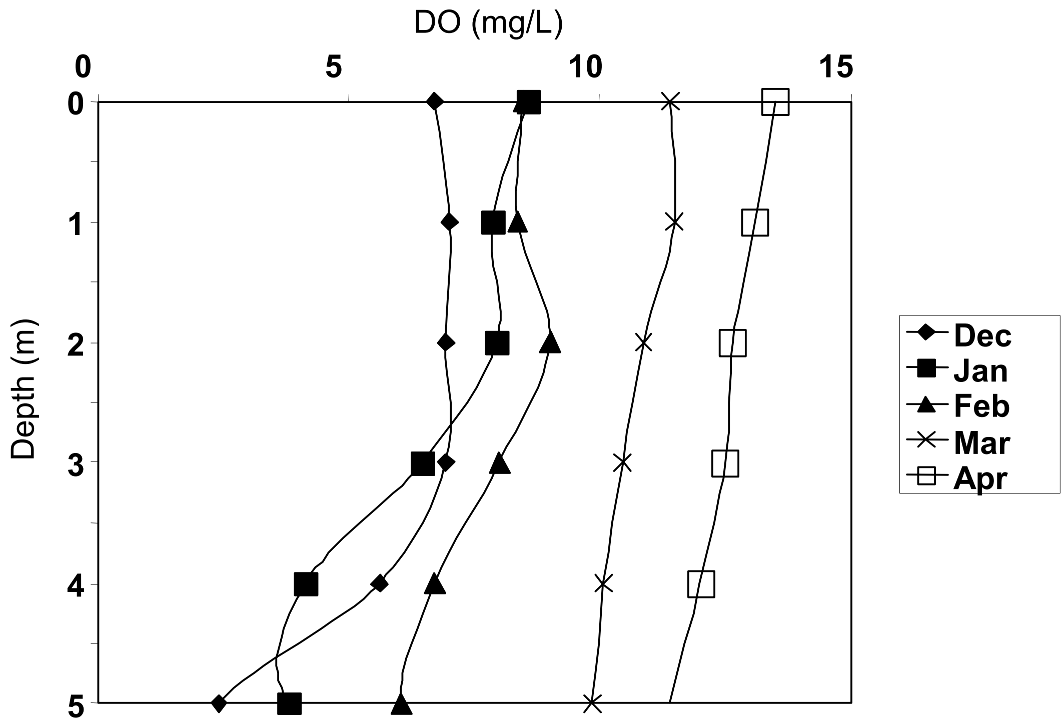


Fig. 5: Dissolved oxygen profiles at the intake tower

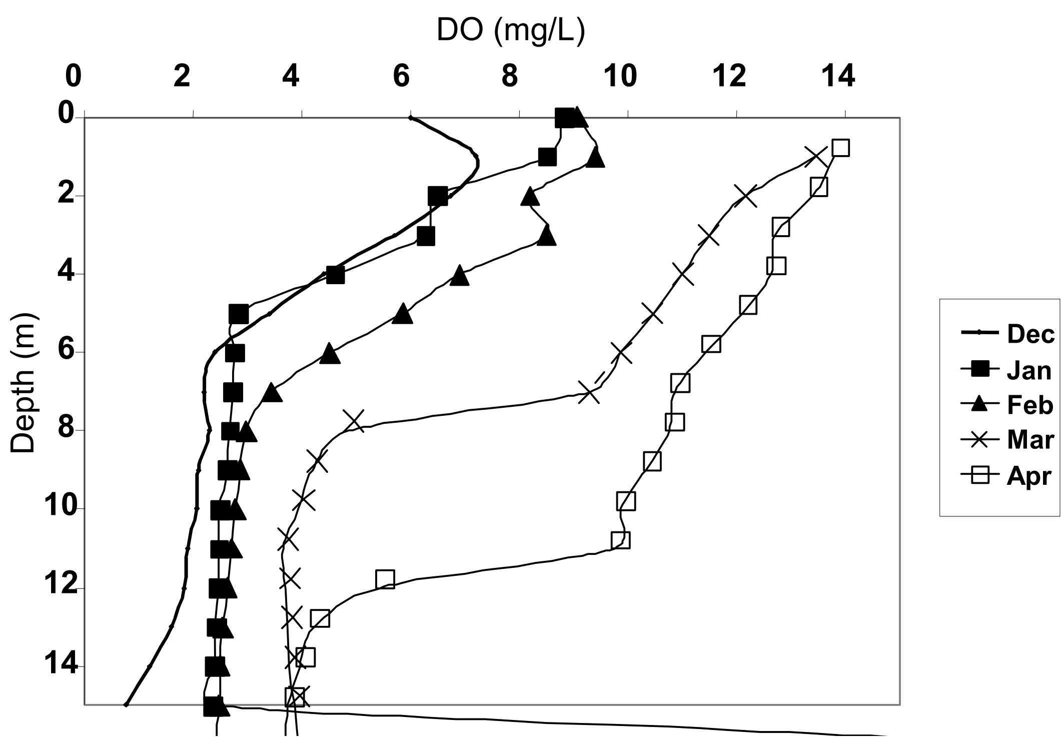


Fig. 6: Dissolved oxygen profiles at the dam wall

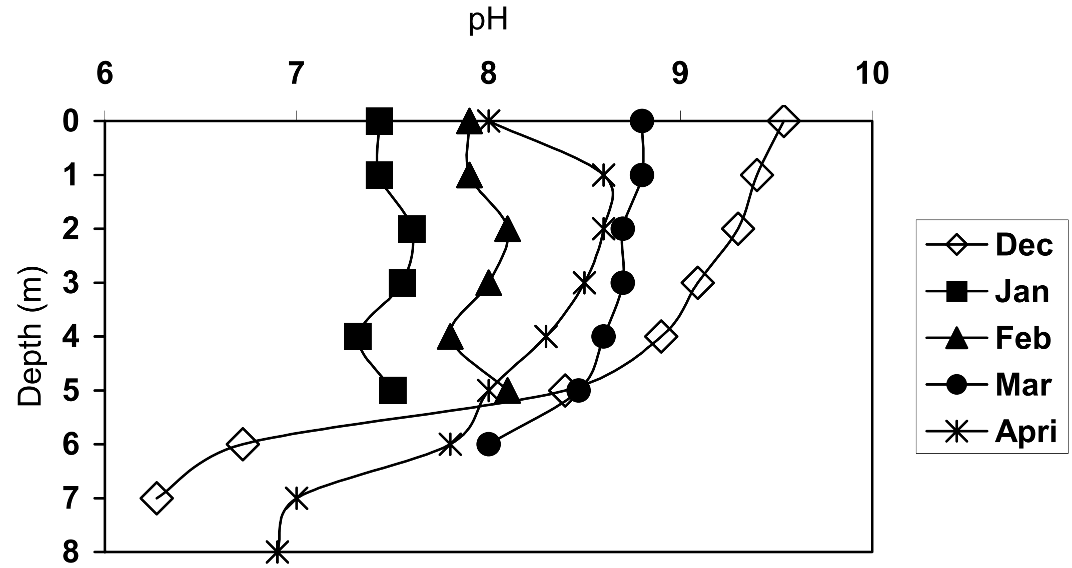


Fig.7: Ph profiles at the intake tower

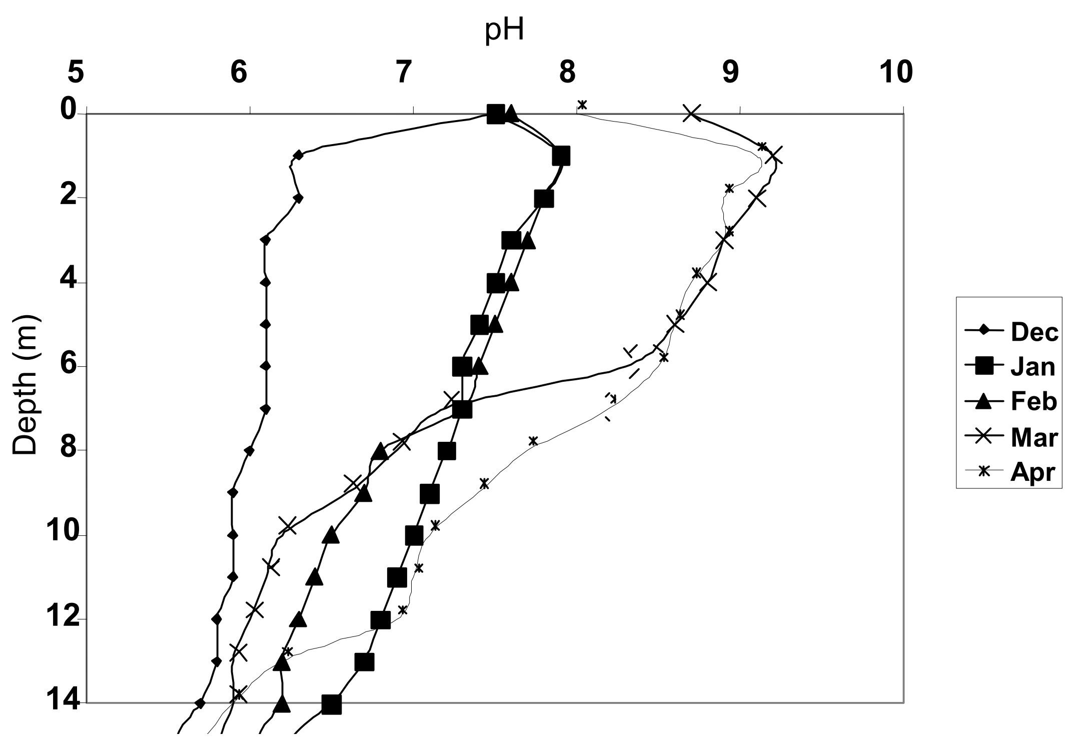


Fig. 8: pH profiles at the dam wall

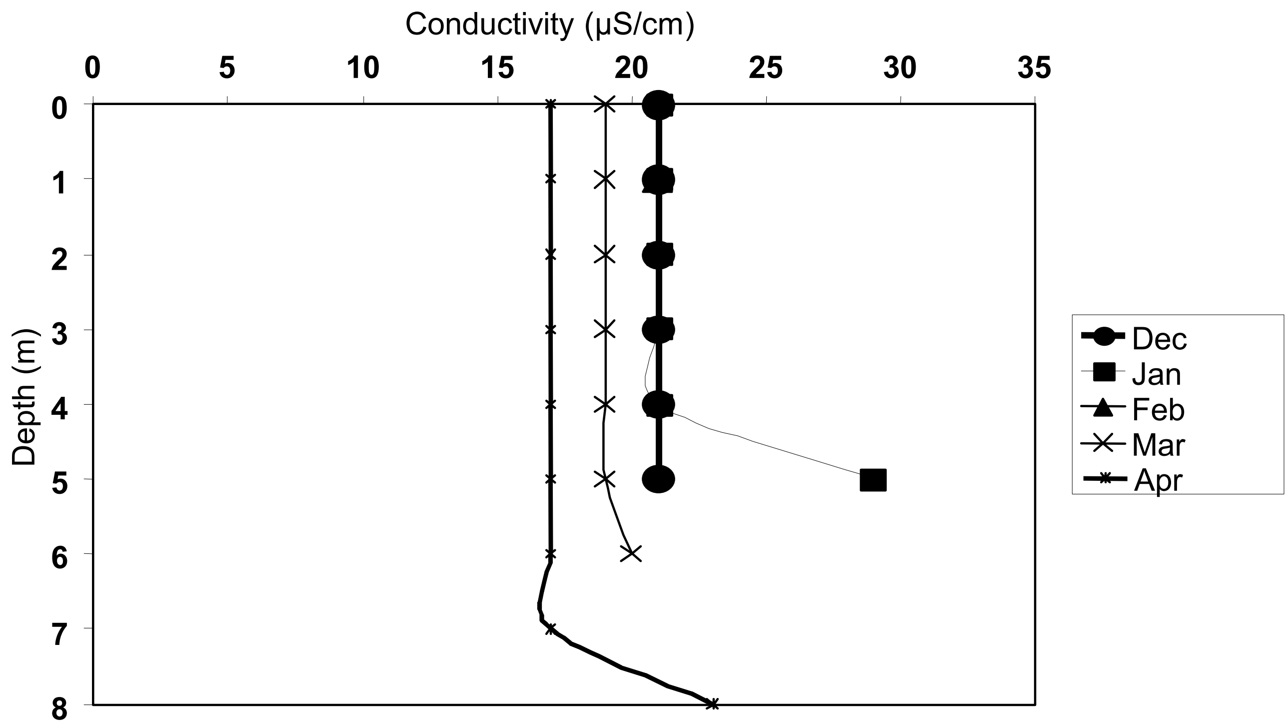


Fig. 9: Conductivity profiles at the intake tower

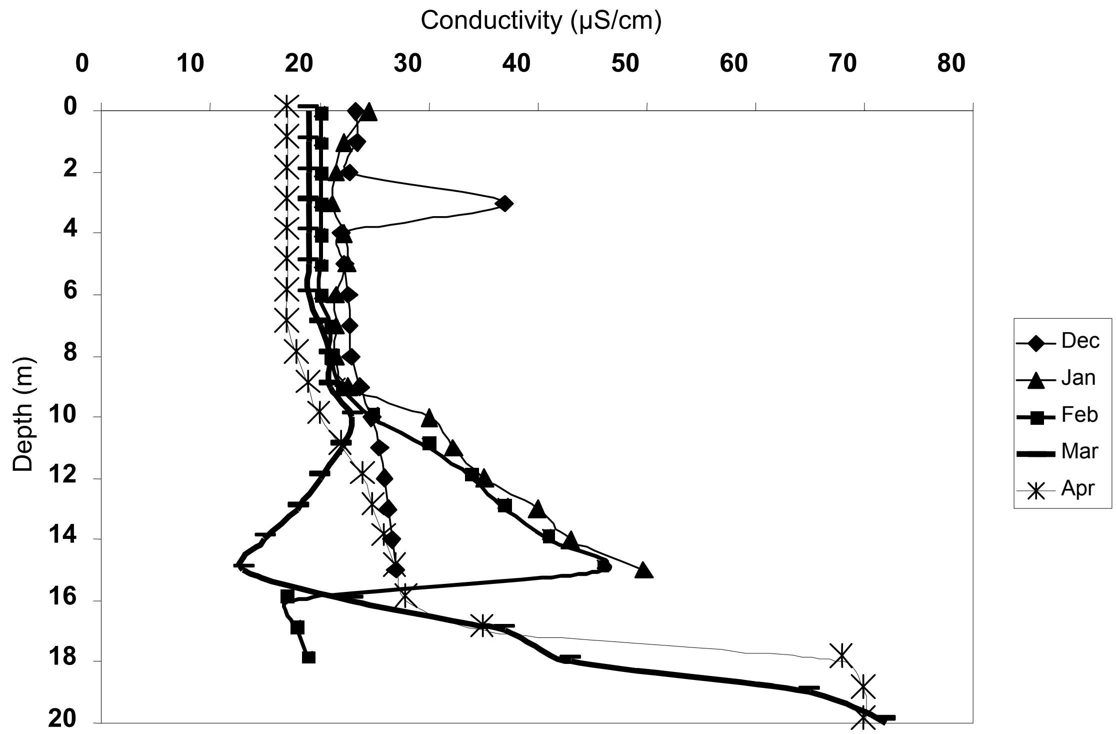


Fig. 10: Conductivity profiles at the dam wall

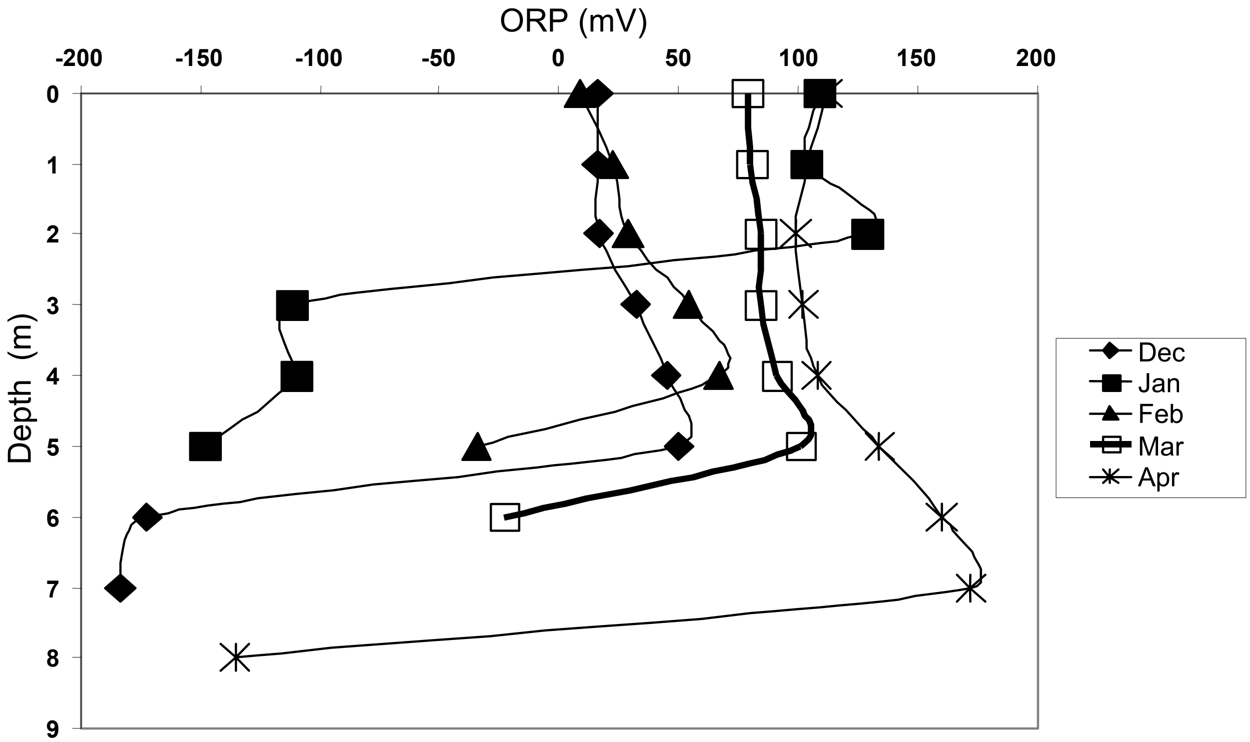


Fig. 11: ORP profiles at the intake tower

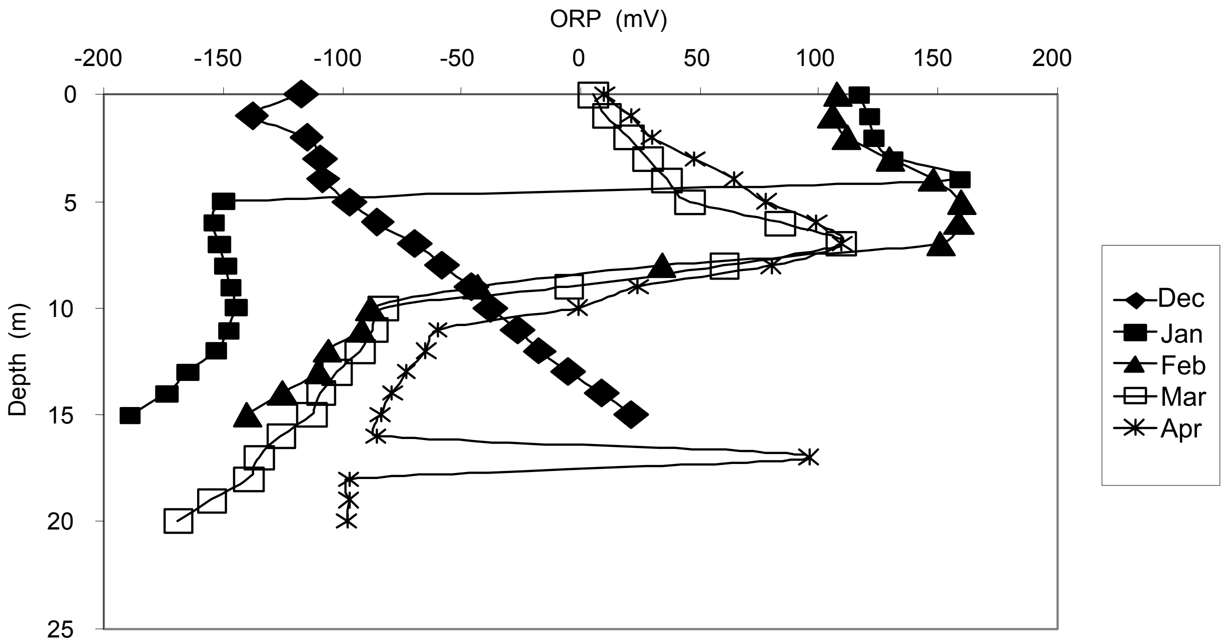


Fig. 12: ORP profiles at the dam wall

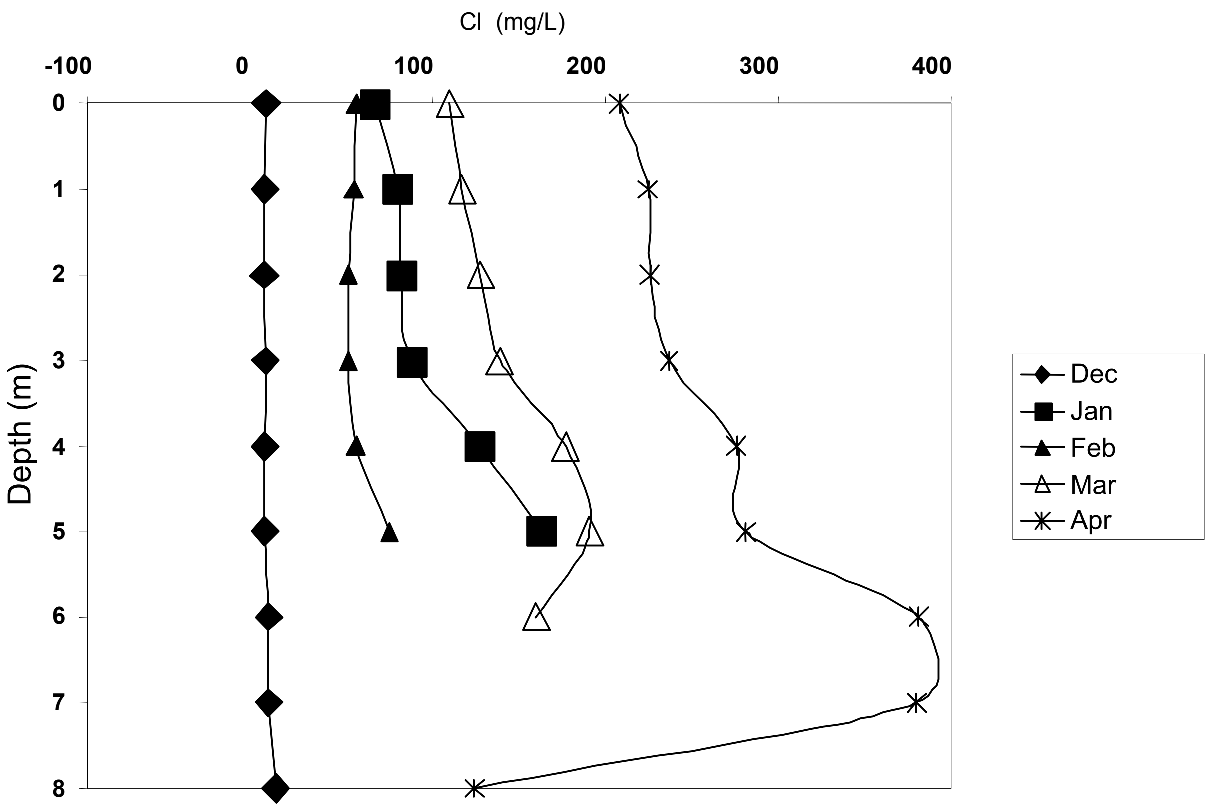


Fig. 13: Cl profiles at the intake tower

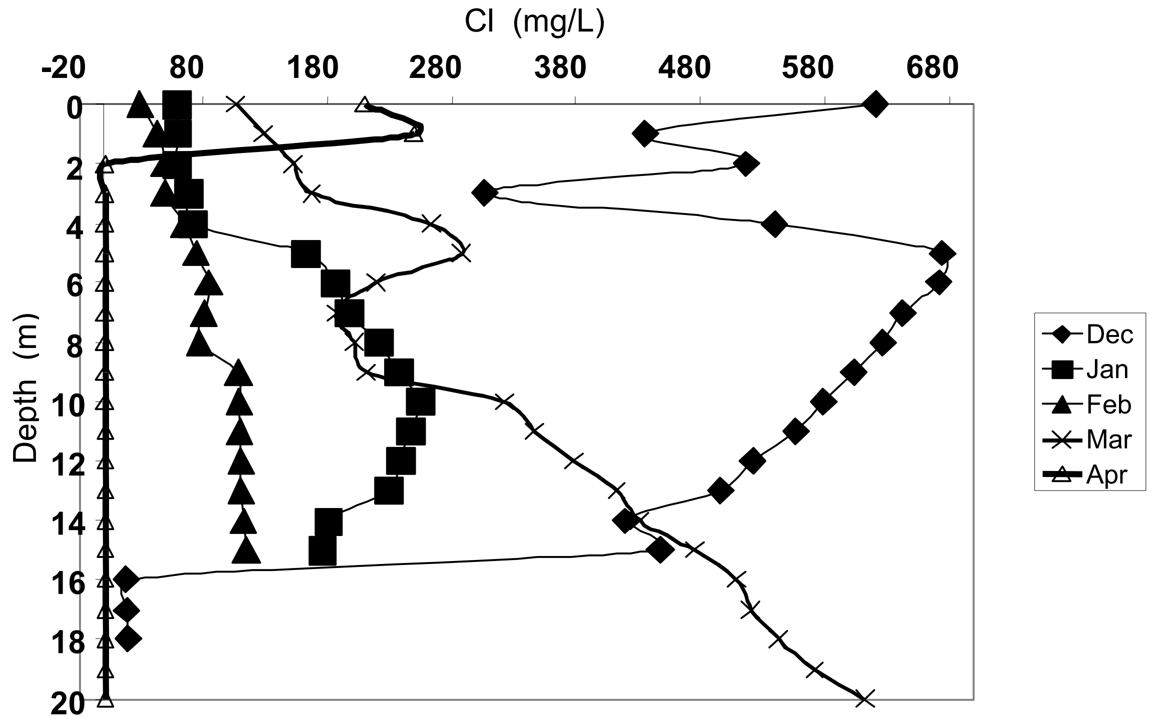


Fig. 14: Cl profiles at the dam wall

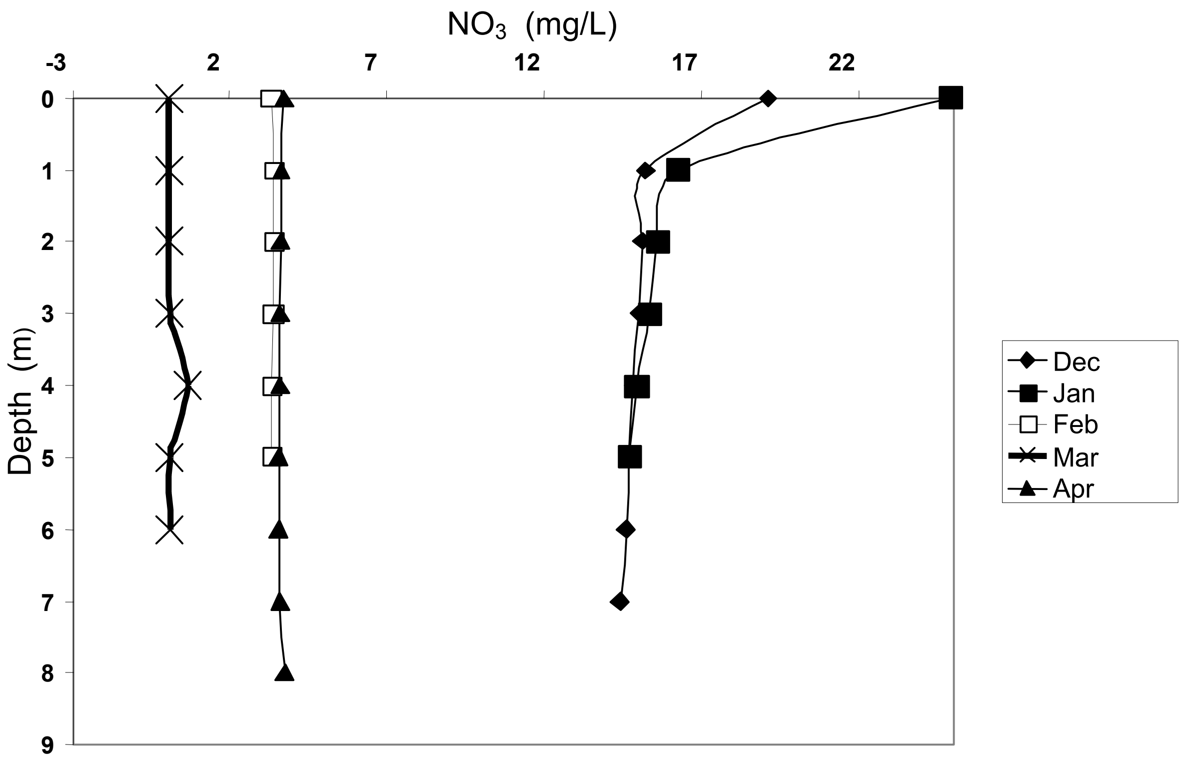


Fig.15: NO_3 profiles at the intake tower

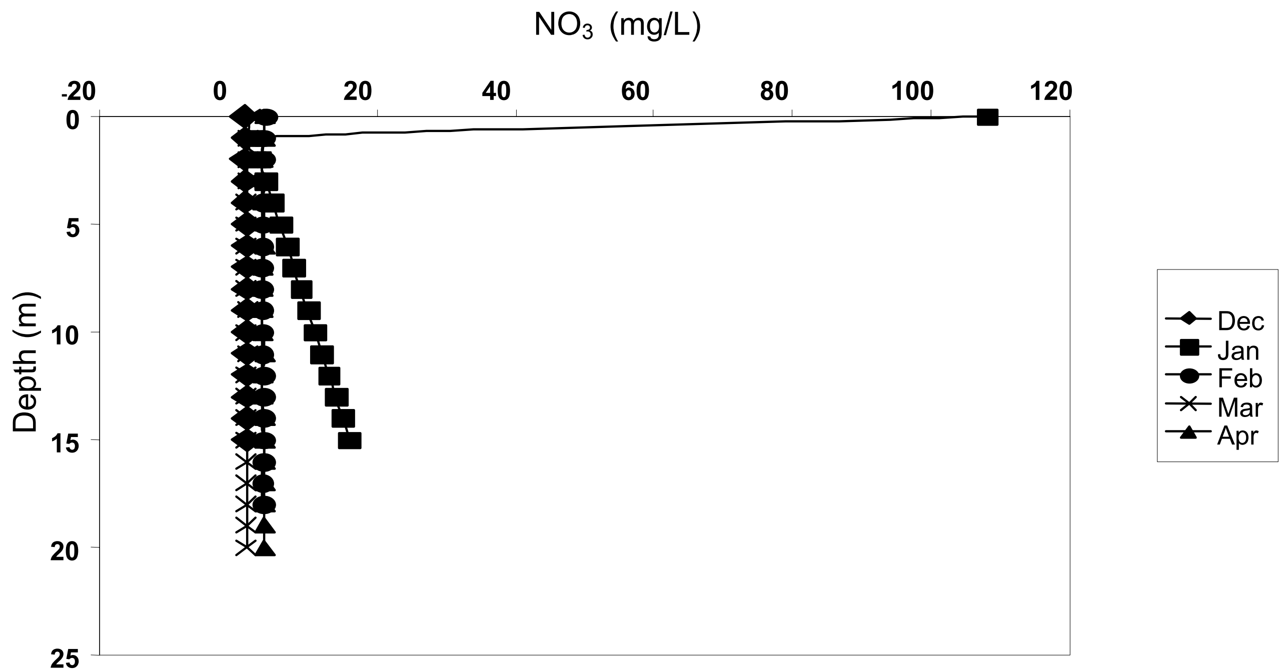


Fig. 16: NO_3 profiles at the dam wall

3.3 INFLOWS INTO THE DAM

The turbidity, TDS, nitrate, reactive and total phosphorus levels in the Nyambuya River downstream (Table 5) were higher than the ZNWA (Zimbabwe National Water Authority) standards (Appendix E), (ZNWA Water Quality Guide) for surface waters whilst the rest of the parameters were within range. The turbidity, nitrate, total nitrogen and phosphorus levels upstream of the Nyambuya River (Table 6) were above ZNWA standards whilst the rest of the parameters were within acceptable standards. All the parameters in the Nyambuya tributary (Table 7), which passes through commercial farmlands only and was used as the control stream for the research were within ZNWA standards for surface streams.

The Dombotombo storm drain upstream (Table 9) presented above acceptable levels of conductivity, turbidity, chloride, nitrate, reactive phosphorus and total phosphorus, according to ZNWA standards. The main storm drain downstream (Table10) that exports water from the Cold storage stream and the Dombotombo storm drain into the dam showed conductivity, turbidity, chloride, nitrate, reactive phosphorus and total phosphorus levels that were above ZNWA standards for surface waters. The main storm drain had higher nitrate levels than the Dombotombo storm drain which is upstream, in February (t- crit = 2.132, t-cal = 2.215. The CSC stream (Table 8) also had lower nitrate levels than the main storm drain downstream in January (t- crit = 2.132, t-cal = 10.03).

Total phosphorus, reactive phosphorus, nitrate, TDS, and conductivity levels in the sewage effluent at the point of entry into the dam (Table 12) were above ZNWA standards for disposal into a surface water system. The Sewage stream generally recorded the highest levels of all other nutrients, except NO_3.

Table 5: Results for samples taken from Nyambuya river downstream: Con = conductivity, Turb = turbidity, Tot = total, Orth P = reactive phosphorus

Parameter	3-11-03	9-12-03	8-01-04	9-02-04	12-03-04	15-04-04	Mean	St Dev	SE mean
Con (μS/cm)	68.70	73.30	96.30	80.00	96.70	60.00	79.20	3.34	0.79
Ph	9.79	7.16	6.98	6.77	6.87	6.33	7.32	0.61	0.14
DO (mg/L)	6.39	4.50	7.82	7.67	9.79	11.41	10.5	2.35	6.78
Temp (^{0}C)	17.00	29.57	23.83	23.83	21.83	19.53	22.6	3.28	0.77
Turb (mg/L)	0.37	67.00	10.00	180.00	17.00	830.00	180.73	306.90	72.30
TDS (g/L)	70.67	0.05	0.06	0.05	0.06	0.04	11.82	0.02	0.00
ORP (mV)	10.65	59.67	9.00	38.33	70.67	143.33	55.28	48.40	11.40
Cl (mg/L)	0.00	0.25	10.17	6.85	10.65	26.00	8.99	104.60	24.70
NO_3 (mg/L)	0.86	17.53	12.4	3.92	0.00	5.50	6.70	5.99	1.41
Ca (g/L)	0.77	34.79	99.90	1.54	0.86	0.03	22.98	45.80	10.80
Tot N (mg/L)	1.03	0.47	0.90	1.50	0.77	0.40	0.85	1.45	0.34
Orth P (mg/L)	2.23	0.23	0.24	0.64	1.03	0.06	0.74	2.73	0.58
Tot P (mg/L)	1.03	1.43	2.57	0.91	2.23	0.57	1.46	0.76	0.18

Table 6: Results for samples taken from Nyambuya river upstream Results for samples taken from Nyambuya river downstream: Con = conductivity, Turb = turbidity, Tot = total, Orth P = reactive phosphorus

Parameter	08-01-04	09-02-04	12-03-04	15-04-03	Mean	St Dev	SE Mean
Con (µS/cm)	93.00	90.00	83.30	60.00	81.7	1.47	0.42
Ph	7.18	7.00	7.13	6.10	6.85	0.90	0.26
DO (mg/L)	8.08	8.01	9.35	12.14	9.40	1.79	0.52
Temp (^{0}C)	23.70	22.43	21.93	19.00	21.77	1.80	0.52
Turb (mg/L)	10.00	183.33	4.67	866.67	261.17	375.00	108.00
TDS (g/L)	0.06	0.06	0.05	0.04	0.05	0.01	0.00
ORP (mV)	47.33	86.00	67.33	90.33	72.75	20.12	5.81
Cl (mg/L)	11.00	8.51	11.97	31.10	15.65	9.57	2.76
NO_3 (mg/L)	10.80	3.88	0.00	4.23	4.73	4.07	1.17
Ca (g/L)	95.33	1.40	0.35	0.07	24.29	42.9	12.4
Tot N (mg/L)	0.53	1.43	0.03	0.27	0.57	0.66	0.19
Orth P (mg/L)	0.13	0.45	0.41	0.19	0.30	0.65	0.04
Tot P (mg/L)	2.53	0.65	2.67	1.18	1.76	0.86	0.25

Table7: Results for samples taken from Nyambuya tributary upstream: Con = Conductivity, Turb = turbidity, Tot = total, Orth P = reactive phosphorus

Parameter	08-0104	09-02-04	12-03-04	15-0404	Mean	St Dev	SE Mean
Con (µS/cm)	46.70	116.70	173.30	00.07	82.00	7.95	2.29
Ph	5.88	7.56	7.63	6.27	6.84	0.99	0.29
DO (mg/L)	7.68	8.25	9.89	9.94	8.94	1.18	0.34
Temp (^{0}C)	22.73	21.27	22.57	20.07	21.66	1.33	0.38
Turb (mg/L)	10.00	193.33	0.00	0.00	45.83	89.3	25.8
TDS (g/L)	0.03	0.06	0.10	0.04	0.06	0.03	0.10
ORP (mV)	79.67	127.33	147.33	79.33	108.42	35.10	10.10
Cl (mg/L)	5.23	3.77	9.75	70.87	22.41	30.18	8.71
NO_3 (mg/L)	8.30	4.54	0.01	0.13	3.25	3.65	1.06
Ca (g/L)	3.71	0.36	0.56	2.81	1.86	1.88	0.54
Tot N (mg/L)	3.00	1.73	0.60	0.77	1.53	1.24	0.36
Orth P (mg/L)	0.08	0.40	0.13	0.03	0.16	0.45	0.12
Tot P (mg/L)	2.17	1.12	1.93	0.47	1.42	0.76	0.22

Table 8: Results for samples taken from the CSC stream Upstream: Con = Conductivity, Turb = turbidity, Tot = total, Orth P = reactive phosphorus

Parameter	09-12-03	08-01-04	09-02-04	12-03-04	15-04-04	Mean	St Dev	SE Mean
Con (µS/cm)	106.00	93.30	93.30	170.00	176.70	127.90	3.95	1.02
Ph	5.85	5.82	6.43	6.93	6.80	6.37	0.57	0.15
DO (mg/L)	2.52	7.71	7.00	8.63	9.40	7.05	2.58	0.67
Temp (^{0}C)	22.00	21.40	20.50	19.40	19.20	20.50	1.12	0.29
Turb (mg/L)	45.00	99.33	94.33	0.00	32.00	3.60	68.40	17.70
TDS (g/L)	0.06	0.06	0.06	0.11	0.09	0.08	0.02	0.01
ORP (mV)	9.80	19.67	24.67	81.33	78.00	38.77	37.50	9.68
Cl (mg/L)	1.10	28.67	62.77	87.07	87.33	53.39	35.21	9.09
NO_3 (mg/L)	11.60	8.26	1.38	0.01	4.93	5.24	4.44	1.15
Ca (g/L)	0.02	0.28	0.01	0.86	0.90	0.41	0.40	0.10
Tot N (mg/L)	0.43	0.53	1.30	1.10	1.47	0.97	0.49	0.12
Orth P (mg/L)	0.92	1.25	1.40	0.27	0.21	0.81	0.52	0.10
Tot P (mg/L)	1.57	1.83	1.10	1.33	1.20	1.41	0.31	0.08

Table 9: Results for samples taken from Dombotombo storm drain (upstream): Con = conductivity, Turb = turbidity, Tot = total, Orth P = reactive phosphorus

Parameter	08-01-04	09-02-04	12-03-04	15-04-03	Mean	St Dev	SE Mean
Con (µS/cm)	383.30	283.30	373.30	130.00	292.5	10.17	2.62
Ph	7.04	6.90	6.80	7.77	7.13	0.38	0.10
DO (mg/L)	8.17	6.45	10.44	14.18	9.81	2.93	0.76
Temp (^{0}C)	25.07	22.13	20.23	18.43	21.47	2.72	0.70
Turb (mg/L)	256.67	98.00	6.00	776.67	284.34	277.60	71.70
TDS (g/L)	0.25	0.18	0.24	0.08	0.19	0.07	0.02
ORP (mV)	39.67	18.33	92.33	64.33	53.67	29.93	7.73
Cl (mg/L)	101.47	637.67	104.07	149.67	248.22	26.56	6.86
NO_3 (mg/L)	11.37	1.65	0.01	3.36	4.10	5.05	1.30
Ca (g/L)	0.02	0.83	0.82	0.03	0.43	0.34	0.11
Tot N (mg/L)	8.77	9.73	9.07	0.42	7.00	3.74	0.96
Orth P (mg/L)	2.23	2.33	3.28	0.16	2.00	1.09	0.28
Tot P (mg/L)	2.93	2.17	3.47	1.16	2.43	0.87	0.22

Table 10: Results for samples taken from the main Storm drain downstream: Con = conductivity, Turb = turbidity, Tot = total, Orth P = reactive Phosphorus

Parameter	03-11-03	09-12-03	08-01-04	09-02-04	12-03-04	15-04-04	Mean	St Dev	SE Mean
Con (µS/cm)	146.20	123.00	180.00	176.70	170.00	160.00	159.30	2.05	0.48
Ph	7.22	8.00	7.26	6.07	7.97	7.70	7.37	0.71	0.18
DO (mg/L)	7.10	4.99	8.39	7.82	10.06	13.47	8.64	2.75	0.65
Temp (^{0}C)	26.33	22.90	26.13	21.47	21.57	19.33	22.96	2.62	0.62
Turb (mg/L)	1.10	51.00	253.33	166.67	297.33	296.67	177.68	120.8	28.50
TDS (g/L)	0.24	0.08	0.12	0.11	0.11	0.10	0.13	0.07	0.16
ORP (mV)	32.67	24.33	0.33	43.33	74.00	66.33	40.06	26.67	6.29
Cl (mg/L)	0.83	1.94	33.17	80.70	117.33	146.67	63.44	57.70	13.60
NO_3 (mg/L)	1.89	15.03	11.80	1.28	0.06	3.22	5.55	5.91	1.39
Ca (g/L)	0.83	0.04	0.01	0.00	0.01	15.97	2.81	6.06	1.43
Tot N (mg/L)	17.60	0.53	1.93	4.23	3.23	0.29	4.64	6.16	1.45
Orth P (mg/L)	4.30	0.22	0.32	3.23	1.12	0.83	1.67	0.85	0.03
Tot P (mg/L)	2.59	2.40	3.60	1.87	0.77	0.76	2.00	1.08	0.25

Table 11: Results for samples taken from the Sewage stream upstream: Con = conductivity, Turb = turbidity, Tot = total, Orth P = reactive phosphorus

Parameter	8-01-04	9-02-04	12-03-04	15-04-04	Mean	St. Dev	SE Mean
Con (µS/cm)	88.00	53.00	40.33	35.33	54.165	21.50	6.21
Ph	7.31	7.44	7.00	6.97	7.18	0.27	0.08
DO (mg/L)	6.86	5.64	8.62	8.44	7.39	1.70	0.49
Temp (^{0}C)	24.13	22.77	22.8	22.87	23.14	0.61	0.18
Turb (mg/L)	210.00	136.67	8.00	4.67	89.83	91.8	26.50
TDS (g/L)	0.57	0.34	0.26	0.20	0.34	0.15	0.04
ORP (mV)	106.67	119.67	135.67	144	126.50	15.81	4.57
Cl (mg/L)	180.33	236.67	306.67	305.67	257.33	59.7	17.2
NO_3 (mg/L)	12.57	13.17	0.08	0.07	6.47	6.81	1.97
Ca (g/L)	2.37	40.63	0.02	0.02	10.76	28.74	8.30
Tot N (mg/L)	32.33	12.67	9.30	6.86	15.29	11.07	3.20
Orth P (mg/L)	3.91	1.77	6.03	4.24	3.99	1.83	0.53
Tot P (mg/L)	7.50	3.12	7.37	5.75	5.94	1.88	0.54

Table 12: Results for samples taken from the Sewage stream downstream: Con = conductivity, Turb = turbidity, Tot = total, Orth P = reactive phosphorus

Variable	03-11-03	09-12-03	08-01-04	09-02-04	12-03-04	15-04-04	Mean	St. Dev	SE Mean
Con (µS/cm)	252.70	794.70	553.30	503.30	420.00	403.30	487.90	17.13	4.04
Ph	9.08	6.99	7.11	6.97	6.90	7.77	7.47	0.84	0.20
DO (mg/L)	6.93	4.99	6.76	7.05	7.53	7.93	6.87	1.82	0.43
Temp (^{0}C)	24.20	19.57	22.87	20.07	22.67	20.40	21.63	1.81	0.42
Turb (mg/L)	0.22	68.67	226.00	116.67	5.33	4.00	70.15	87.60	20.70
TDS (g/L)	0.11	0.51	0.35	0.33	8.85	0.25	1.73	0.12	0.03
ORP (mV)	49.00	52.67	6.33	19.67	121.3	107.0	34.33	66.40	15.70
Cl (mg/L)	398.00	20.37	239.67	408.67	442.67	46.77	259.36	180.90	42.60
NO_3 (mg/L)	1.89	15.17	11.60	13.30	0.08	4.97	7.84	5.97	1.41
Ca (g/L)	0.25	0.00	0.00	0.53	0.02	0.02	0.14	0.34	0.08
Tot N (mg/L)	8.03	22.53	8.90	10.40	9.20	8.53	11.27	5.36	1.26
Orth P (mg/L)	6.54	8.85	2.78	2.52	3.28	2.82	4.47	2.10	0.43
Tot P (mg/L)	3.51	8.87	3.27	2.16	4.73	3.58	4.35	2.40	0.56

3.4 THE OUTFLOW

The dam did not spill and from January to April (Table 13) when it was raining no water was being released for irrigation. The conductivity, Ph, temperature and turbidity (Table 13) were less in the water coming out than in the dam. The TDS was the same as that of the dam water. In November the total nitrogen was higher at the dam wall than at the outlet (t- crit = 2.132, t- cal = 5.77). In November the total phosphorus level was also higher at the dam wall than at the outlet (t- crit = 2.132, t- cal = 42.44), with the orthophosphate levels being significantly higher at the dam wall than at the outlet (t- crit = 2.132, t- cal = 38.44). In December the total phosphorus was higher at the dam wall than at the outlet (t- crit = 2.132, t- cal = 9.14) with orthophosphate levels also being significantly higher at the dam wall than at the outlet (t- crit = 2.132, t- cal = 37.7). The mean total phosphorus concentrations of 2.2 mg/L N and 1.26 mg/L P in the outlet compared to 2.4 mg/L N and 1.99 mg/L P indicated a loss of nutrients from the dam water. The much higher differences in calcium levels between the dam water (39,72mg/L) and the outflow (1.41 mg/L) showed that a lot of calcium was retained within the dam water.

Table 13: Results for samples taken from the outlet valve:
Con = conductivity, Turb = turbidity, Tot = total,
Orth P = reactive phosphorus

Parameter	03-11-03	09-12-03	Mean	St Dev	SE Mean
Con (µS/cm)	223.00	237.70	230.35	0.81	0.33
Ph	6.34	6.43	6.39	0.16	0.06
DO (mg/L)	5.30	5.35	5.33	0.15	0.06
Temp (^{0}C)	21.27	18.27	19.77	1.64	0.67
Turb (mg/L)	0.11	19.33	9.72	15.51	6.33
TDS (g/L)	0.16	0.15	0.16	0.01	0.00
ORP (mV)	49.67	97.00	23.67	80.40	32.80
Cl (mg/L)	619.33	4.26	311.79	340.00	139.00
NO_3 (mg/L)	1.05	15.20	8.12	7.76	3.17
Ca (g/L)	2.66	0.15	1.41	1.43	0.59
Tot N (mg/L)	1.53	2.87	2.20	0.86	0.35
Orth P(mg/L)	0.22	0.15	0.19	0.91	0.38
Tot P (mg/L)	0.42	2.10	1.26	0.98	0.40

3.5 PRECIPITATION

Fig 17 shows the precipitation levels during the sampling period. The dam area received the highest rainfall in December, with January and March receiving high but slightly less. The lowest precipitation was received in April.

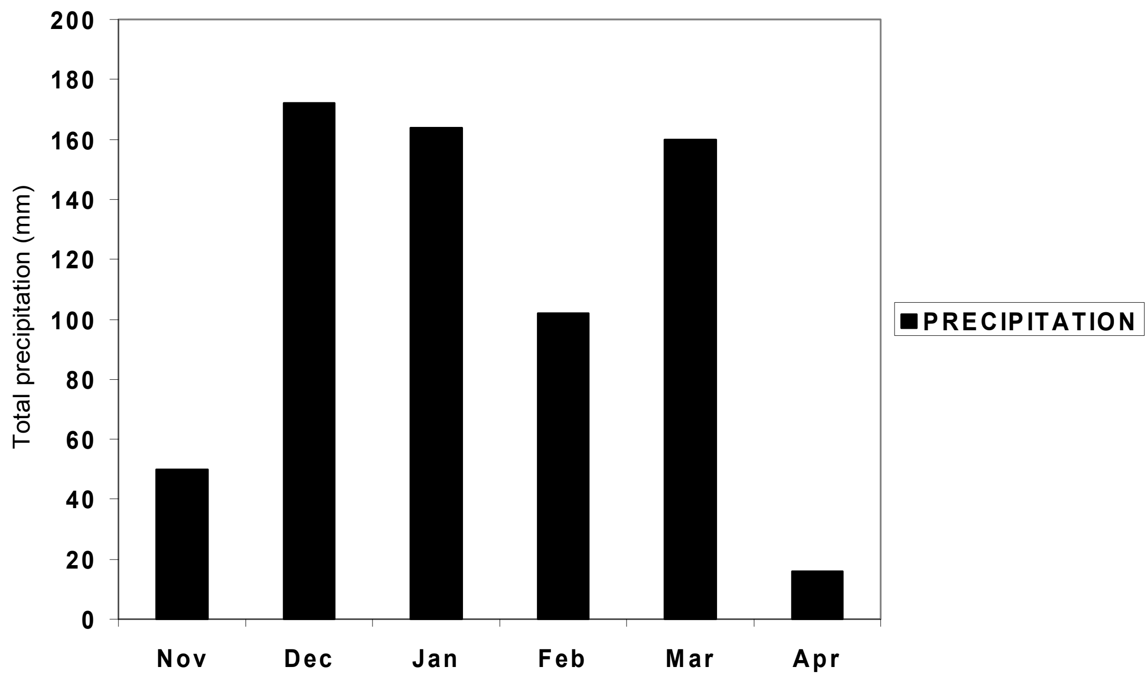


Fig17: Precipitation during the sampling period

3.6 CHANGES IN NUTRIENT CONCENTRATIONS OVER THE SAMPLING PERIOD IN THE MAIN STREAMS AND THE DAM.

In December, sampling was done before the heavy rains had commenced. The highest concentrations of total phosphorus (Fig19) in November were at the intake tower and in December they were in the sewage stream with the dam wall having the second highest concentrations. The intake tower presented peak concentrations of total phosphorus in November and a smaller peak in February whilst the main storm drain and the main river had their peak concentrations in January. The peak concentration of total phosphorus at the dam wall coincided with that of the sewage stream in December. The dam wall peak concentration of reactive phosphorus (Fig 20) coincided with the total phosphorus peak (Fig 19) in January whilst the dam wall peak of reactive phosphorus coincided with that of the storm drains in November.

The sewage stream contained the highest concentrations of total nitrogen (Fig 20), with the peak concentration in December. The main storm drain had the second highest concentration of total nitrogen, but with its peak concentration in November. The main river presented the highest concentration of NO_3 with the peak concentration in December that coincided with the sewage and storm drain peaks. The dam wall and intake tower peaks occurred after the peaks of the all the inflows in January.

NB* For figs 18 to 21 NY down = Nyambuya river downstream, Sd down = Main storm drain downstream, Sew down = sewage stream downstream, IT = Intake tower, DW = Dam wall

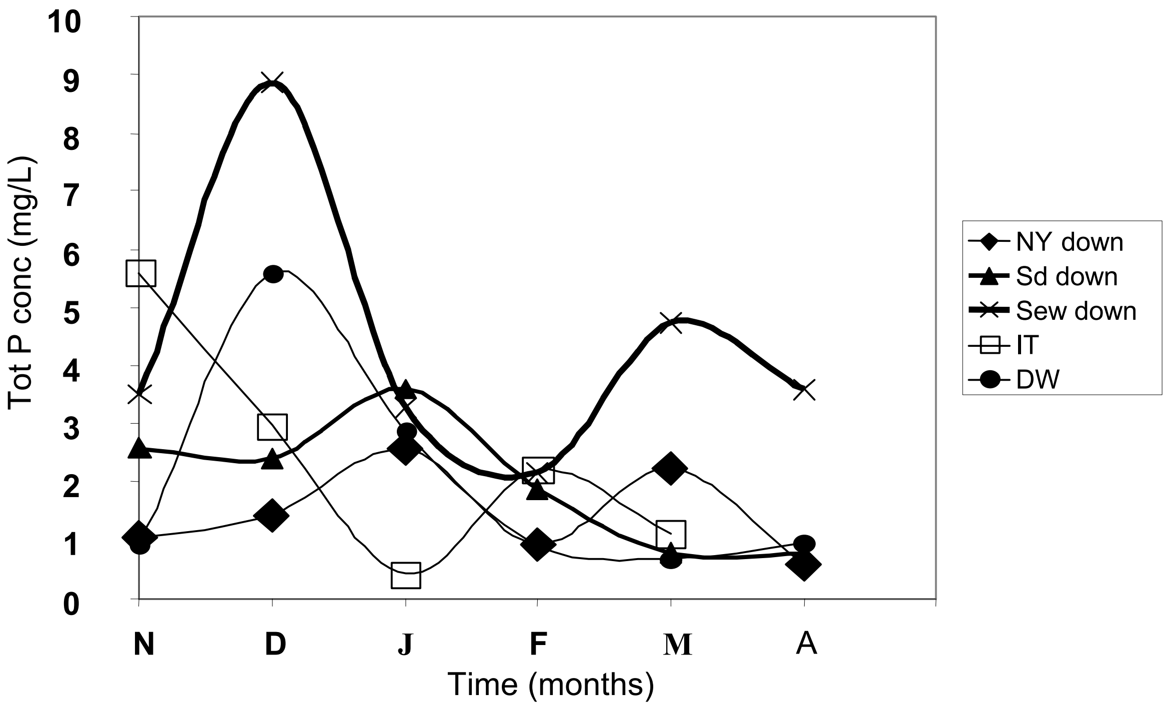


Fig. 18: Variation in mean concentration of total phosphorus from November 2003- April 2004.

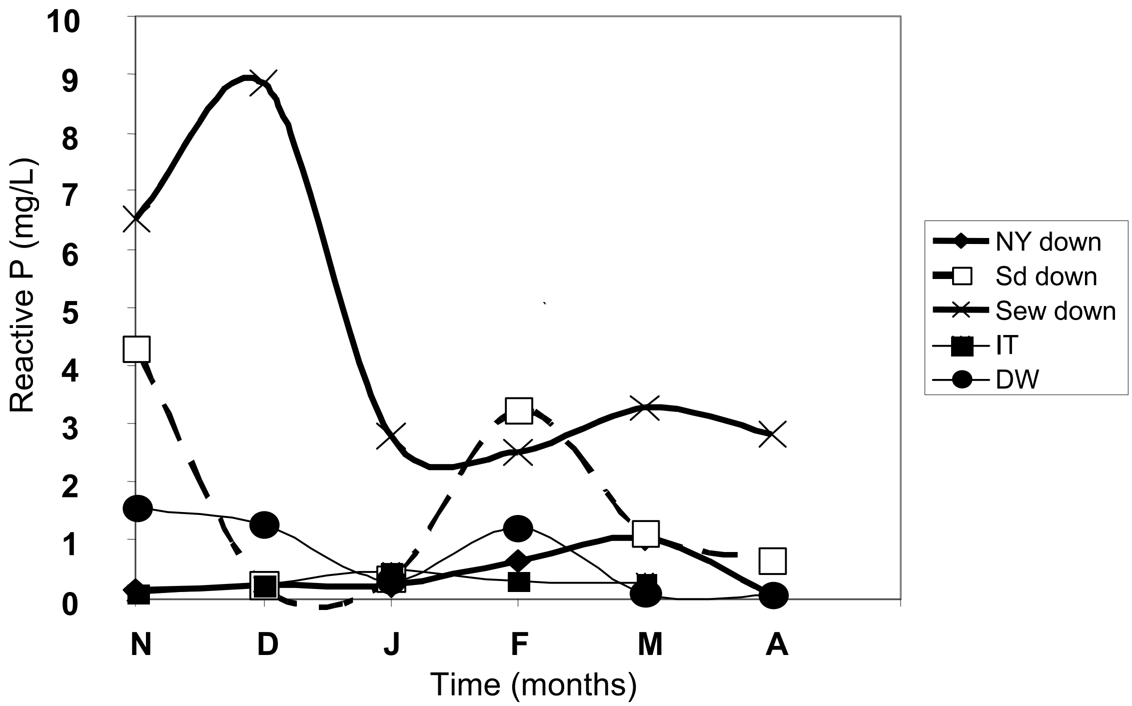


Fig.19: Variation in mean concentration of reactive phosphorus from November 2003-April 2004.

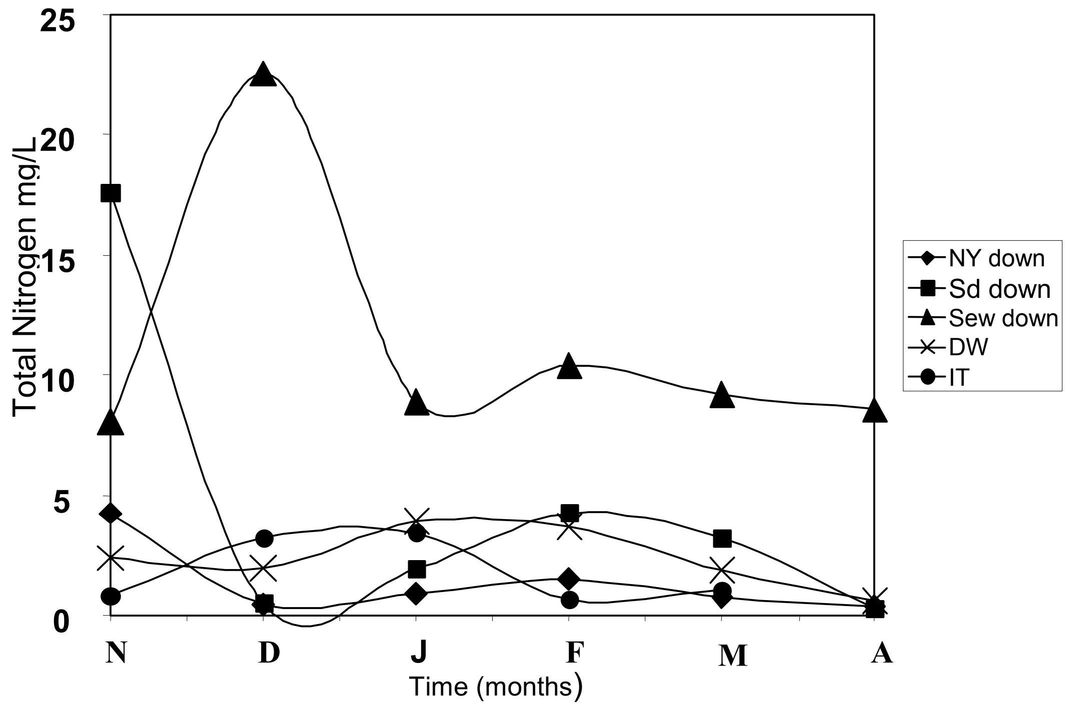


Fig. 20: Variation in mean concentration of Total N from November 2003- April 2004

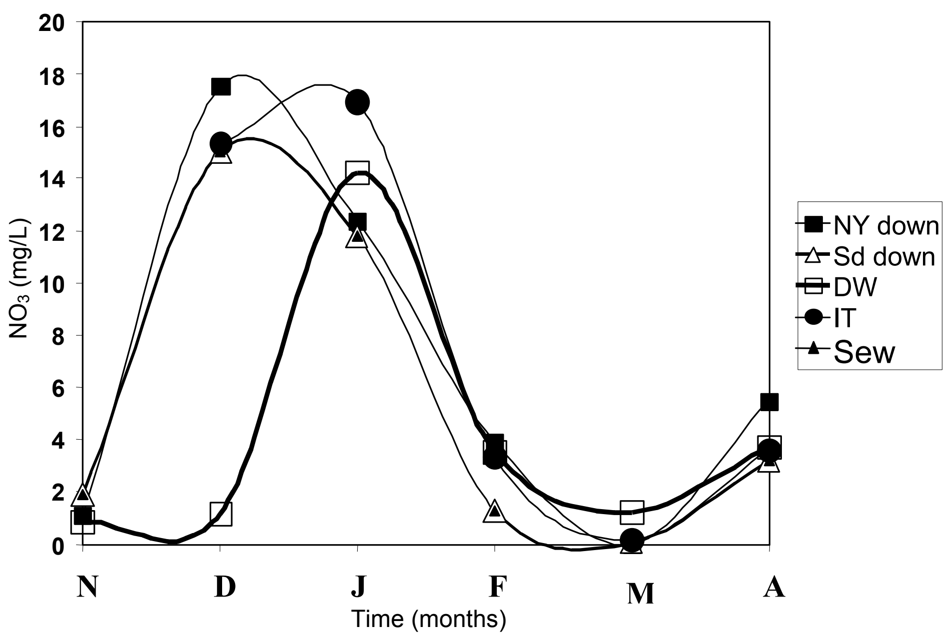


Fig. 21: Variation in mean concentration of NO_3 from November 2003- April 2004

3.7 THE NUTRIENT LOADINGS

The highest loadings of reactive phosphorus, total phosphorus and nitrogen (figs. 23-24) were from the sewage stream with the storm drains coming second highest, whilst the storm drains presented the highest loadings of nitrates (fig.25) with the Nyambuya river exporting the second highest amount. The highest loadings of nutrients generally occurred during periods of highest precipitation. The largest loadings in the sewage stream occurred in March and a smaller peak in December. The periods of peak loadings coincided with periods of peak precipitation in the main river, but in the sewage stream the highest precipitation in December did not coincide with the largest loadings that occurred in March.

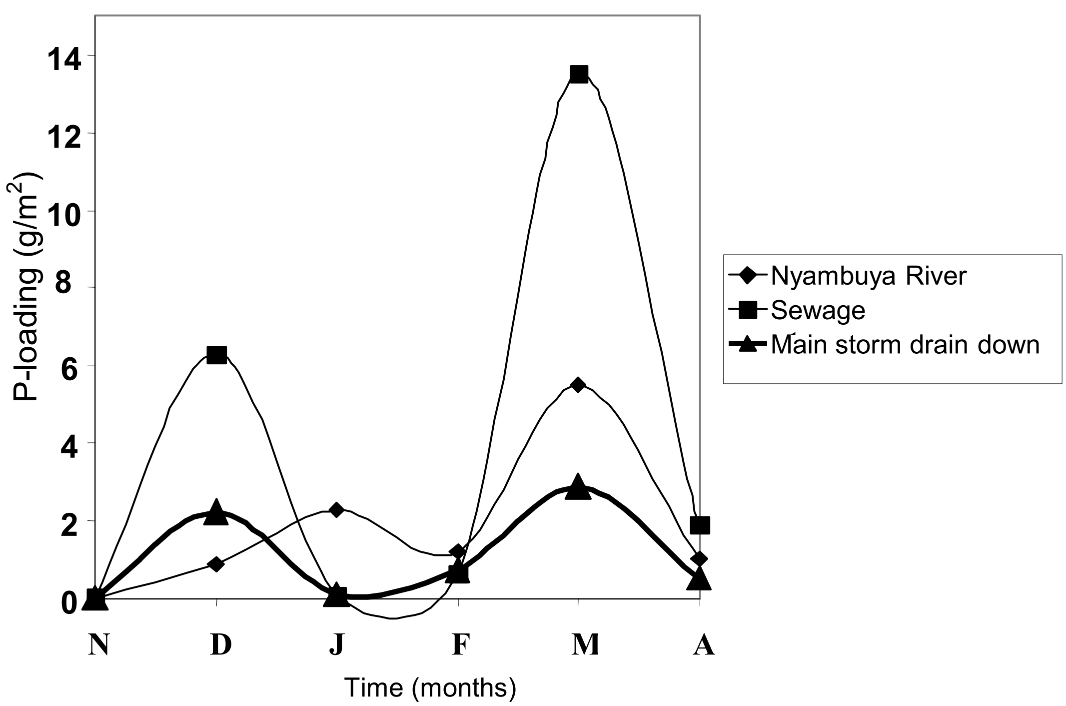


Fig. 22: Total P loadings (g/m^2) for each stream over sampling period

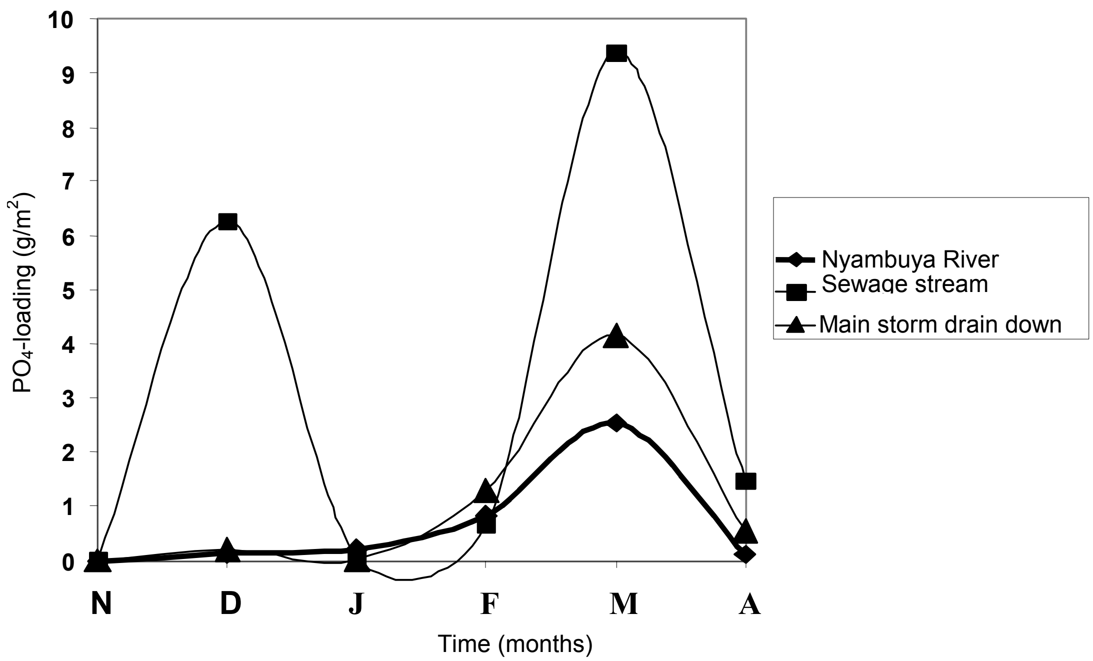


Fig. 23: Total Orthophosphate loadings (g/m^2) for each stream over sampling period

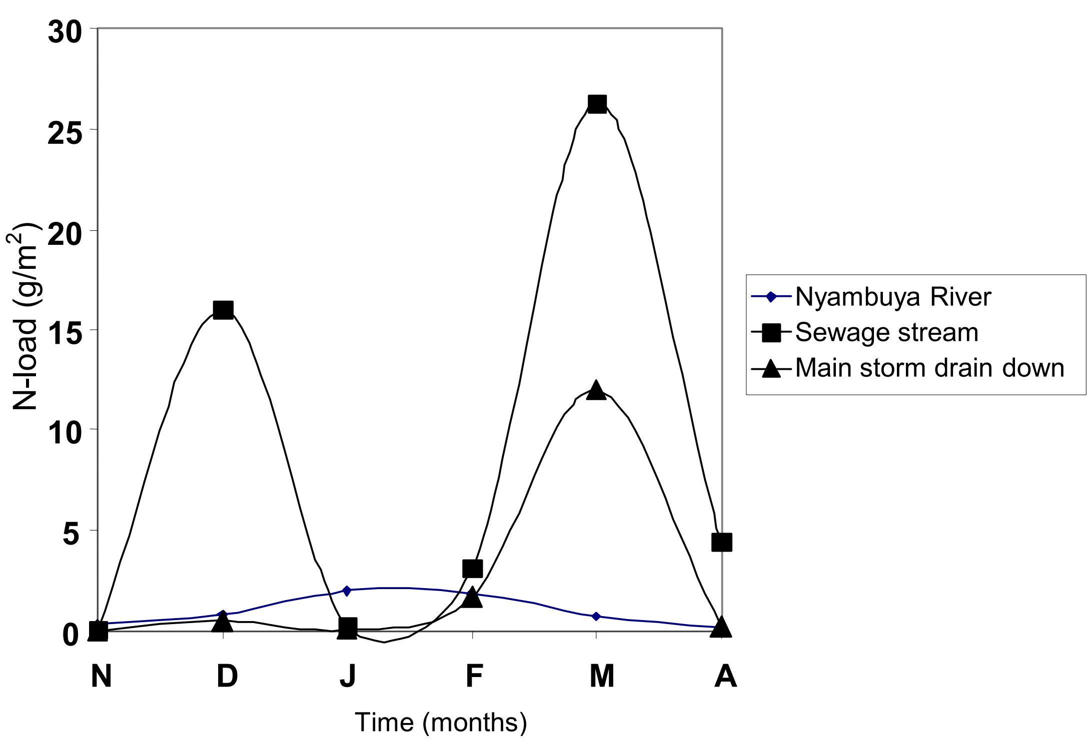


Fig. 24: Total N loadings (g/m^2) for each stream over sampling period

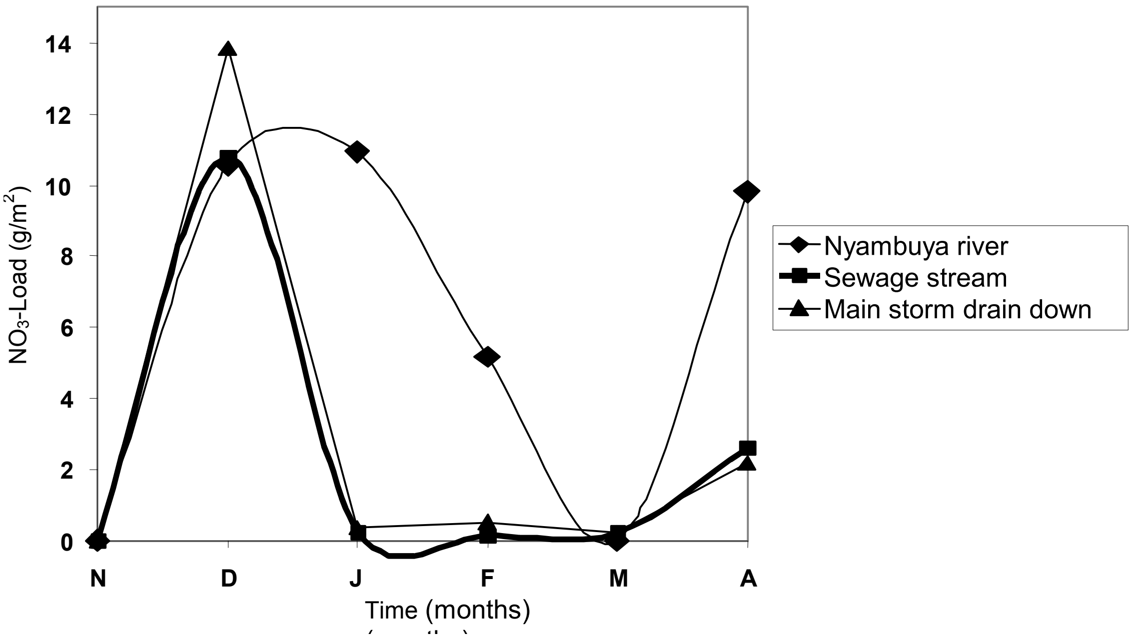


Fig. 25: Total NO_3 loadings (g/m^2) for each stream over sampling period

3.8 STATISTICAL ANALYSES

3.8.1 Analysis of variance

The one- way analysis of variance (Table 14) showed that for temperature and nitrates the sites were not significantly different (P> 0.05), but the sites showed significant differences for the rest of the variables measured (P< 0.05). A one- way analysis of variance for the dates of collection showed no significant variation in all other variables (P > 0.05) except for DO, turbidity, Cl, NO_3, and total phosphorus (P< 0.05).

Table 14: One- way ANOVA of sites and dates for each variable

Variable	P- value for sites	P- value for dates
Conductivity	0	0.124
Ph	0	0.342
DO	0	0
Temperature	0.277	0.489
Turbidity	0.01	0
Total dissolved solutes	0	0.183
Oxygen reduction potential	0	0.06
Cl	0	0
NO_3	0.265	0
Ca	0	0.066
Total N	0	0.06
Total P	0	0

3.8.2 Principal Component Analysis

The most important component was the first component with an Eigen value of 4.08 and a proportion of 0.34 (Table 15). The most important variables along this component were conductivity, total dissolved solutes, oxygen reduction potential (ORP), total nitrogen and phosphorus with ORP being negatively correlated to all the other important variables (Table 16). Along PC2 pH, DO and turbidity were positively correlated, whilst Cl was negatively correlated to NO_3 and Ca along PC3 (Table 16).

Table 15: Eigenanalysis of the correlation matrix

Eigenvalue	4.0788	1.6431	1.3580	1.1459	1.0726	0.7303
Proportion	0.340	0.137	0.113	0.095	0.089	0.061
Cumulative	0.340	0.477	0.590	0.685	0.775	0.836
Eigenvalue	0.5953	0.5344	0.2821	0.2586	0.2299	0.0711
Proportion	0.050	0.045	0.024	0.022	0.019	0.006
Cumulative	0.885	0.930	0.953	0.975	0.994	1.000

Table 16: Weight of the variables along the main principal components. Numbers in bold print = weights of the most important variables

Variable	PC1	PC2	PC3	PC4
Cond	**-0.404**	0.257	-0.046	-0.183
Ph	-0.022	**0.369**	0.302	-0.365
DO	0.244	**0.557**	-0.061	-0.035
Temp	-0.017	0.035	-0.026	**-0.663**
Turb	0.173	**0.529**	0.006	0.320
TDS	**-0.440**	0.242	0.020	0.092
ORP	**0.386**	0.172	0.011	-0.062
Cl	-0.186	-0.138	**-0.565**	-0.148
NO_3	-0.185	-0.156	**0.615**	0.292
Ca	0.004	-0.114	**0.451**	-0.403
Tot N	**-0.409**	0.236	-0.017	0.089
Tot P	**-0.410**	0.078	-0.014	0.028

3.8.3 PCA plot for sites

A PCA plot of the sites sampled, grouped the sites into three main classes (Fig.

Group1; (i) Nyambuya downstream

(ii) Nyambuya upstream

(iii) Nyambuya tributary and

(iii) CSC

(v) Intake Tower

(vii) Main Storm drain downstream

Group 2; (i) Storm drain Dombotombo upstream

(ii) Sewage upstream

(iii) Sewage downstream

Group 3 (i) Dam Wall

(ii) Outlet

.

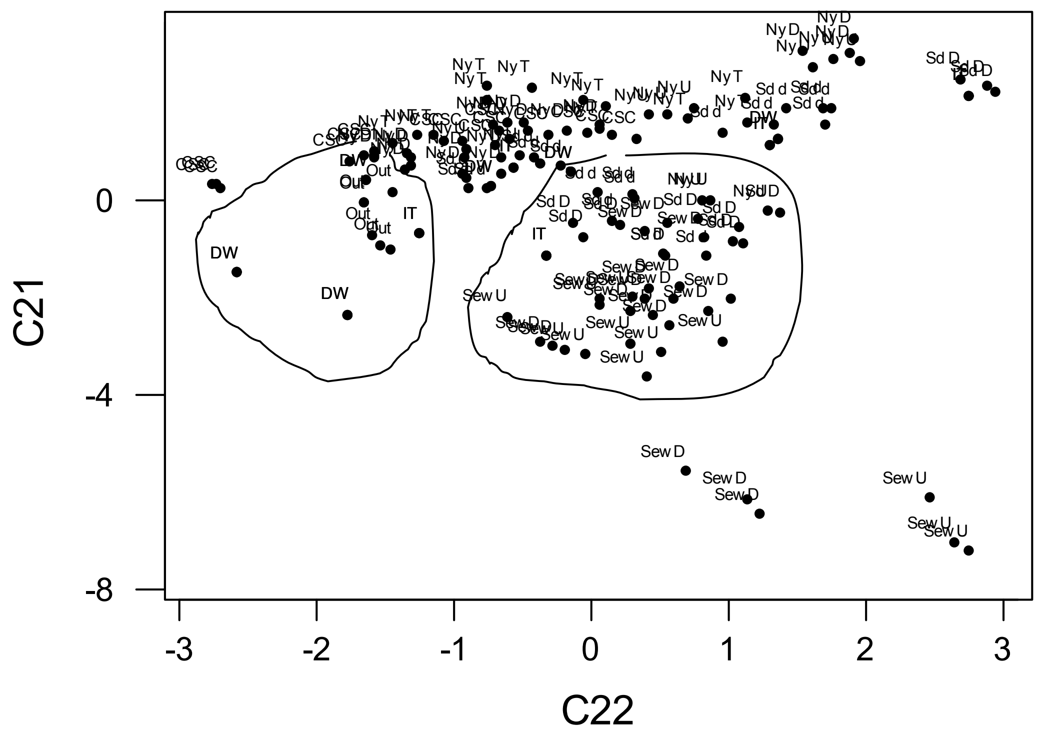


Fig.26: PCA plot for sites. Ny D= Nyambuya downstream, Ny U = Nyambuya upstream, Ny T= Nyambuya tributary, Sd D = Storm drain Dombotombo upstream, CSC = Cold Storage Commission Stream, Sd d = Main Storm drain downstream, Sew U = Sewage upstream, Sew D = Sewage downstream, Out =Outlet, IT = Intake tower, DW= Dam Wall.

3.8.4 The Discriminant Analysis

A Discriminant analysis (DA) of the groups with class validation (Table 18) placed the December CSC observations into the dam wall and outlet group. The April and January Dombotombo storm drain upstream observations were grouped with the rivers. The dam wall April observations were grouped with the sewage stream and the storm drains and the dam wall March observations were grouped with the rivers.

Table 17: Discriminant Analysis: Summary of classification with cross- validation

PCA group	True group		
	1	2	3
1	88	5	3
2	0	36	3
3	2	1	18
Total N	90	42	24
N correct	88	36	18
Proportion	0.98	0.86	0.75

Table 18: Summary of misclassified observations

Misclassified site	Date	PCA group	X- validation group
CSC	9/12/03	1	3
CSC	9/12/03	1	3
Storm drain Dombotombo	15/4/04	2	1
Storm drain Dombotombo	15/4/04	2	1
Storm drain Dombotombo	15/4/04	2	1
Storm drain Dombotombo	9/2/04	2	3
Storm drain Dombotombo	8/1/04	2	1
Storm drain Dombotombo	8/1/04	2	1
Dam wall	15/4/04	3	2
Dam wall	15/4/04	3	2
Dam wall	15/4/04	3	2
Dam wall	12/3/04	3	1
Dam wall	12/3/04	3	1
Dam wall	12/3/04	3	1

3.9 PAMOLARE MODELLING RESULTS

The results from modelling with the programme PAMOLARE are given in Appendix D. Modelling was done using the current conditions as the base line under the following conditions (a) doubling the population, (b) reducing the precipitation by 6.2 % as predicted using SCENGEN and scenario SARES 98A1 (c) sewage treatment using the BNR, which is still under construction and (d) diverting the storm drain water to the BNR before release into the dam. The state variables were total nitrogen and phosphorus in water and sediments, nitrogen and phosphorus loadings, nitrogen and phosphorus release from sediments and the fraction of nitrogen and phosphorus bound in sediment. The response variables from the model were total nitrogen and phosphorus in water and sediments, limiting nutrient, secchi depth, chlorophyll a concentration and primary, zooplankton and fish productivities. Although there was no base line data for chlorophyll a concentration, primary, zooplankton and fish productivities these were predicted by the model from the state variable inputs.

The PAMOLARE model predicted that if current conditions of nutrient loadings were maintained, there would be an increase in total nitrogen in water (fig. 27) with the concentration, stabilising within six years at 19.9 mg/L. This would be coupled with an increase in nitrogen in sediments (fig. 28), which would stabilise to 16.48 mg/L within 15 years under the current conditions. The total phosphorus in water (fig. 29) would decrease from the present 2.25mg/L and stabilize at 0.72mg/L in two years time, whilst the phosphorus level in sediments (fig. 30) would rise from the present 0.079g/m^2 and stabilize at 1g/m^2 within a year. The secchi depth would change from the present 0.5m in November and December and 0.75m from March to April to stabilise at 0.53m within two years.

Modelling with the population doubled would have a small effect on all the parameters shown in the graphs. Predictions of precipitation using the model SCENGEN and scenario SRES 98 A1 predicted a 6.2 % fall in precipitation, and a mean rise in temperature of about 0.6^{0}C. It was assumed that these conditions would increase the water residence time by 6.2 %. Reducing the precipitation by 6.2% would raise the total nitrogen levels in water to a maximum of 20.98 mg/L within seven years. The use of the BNR would reduce nitrogen levels to a minimum of 16mg/L within one and half years whilst diversion of storm drain water would reduce the nitrogen in water to a minimum of 12 mg/L within two and half years. The changes in nitrogen levels showed a similar trend but the nitrogen in sediment levels would take 13 years to stabilise, which is a longer time than the stabilization time for the nitrogen in water levels.

Reducing the precipitation would increase the phosphorus in water from 0.72mg/L under current conditions to 0.75 mg/L. Using the BNR would reduce the phosphorus levels to 0.52mg/L whilst diversion of storm drain water to the BNR would reduce them to 0.42mg/L. All the changes would not affect the final level of phosphorus in sediments, which would remain at 1mg/l.

Phosphorus would remain a limiting nutrient with all simulations. The secchi depth would be increased most by diverting the storm water drain to the BNR and be increased most by a decrease in precipitation. The highest levels of chlorophyll a, primary productivity, zooplankton productivity and fish productivity would be caused by a decrease in precipitation and the lowest levels would be obtained by diverting the storm drains to the BNR.

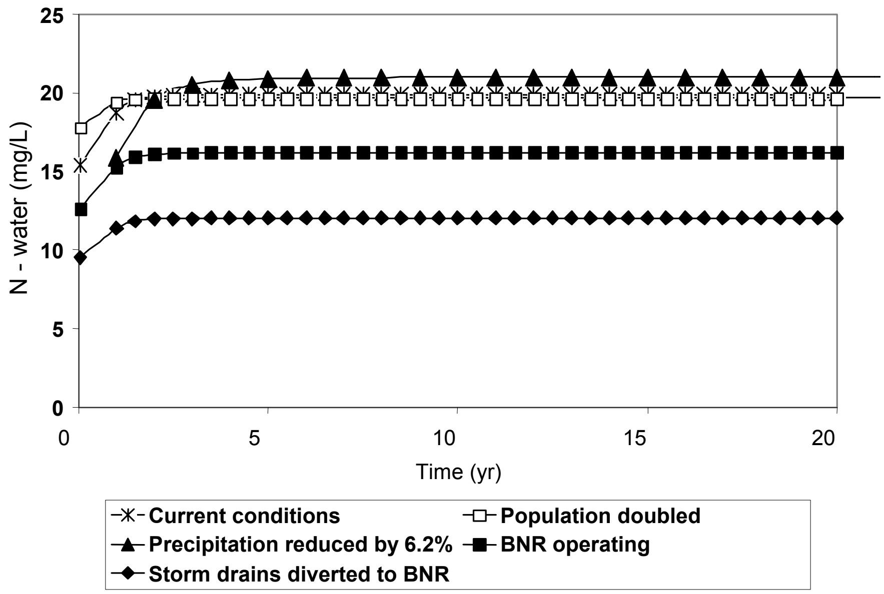


Fig. 27: 20 year simulation of nitrogen in water (mg/L)

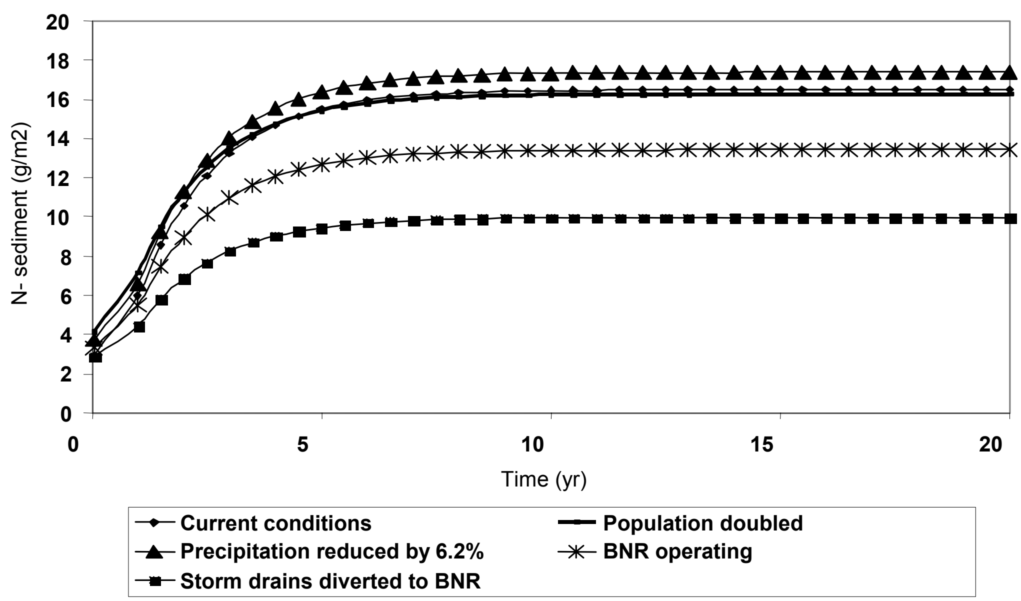


Fig. 28: 20 year simulation of nitrogen in sediments

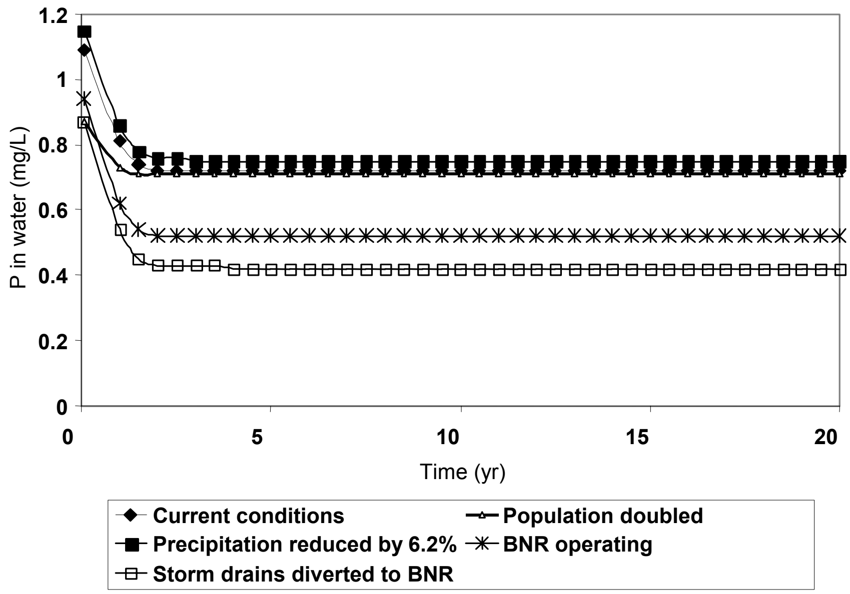


Fig. 29: 20 year simulation of phosphorus in water (mg/L)

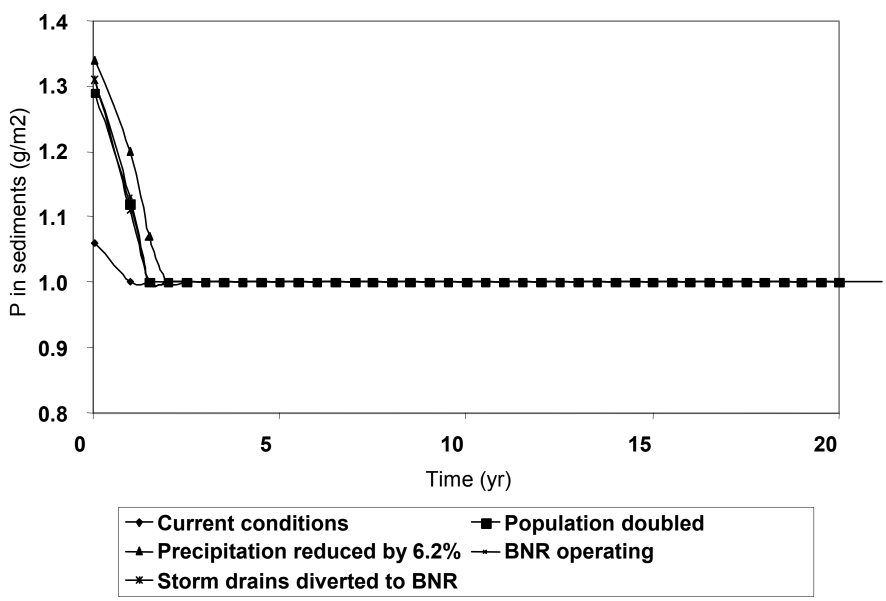


Fig. 30: 20 year simulation of phosphorus in sediments (g/m^2)

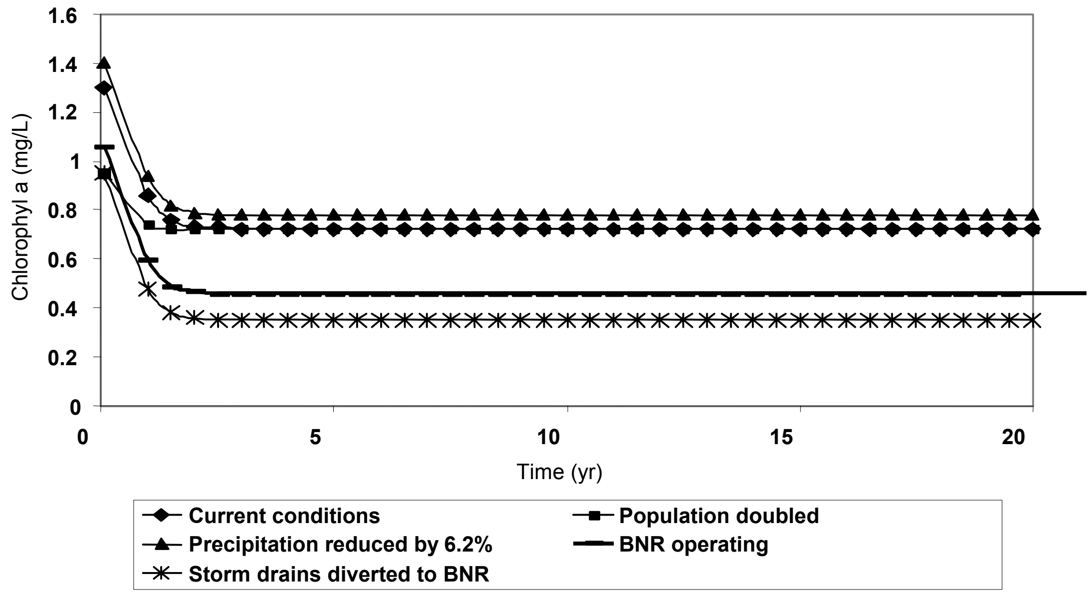


Fig. 31: 20 year simulation of chlorophyll a

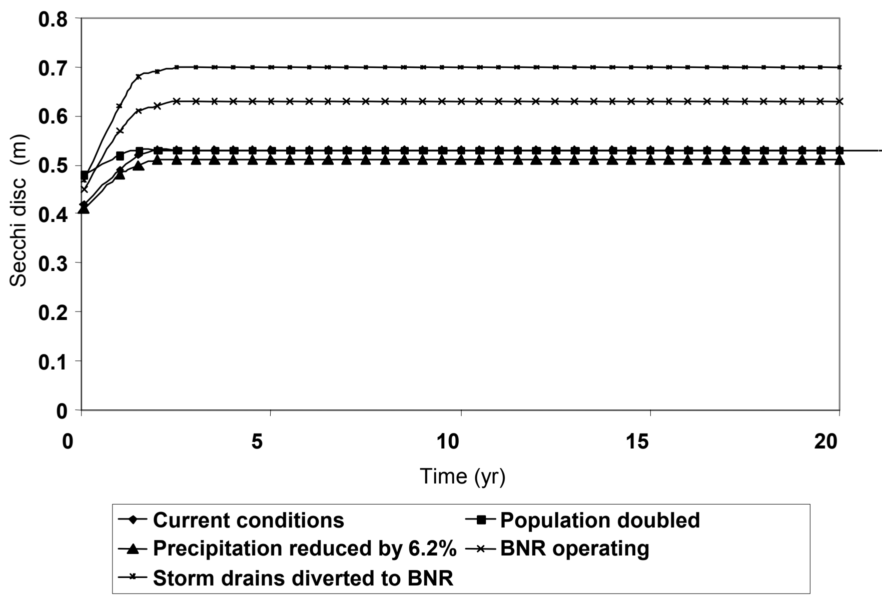


Fig. 32: 20 year simulation of secchi disc depth

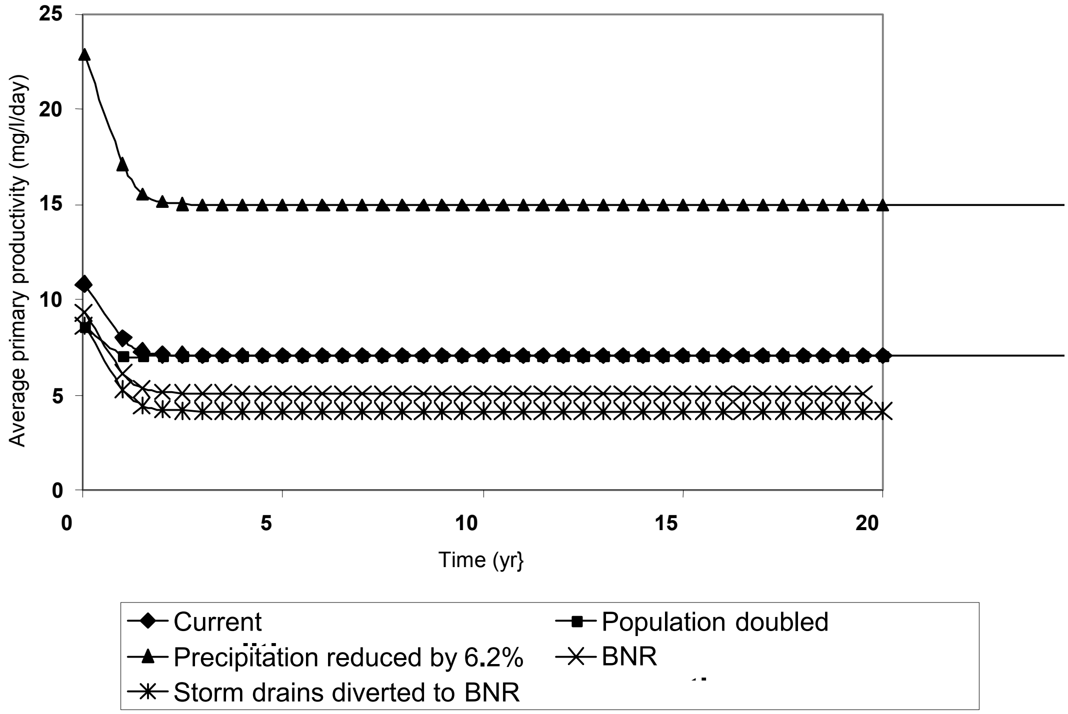


Fig. 33:20 year simulation of average primary productivity

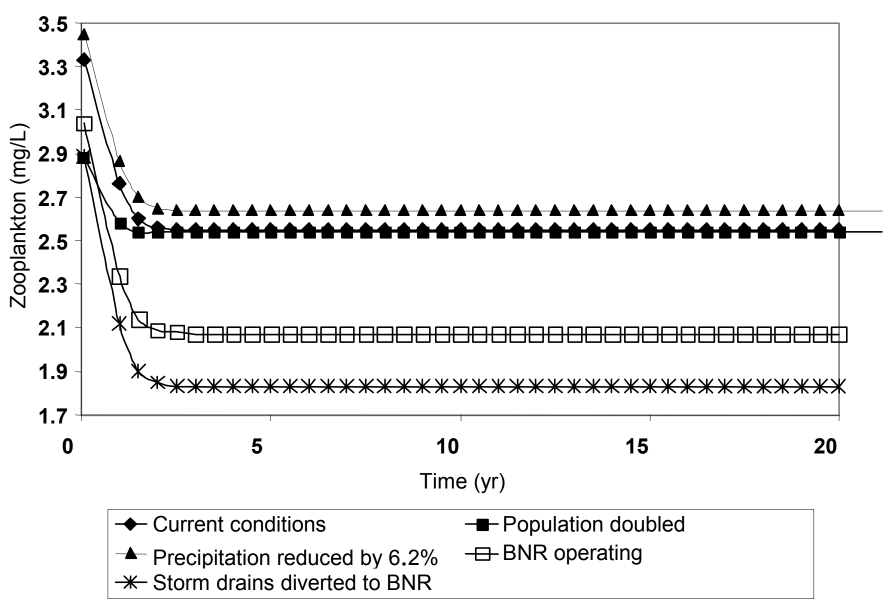


Fig. 34: 20 year simulation of zooplankton productivity

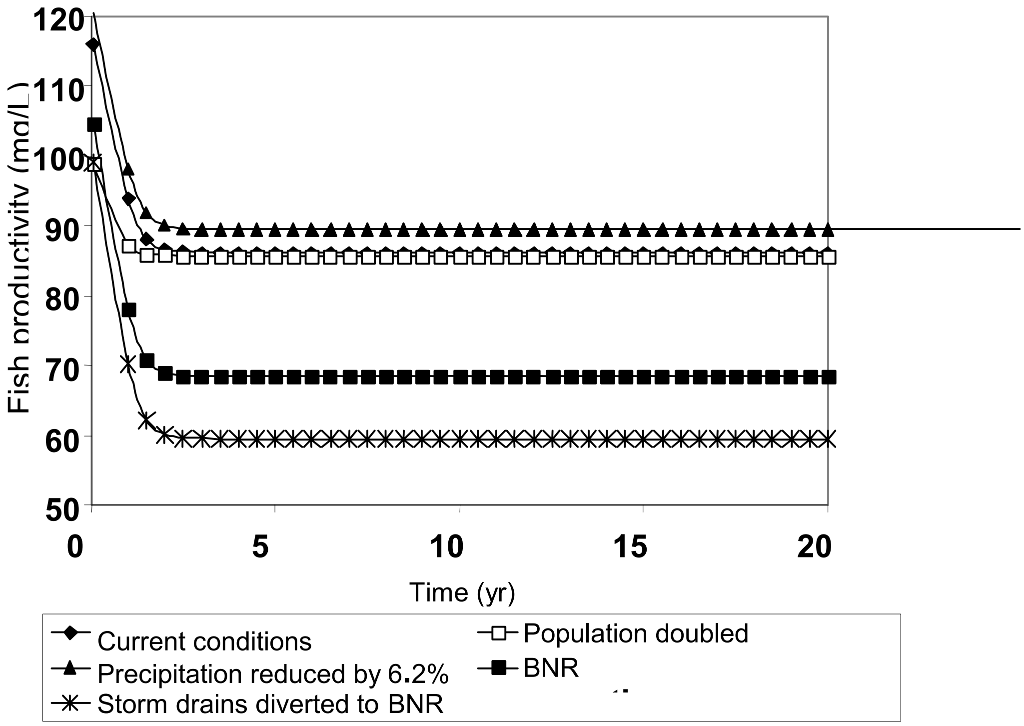


Fig. 35: 20-year simulation of fish productivity

CHAPTER 4

4 DISCUSSION AND CONCLUSIONS

4.1 GENERAL LIMNOLOGY OF THE DAM

With regard to stratification the dam behaved like some African lakes like Lake Chivero (Marshall & Falconer, 1973), with an unstable thermocline and mixing of waters above the14 m depth occurring from March to April. A temperature gradient of water results in a density gradient, which results in stratification. The incomplete mixing could have been due to the inflow waters having a temperature higher than that of the water body at depths below14m (Fig. 4), thus preventing it from sinking and mixing with water below 14m, resulting in the persistence of the thermocline below this depth. The presence of kinks of lower temperature, ORP, Cl, Ph and conductivity as well as a higher DO, in the December depth profiles could be due to an under current of cooler water from the main Nyambuya River. The kinks of higher conductivity, ORP and Cl could be due to an undercurrent of sewage water around 6m depth.

The absence of completely anoxic conditions at the Intake tower could be due to the shallow nature of this part, which makes the water body highly susceptible to mixing by the wind (Cotteril & Thornton 1985) and the influence of heavy storms. At the dam wall end anoxic conditions could have partly been prevented by abstraction of water for irrigation from the bottom and the fact that in 1985 on construction of the dam the river bed and banks were cleared of sediments and vegetation which was replaced with fine sand before the dam was flooded (ZNWA 1986), thus reducing the initial BOD in the hypolimnion. Water abstraction from the bottom removes hypolimnetic water that has low oxygen concentrations and is rich in nutrients, released from the sediments (Table 12), resulting in the hypolimnetic water being replaced by more oxygenated water above it. This set up also has the advantage of removing nutrients from the dam that can be used for growth by the irrigated crops.

The higher pH in the 0-2m column (Figs 7 & 8) in December which coincided with highest nitrate levels (Fig 15) in December and January implies that the euphotic zone falls within this depth. Although the secchi disc depth varied from 0.5 to 0.75 m light can still penetrate as deep as two to three times the secchi depth (Texas Commission on Environmental Quality 2004). The high oxygen levels in the upper layers might explain the lower conductivity in the epilimnion than in the hypolimnion. The higher oxygen levels in the epilimnion coupled with the presence of iron from the laterite observed in the area, might promote precipitation of ions whilst the low oxygen levels of less than 2mg/L in the hypolimnion in November (Appendix Table B) and December (Table 4) could promote resolubilisation of cations like Ca^{2+}, Mg^{2+}, K^+ and Na^+ as well as anions like $NO_4^-$and $PO4_3^-$ (Nduku, 1976). This could happen because an oxygen concentration of 2mg/L is the critical level for the release of soluble phosphorus from sediments (Broch 1993).

The average conductivity of the dam of 246.78µS/cm and Ph of 7.35 were less than those of Lake Chivero, 480 µS/m and 8.5 respectively (Marshal, 1997) implying that the dam had not yet reached Lake Chivero's level of eutrophication. This could be due to the fact that only one industry, a small brewery releases wastewater into the sewage stream of Marondera town, compared to many industries in Harare. The conductivity of

246.78µS/cm places it in the class I type lakes of Talling & Talling (1965) together with lakes Malawi and Victoria (Oliver, 2002). Such reservoirs get their water from direct surface runoff of rivers with little salt (Talling & Talling, 1965).

The concentrations of total nitrogen and phosphorus in the dam were above the EPA standards for reservoirs (Appendix E) of 0.492 mg/L for N and 0.032 mg/L for P (Texas Commission on Environmental Quality, 2004). At the Intake tower where drinking water is abstracted from, the total phosphorus exceeded 1 mg/L, which might pause problems to water treatment since such high phosphorus levels reduce the complete removal of organic particles, which harbour microorganisms during water treatment, by interfering with the coagulation process (Murphy, 2002). The nitrate concentration at the intake tower of 7.88 mg/L was below the recommended 10 mg/L, which is the critical level for the prevention of methemoglobinemia, in infants below six months (Cassia County Groundwater Quality Advisory Committee and Technical Advisory Committee, 2004). The concentrations of total nitrogen and phosphorus (Tables 2 & 3) in the dam water imply that considerable amounts of precipitants need to be used to reduce the nitrogen and phosphorus concentrations during water treatment. Management in this dam should therefore focus at reducing the phosphorus and nitrogen levels after identifying the main sources of these nutrients.

The nitrate levels above 0.5 mg/L in the dam (Walk, 2004) and phosphorus concentrations exceeding 0.020 mg/L (Muller and Helsel, 1999) are considered to make a water body eutrophic. According to South African standards of the trophic status of reservoirs where phosphorus levels ranging from 0.145 to 0.545 mg/L are indicative of a hypereutrophic state (Magadza, 2003), Rufaro dam is in a hypereutrophic state (Tables 3 & 4). With reference to the Vollenweider plot (Fig 1) the dam is eutrophic.

The ratio of total nitrogen to phosphorus of 2: 3 and loading ratios of 2N: 3P could mean that nitrogen is the limiting nutrient in Rufaro dam (Robarts, 1981). This might be causing the proliferation of blue green algae that can fix nitrogen. The growth of blue green algae could be the cause of the bad taste, nasty odour of the drinking water (Marshall, 1997) and the prevalence of diarrhoeal diseases after heavy floods in Marondera town. The dam wall pH (8.15) could be a result of algal blooms (Thornton, 1980).

The reactive phosphorus concentrations of 0.75mg/L were higher in Rufaro dam that was constructed in 1985 than the Lake Chivero value of 0.65 mg/L in 2000 (Magadza, 2003) after 48 years of construction as well as those of lakes Victoria, Malawi and Tanzania, which were less than 0.03 mg/L. The higher concentrations could be a result of the higher phosphorus loadings of 40.35 g / m^2 in Rufaro dam coupled with the smaller size of the dam ($5.25 * 10^6$ m^3), compared to 13.99 g / m^2 of the Lake Chivero 1990-1996 value with a maximum capacity of $2.50*10^{11}$ m^3. Rufaro dam receives partially pond treated sewage water whilst Lake Chivero was receiving water treated using the Biological Filter and BNR methods. The sewage ponds have been in operation since pre-independence and they have therefore become shallower, consequently overflowing easily, since they tend to fill due to settling of bacteria and algae (Aiezza & Streeter, 2004). The overflowing problem is exacerbated by the frequent break down of old pumps which, should pump the sewage effluent from the primary ponds in Dombotombo high density suburb to a secondary pond system, which discharges the effluent into the Save catchment.

4.2 NUTRIENT CONCENTRATIONS IN THE STREAMS AND THE DAM OVER THE SAMPLING PERIOD

The general trend was a decrease in the concentration of all the nutrients in the water from November to April at all the sites, which were sampled (Figs 18 -21), which could be a result of dilution by the rains and use of nutrients by plants during the growing season. A noteworthy feature is the occurrence of peaks and dips in the level of nutrients in each stream, particularly the sewage stream and the storm drains, over the sampling period implying the episodic release of nutrients into the streams.

The CSC stream and the main river generally recorded low levels of nutrients throughout the sampling period compared to all the streams. The average concentrations of reactive phosphorus downstream of the main river and total phosphorus in the CSC stream were above EPA standards. The higher concentrations of total phosphorus and nitrates upstream of the main river than down stream could be a reflection of fertilizer use by the farmers and since the nitrate level was above EPA standards for surface streams (Appendix E), it could imply that the fertiliser applications could be too much for the type of crops grown in the area and the type of soil (Ingerstad 1977). The fact that all parameters in the Nyambuya River tributary were lower than ZNWA standards(Appendix E) implies that the Nyambuya river could also be a subject of diffuse pollution from the nearby Dombotombo high density suburb.

The Sewage stream generally recorded the highest levels of all other nutrients, except NO_3 throughout the sampling period implying that sewage effluent is the major source of nutrients and therefore control of eutrophication should aim at reducing nutrients in this source. Total phosphorus, reactive phosphorus, nitrate, TDS, and conductivity levels in the sewage effluent at the point of entry into the dam were above ZNWA standards for disposal into a surface water system.

The storm drains (Tables 9 and 10) showed an almost similar pattern to the sewage stream, with the exception of conductivity levels thus concurring with the PCA groupings. The feature of total phosphorus exports exceeding total nitrogen exports contradicted Thornton and Nduku's findings (1981) and might be evidence for the storm drain water concentrations being heavily influenced by sewage effluent, probably through overflowing of the primary ponds in Dombotombo Township, blocked sewers and burst sewage pipes. The higher levels of nitrates downstream of the storm drains than upstream in both the Dombotombo storm drain and the CSC stream could be due to stream bank cultivation along the entire main storm drain streams.

The simultaneous occurrence of peak concentrations of total phosphorus and nitrate in the sewage stream and the dam wall area in early December could imply a dominating influence of sewage effluent on the dam water during the dry hot season. Hence Marondera town residents could have been depending mostly on recycled sewage water during the hot dry weather in early December before the rains. (NB* December sampling was done before the rains had started). The coincidence of the storm drain and the dam wall peaks for reactive phosphorus in November could imply that most of the flow into the dam in November came from the storm drains. Thus the storm drains and the sewage stream might be the major inflows into the dam during the dry season. These two streams should be the targets for control of nutrients.

4.3 THE NUTRIENT LOADINGS

The periods of peak loadings coincided with periods of peak precipitation in the main river, but in the sewage stream the highest precipitation in December did not coincide with the largest loadings which occurred in March probably because the main sewage pipe burst in March and raw sewage was diverted into this stream without passing through stabilisation ponds and such events create problems in the control of eutrophication (Mason 1996). Maximum loadings of the various nutrients in the main river occurred mainly in December and March at peak precipitation, which according to Thornton (1979) causes high flow rates, which are weakly correlated with phosphorus loadings and probably other nutrients.

The storm water drains exported the second highest loadings of reactive phosphorus and total nitrogen, but they exported the highest quantities of nitrates and the lowest total phosphorus loadings. The ratio of total nitrogen to total phosphorus loadings of 1:1 in storm drains did not conform with the 6:1 to 35: 1 range found by Thornton and Nduku (1981) for Southern African catchments, probably signifying the heavy influence of sewage effluent on the storm water drains.

The main river exported the least quantities of total nitrogen and reactive phosphorus, but exported the second highest quantities of nitrates, which could reflect fertiliser applications by rural farmers within the catchment (Thornton and Nduku, 1981) or diffuse pollution of the river water from the nearby Dombotombo high density suburb and probably seepage. The peak total phosphorus loadings in the main river which occurred in January and March and high nitrate loadings between December and February coincided with the growing season of tobacco, paprika and maize, the main crops grown in this area, again a probable reflection of the role of fertiliser use in the catchment.

4.4 THE PRINCIPAL AND DISCRIMINANT ANALYSES.

The PCA plot confirmed the analysis of variance result that the sites were different in their physical and chemical properties. Along PC 1, conductivity, TDS, total phosphorus and nitrogen were positively correlated, because conductivity reflects the amount of ions in a water sample. Thus high TDS, total phosphorus and nitrogen content would increase conductivity. ORP was negatively correlated to conductivity because ORP is the potential to oxidise contaminants (Lowry and Dickman, 2004) e.g. remove electrons from negative ions thus reducing the quantity of ions.

Along PC 2 dissolved oxygen and turbidity were positively correlated probably because as phytoplankton productivity increases the oxygen production increases whilst the increasing phytoplankton density increases turbidity. pH was positively correlated to DO probably because as the phytoplankton photosynthesise in the water they release oxygen and increase pH by removing carbon dioxide that forms carbonic acid in aqueous solution.

A discriminant analysis of the groups showed that the groups from the PCA plot could be relied upon as it produced the percentages of correct observations ranging from 75% to 90% (Table 17). The discriminant analysis put the December CSC observations into the dam wall group probably because the December samples were collected before the rains, when the flow comes entirely from the water purifying works. The January and April Dombotombo storm drain observations were classified with the rivers after discriminant analysis, maybe because the samples were collected after heavy downpours which had a diluting effect on nutrient concentrations. The April dam wall observations were grouped with the sewage streams and storm drain observations probably due to mixing of nutrients by turnover (Nduku, 1976) as implicated by the nitrate profiles at the dam wall (Fig 16). The March dam wall observations were put in the same group as the rivers probably because most of the inflow into the dam had been coming from the main river.

4.5 PAMOLARE MODELLING

The increase in nitrogen levels under the current conditions could be due to continuous loadings from sewage addition. The initial loading ratio of nitrogen to phosphorus was 1:2 and according to Robarts (1981) such ratios produce systems that are nitrogen limited. In such systems nitrogen fixing blue green algae overcome the limitation (Robarts, 1981), thus allowing the nitrogen levels to rise with continued addition of sewage effluent. Eventually the nitrogen levels would get to levels which inhibit nitrogen fixation, but permit other algal species to proliferate to levels where the nitrogen input would balance the nitrogen uptake from the water resulting in the leveling off of the nitrogen levels after about four years as predicted by the model. The nitrogen levels in the sediments would increase probably due to increased sedimentation of phytoplankton as nitrogen levels rise, coupled with low denitrification rates due to the high oxygen levels of about 6.57mg/L in the water column. Decomposition of the sediments might occur, but because of the incomplete mixing of water, the nitrogen released would remain at the water sediment interface thus maintaining high nitrogen levels in the sediments.

The model predicted that the phosphorus levels would fall. This could happen as a result of increase in algal biomass as a result of increase in nitrogen levels as predicted and explained above, which would result in the massive absorption of phosphorus coupled with precipitation of PO_4-P by combining with the Fe^{3+} from the laterite in the area, thus reducing phosphorus levels in the water column. Phosphorus would then become a limiting nutrient as predicted, causing a reduction in primary productivity. The fall in primary productivity would result in less food for zooplankton. Both reduced primary and zooplankton productivity would result in the fall of fish productivity.

Doubling the population as predicted by the model would cause a very small fall to negligible change on the total nitrogen in water and sediments, phosphorus in water, chlorophyll a and the average primary, zooplankton and fish productivity and no change on the secchi depth and phosphorus in sediments. This implies that under the current conditions, five years from now, which is the doubling time of Marondera population there would be very little change in the dam parameters. Phosphorus would however be the limiting nutrient and the water quality manager would have to work at reducing phosphorus loadings into the dam in order to reduce eutrophication. The municipal authorities would have to seek alternative means of treating sewage other than the pond system. For long term planning more simulations with the population trebled, quadrupled and so on need to be done, as five years would be a very short period for planning purposes.

The higher levels of total nitrogen, total phosphorus coupled with increased primary and secondary productivity effected by the reduction of precipitation imply the inevitable occurrence of eutrophic conditions during years of drought or lower rainfall and consequences of global climate change. Planning for such eventualities is imperative with the solution lying more in managing the consumption of water rather than demand management.

The decrease in nutrients by installation of the BNR to 16 mg/L total nitrogen and 0.52 mg/L of phosphorus within one and half years would still leave the dam hyper eutrophic according to South African standards (Magadza, 2003). Methods of reducing nutrients from the BNR effluent would still need to be effected. Whilst diversion of storm drain water to the BNR would further reduce the nutrients to 12 mg/L total nitrogen and 0.42 mg/L total phosphorus, the water body would still be hyper eutrophic according to South African standards and according to EPA reference criteria of 0.492 mg/L total N and 0.032 mg/L total P (Appendix E), these levels would still be too high.

The decrease in nutrients caused by the BNR would be desirable, but it would be coupled with a reduction in primary, zooplankton and finally fish productivity. However since the primary purpose for the construction of the dam was provision of water to Marondera residence reduction of nutrients getting into the dam should be a priority.

The model is useful in predicting changes in nutrients and productivity, but it has some shortcomings. The model assumes that the state variables i.e. total nitrogen and phosphorus remain the same throughout the whole period, yet under natural conditions these will vary. The model also assumes that conditions are similar in all dams and yet climate varies with regions, altitude and seasons, which would affect factors like turnover, water residence time and productivity rates.

4.6 CONCLUSIONS

The limnological parameters of the dam showed that the dam behaved like any other African dam. A considerable amount of nutrients were being lost through the outlet for irrigation water. The total nitrogen to total phosphorus ratio of 1: 2 implied that the dam was nitrogen limited and blue green algae species could be the main photosynthetic species which could be causing water treatment problems as well as the undesirable smell and taste of the water.

The major sources of nutrients were the sewage effluent and storm drains with the main river exporting a significant amount of nitrates, hence implying the heavy use of fertilizers in the catchment. Stream bank cultivation along the storm drains could be playing a part in polluting the dam. ZNWA fines seem to be effective at motivating the major polluter, the municipal authority to repair their pumps speedily.

Modelling with PAMOLARE predicted an increase in total nitrogen levels to 19.9mg/L in six years time and a decrease in total phosphorus levels to 0.72mg/L, with phosphorus becoming a limiting nutrient in 2years time. These adjustments would result in reduced productivity within the dam.

Further modelling at 6.2% reduced precipitation predicted higher maximum levels of total nitrogen (20.98mg/L) and higher levels of total phosphorus (0.75mg/L) coupled higher productivity and reduced light penetration. The use of the BNR was expected to reduce total nitrogen by 20% and total phosphorus by 28%, whilst the diversion of storm drains to the BNR would further reduce the total nitrogen by 40 % and total phosphorus by 42%These reductions would however not bring the dam to mesotrophic or oligotrophic status and would need to be backed up by other methods of sewage treatment like irrigation, wetlands and precipitation.

4.7 MANAGEMENT OPTIONS

The loadings show that sewage is the major source of phosphorus into Rufaro dam. The management option to this problem would be the installation of a BNR, which is already under construction in Marondera town. Urgent completion of this plant should be made a priority to facilitate the management of eutrophication in the dam. However as discussed above the installation of the BNR alone would not completely solve the problem. Thus the diversion of storm drain water to the BNR for treatment would help to improve the situation, but would not meet the EPA reference criteria (Appendix E). Additional options would have to be considered.

One alternative option would be to use the effluent from the BNR for irrigation of pastures (Williams, 1970) that the council could hire out to people interested in using the pastures. The effluent could also be used for the irrigation of grain crops using the flooding method. Since the Municipality has a farm, women who are engaging in stream bank cultivation along the storm drains could get involved in a project where they would grow grain crops for sale, irrigating their crops with the sewage effluent and pay a fee to the Municipality for using their land and the water. This might reduce poverty, which forces them to resort to stream bank cultivation.

However irrigation poses some problems such as: (i) For every 5 mega litres of sewage effluent, 400 acres of land must be available (Williams,1970)

(ii) Irrigation is limited to grain crops as salad crops may be contaminated with coliform bacteria resulting in the spread of waterborne diseases.

(ii) The sewage effluent is discharged on a daily basis and must be disposed of on a daily basis even during the rainy season when irrigation may not be needed. However, considering the threat of reduced precipitation due to global climate change this option is worth considering as it has worked for Lake Chivero (Thornton, 1981).

The effluent could also be passed through a constructed/ artificial wetland which can remove about 55-80% of the organic matter and 55-85 % of suspended solids (Zipper, 2003).The wetlands could be reed beds or water tolerant grass species. The artificial wetlands have the disadvantage of having high phosphorus removal efficiency at the beginning that decreases with time. They are however fairly cheap to construct and to maintain compared to other sewage treatment plants (Zipper, 2003).

The application of chemical precipitants such as calcium, aluminium or iron salts (Williams, 1970) to the wastewater is another alternative. The precipitants precipitate the phosphorus, the limiting nutrient that can then be filtered out. This however tends to be expensive as most of the chemicals have to be imported.

Educating farmers on the correct use of fertilizers could solve the problem of high nitrate levels in the main river. It would help to encourage the farmers to have their soils analysed to enable then to use the correct amounts of fertilizer for the right type of crop to reduce wastage and loss into water systems.

The banning of phosphorus containing detergents is another alternative (World Lake Vision Committee, 2003), but this may not be feasible in a developing country like Zimbabwe.

Considering the threat of water shortage due to global climate change a change in water consumption management rather than water demand management should be considered. The reduction of consumption would reduce the amount of sewage effluent, hence the nutrient load.

The control of garbage (World Lake Vision Committee, 2003) through sweeping streets and efficient refuse removal to reduce the export of organic matter into water systems would be a backup to sewage treatment. The conservation of vegetation and control of erosion would help reduce eutrophication.

The success of water consumption management, garbage control, soil erosion prevention, conservation of vegetation and the stoppage of stream bank cultivation would require public awareness and education backed with appropriate legislation. The public awareness could be by electronic media, pamphlets, primary and secondary school syllabi and the participatory approach.

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Appendix B: Raw data for the six sampling sessions at the different sites

Actual date	Site	Cond	Ph	DO	TEMP	Turb	TDS	ORP	Cl	NO_3	Ca	TotN	Orth P	Tot P
3/11/03	Ny D	10.61	6.36	6.16	25.6	-1.1	0.07	38	319	1.15	0.82	4.5	0.11	1.04
3/11/03	Ny D	9.67	6.2	6.5	26.3	1.1	0.05	40	228	1.1	1.35	3.9	0.13	1.02
3/11/03	Ny D	10.51	6.2	6.5	24.8	1.1	0.08	43	292	1.14	1.79	4.3	0.15	1.03
3/11/03	Sd d	14.22	7.07	7.8	26.2	1.1	0.36	37	1.11	1.18	0.57	18.2	4.1	2.1
3/11/03	Sd d	15.03	7.4	6.4	26.5	1.1	0.11	24	0.382	1.15	0.66	17.2	4.3	2.4
3/11/03	Sd d	14.61	7.2	7.1	26.3	1.1	0.26	37	0.987	3.35	1.26	17.4	4.5	3.28
3/11/03	Sew D	23.2	9.7	6	25.5	0.22	0.06	40	350	2.38	0.31	7.2	6.7	3.65
3/11/03	Sew D	26.5	9.16	7.3	23.7	0.22	0.15	61	434	1.76	0.21	8.7	6.93	3.37
3/11/03	Sew D	26.1	8.38	7.5	23.4	0.22	0.12	46	410	1.53	0.22	8.2	5.98	3.5
3/11/03	Out	22.28	6.53	5.2	21.3	0.11	0.14	50	531	0.817	1.92	1.8	0.22	0.41
3/11/03	Out	22.31	6.2	5.4	21.3	0.11	0.17	51	670	1	2.99	1.5	0.2	0.44
3/11/03	Out	22.3	6.3	5.3	21.2	0.11	0.16	48	657	1.34	3.07	1.3	0.25	0.42
3/11/03	DW	20.71	7.11	2.2	21.8	-0.11	0.07	48	227	0.86	0.69	2.4	1.57	0.91
3/11/03	DW	20.71	7.11	2.2	21.8	-0.11	0.07	48	227	0.86	0.69	2.4	1.57	0.91
3/11/03	DW	20.71	7.11	2.2	21.8	-0.11	0.07	48	227	0.86	0.69	2.4	1.57	0.91
9/12/03	Ny D	8	7.08	4.43	31.3	53	0.05	68	0.217	19	1.6	0.5	0.22	0.9
9/12/03	Ny D	6.6	7.09	4.17	29.1	94	0.04	52	0.254	17.7	2.86	0.5	0.22	0.9
9/12/03	Ny D	7.4	7.31	4.9	28.3	54	0.05	59	0.266	15.9	99.9	0.4	0.25	1.5
9/12/03	CSC	10.6	5.85	2.52	22	-45	0.06	-9.8	1.1	11.6	0.02	0.42	0.92	1.4
9/12/03	CSC	10.5	5.73	2.6	22.1	-52	0.06	-8	1.5	11.3	0.15	0.5	0.86	1.6
9/12/03	CSC	10.8	5.92	2.41	21.8	-39	0.06	-12	1	11.9	0.15	0.36	0.99	1.7
9/12/03	Sd d	13	8.26	4.9	23.3	55	0.08	13	2.34	15.1	0.03	0.3	0.25	2.4
9/12/03	Sd d	12.1	7.92	5.1	22.7	50	0.08	20	1.64	15.6	0.06	0.6	0.19	2.6
9/12/03	Sd d	11.8	7.83	4.96	22.7	48	0.08	40	1.85	14.4	0.01	0.7	0.23	2.2
9/12/03	Sew D	77.7	6.9	3.2	20.1	-10	0.5	-44	16.6	15.2	0	23	8.42	6.6
9/12/03	Sew D	80.2	7	3.27	19.3	130	0.51	-65	21.3	15.6	0	23.2	9.09	10.3
9/12/03	Sew D	80.5	7.08	3.3	19.3	86	0.51	-49	23.2	14.7	0	21.4	9.03	9.7
9/12/03	Out	23.7	6.29	5.6	18.3	20	0.15	-92	3.9	16	0.12	2.7	0.18	1.5
9/12/03	Out	23.7	6.39	5.26	18.2	37	0.15	-99	2.97	15	0.15	2.3	0.11	2.6
9/12/03	Out	23.9	6.62	5.19	18.3	1	0.16	-100	5.91	14.6	0.17	3.6	0.16	2.2
9/12/03	DW	24.82	5.88	1.84	24.12	0.11	0.08	-31.5	556.8	1.19	223.6	1.97	1.26	5.6
9/12/03	DW	24.82	5.88	1.84	24.12	0.11	0.08	-31.5	556.8	1.19	223.6	1.97	1.26	5.6
9/12/03	DW	24.82	5.88	1.84	24.12	0.11	0.08	-31.5	556.8	1.19	223.6	1.97	1.26	5.6
9/12/03	IT	24.97	8.13	5.6	23.3	4.71	0.17	0.67	3.84	15	1.01	0.8	0.08	5.8
9/12/03	IT	24.97	8.13	5.6	23.3	4.71	0.17	0.67	3.84	15	1.01	0.8	0.08	5.8
9/12/03	IT	24.97	8.13	5.6	23.3	4.71	0.17	0.67	3.84	15	1.01	0.8	0.08	5.8
8/1/04	Ny D	9.9	7.3	8.56	23.9	-10	0.06	-2	9.02	12.4	99.9	1.1	0.26	2.7
8/1/04	Ny D	10	6.89	8	23.8	-10	0.06	15	11.5	12.7	99	0.4	0.2	3.2
8/1/04	Ny D	9	6.74	8.55	23.7	-10	0.06	14	10	12.1	99.9	1.2	0.25	1.8
8/1/04	Ny U	9	7.42	8.55	23.7	-10	0.06	43	10.8	11.8	99.9	0.3	0.12	2.5
8/1/04	Ny U	10	7.23	8	23.7	-10	0.06	47	10.8	10.5	86.2	0.8	0.13	2.5
8/1/04	Ny U	9	6.9	7.69	23.7	-10	0.06	52	11.4	10.1	99.9	0.5	0.15	2
8/1/04	Ny T	6	6.09	7.92	23.3	-10	0.04	75	5.06	8.77	4.09	2.9	0.03	1.6
8/1/04	Ny T	4	5.6	8.51	22.1	-10	0.03	77	4.97	8.13	4.34	3	0.12	2.4
8/1/04	Sd D	38	6.84	9.77	25.3	250	0.26	17	89.4	11.2	0.01	7.5	2.08	2.7

Actual date	Site	Con	Ph	DO	TEMP	Turb	TDS	ORP	Cl	NO_3	Ca	TotN	Orth P	Tot P
8/1/04	Sd D	38	7.12	6.53	25	220	0.25	60	107	12.1	0.02	8.9	2.29	3.1
8/1/04	CSC	10	5.7	8.42	21.4	-99	0.06	17	25	8.21	0.14	0.4	1.28	1.7
8/1/04	CSC	9	5.93	6.89	21.3	-100	0.06	23	32	8.34	0.31	1	1.18	1.9
8/1/04	CSC	9	5.83	7.82	21.5	-99	0.06	19	29	8.24	0.38	0.2	1.29	1.9
8/1/04	Sd d	18	7.18	8.5	26.2	210	0.12	-5	34	12.5	0.02	1.5	0.28	3.2
8/1/04	Sd d	18	7.28	8.28	26.1	280	0.12	2	33.9	11.5	0.01	2.5	0.36	3.5
8/1/04	Sd d	18	7.31	8.38	26.1	270	0.12	2	31.6	11.4	0.01	1.8	0.33	4.1
8/1/04	Sew U	87	7.26	6.75	24.6	190	0.57	-112	146	13.5	0.13	39	4.07	7.3
8/1/04	Sew U	88	7.32	7.55	24	210	0.57	-103	175	12.3	2.58	24	3.73	7.4
8/1/04	Sew U	89	7.34	6.29	23.8	230	0.57	-105	220	11.9	4.37	34	3.92	7.8
8/1/04	Sew D	56	7.09	6.89	22.7	240	0.35	-2	219	11.6	0	8.5	2.36	3.3
8/1/04	Sew D	55	7.12	5.41	22.9	220	0.35	6	243	11.4	0	9.3	2.93	3.9
8/1/04	Sew D	55	7.11	7.98	23	218	0.35	15	257	11.8	0	8.9	3.04	2.6
8/1/04	DW	31.71	6.91	2.54	19.3	48.4	0.23	-157.6	216.1	14.23	13.77	3.9	0.31	2.87
8/1/04	DW	31.71	6.91	2.54	19.3	48.4	0.23	-157.6	216.1	14.23	13.77	3.9	0.31	2.87
8/1/04	DW	31.71	6.91	2.54	19.3	48.4	0.23	-157.6	216.1	14.23	13.77	3.9	0.31	2.87
8/1/04	IT	22.3	7.47	6.45	24	-10	0.15	-4.83	101.03	16.93	4173.55	3.23	0.22	2.97
8/1/04	IT	22.3	7.47	6.45	24	-10	0.15	-4.83	101.03	16.93	4173.55	3.23	0.22	2.97
8/1/04	IT	22.3	7.47	6.45	24	-10	0.15	-4.83	101.03	16.93	4173.55	3.23	0.22	2.97
9/2/04	Ny D	8	6.4	8.1	24	170	0.05	36	6.27	3.89	1.6	2.8	0.61	0.51
9/2/04	Ny D	8	6.5	7.6	23.4	190	0.05	32	6.95	3.93	99.9	0.1	0.67	1.12
9/2/04	Ny D	8	6.1	7.6	24.1	180	0.05	47	7.33	3.93	0.71	1.6	0.65	1.11
9/2/04	Ny T	21	8.57	8.4	22.9	210	0.11	146	6.43	6.22	0.1	0.5	0.3	1.15
9/2/04	Ny T	8	6.9	8.36	20.9	180	0.04	118	3.11	3.7	0.62	1	0.47	1.09
9/2/04	Ny T	6	7.2	8	20	190	0.03	118	1.76	3.71	1.04	3.7	0.42	1.12
9/2/04	Ny U	10	8.3	7.9	22.7	170	0.06	98	8.57	3.9	0.99	2.3	0.53	0.58
9/2/04	Ny U	9	8.49	8.4	22.5	190	0.06	96	8.55	3.88	2.2	1.2	0.34	0.69
9/2/04	Ny U	8	8.39	7.65	22.1	190	0.05	64	8.4	3.87	1	0.8	0.49	0.67
9/2/04	Sd D	29	7.01	7	22.4	110	0.19	21	150	1.98	0.8	9.4	2.31	2.05
9/2/04	Sd D	28	6.8	6.2	22	90	0.18	13	153	1.54	0.7	11.8	2.35	2.25
9/2/04	Sd D	28	6.9	6.15	22	94	0.18	21	161	1.44	1	8	2.33	2.21
9/2/04	CSC	10	6.7	7.17	20.6	93	0.06	45	58.5	1.39	0.01	1.7	1.43	0.77
9/2/04	CSC	9	6.4	7.1	20.4	95	0.06	7	65.8	1.16	0.01	0.9	1.42	1.29
9/2/04	CSC	9	6.2	6.74	20.5	95	0.06	22	64	1.6	0.01	1.3	1.35	1.25
9/2/04	Sd d	18	6.1	7.69	21.8	170	0.12	36	81.9	1.25	0	2.5	3.26	1.55
9/2/04	Sd d	18	6.2	7.94	21.3	160	0.11	45	80.1	1.29	0	5.2	3.19	2.04
9/2/04	Sd d	17	5.9	7.84	21.3	170	0.11	49	80.1	1.3	0	5	3.23	2.03
9/2/04	Sew U	53	7.35	6	23.6	140	0.34	-118	220	15.9	99.9	15.9	1.85	3.54
9/2/04	Sew U	53	7.48	4.85	23.2	130	0.34	-127	260	13.6	0.3	10.1	1.68	2.51
9/2/04	Sew U	53	7.5	6.08	23.1	140	0.34	-114	230	10	21.7	12	1.78	3.3
9/2/04	Sew D	49	7.2	7	20.1	130	0.32	11	400	13.4	0.09	13	2.02	2.1
9/2/04	Sew D	51	6.8	7	20.1	110	0.33	21	408	13.1	1.47	7.3	2.79	2.14
9/2/04	Sew D	51	6.9	7.15	20	110	0.33	27	418	13.4	0.02	10.9	2.75	2.24
9/2/04	DW	23.09	6.99	4.66	21.4	238	0.19	98.05	88.38	3.54	0.11	3.6	1.22	0.91
9/2/04	IT	21	7.97	7.76	23.18	-6.67	0.14	24.67	57.27	3.35	5550.7	3.4	0.48	0.4
9/2/04	IT	21	7.97	7.76	23.18	-6.67	0.14	24.67	57.27	3.35	5550.7	3.4	0.48	0.4

Actual date	Site	Con	Ph	DO	TEMP	Turb	TDS	ORP	Cl	NO_3	Ca	TotN	Orth P	Tot P
3/12/05	Ny D	10	6.8	9.94	22	26	0.06	68	9.86	4.8	1.02	0.5	1.05	2.4
3/12/05	Ny D	9	6.7	9.1	21.9	17	0.06	66	11.2	4.67	0.83	0.4	1.03	2.1
3/12/05	Ny D	10	7.1	10.33	21.6	8	0.06	78	10.9	4.24	0.74	1.4	1.02	2
3/12/05	Ny U	85	7	9.4	221.8	4.5	0.05	68	11.8	0.01	0.37	0.03	0.39	2.68
3/12/05	Ny U	82	7.2	9.2	21.9	4.8	0.05	67	12.1	0.009	0.35	0.04	0.43	2.66
3/12/05	Ny U	83	7.1	9.1	22	4.7	0.05	69	11.7	0.009	0.33	0.02		2.67
3/12/05	Ny T	14	8.5	10.76	22.9	0	0.07	152	9.82	0.0082	0.68	0.6	0.12	1.4
3/12/05	Ny T	22	7.7	9.32	22.5	0	0.11	173	8.93	0.0058	0.4	0.7	0.13	2
3/12/05	Ny T	16	6.7	9.58	22.3	0	0.11	117	10.5	0.0042	0.01	0.5	0.13	2.4
3/12/05	Sd D	38	6.8	11.59	20.3	5	0.24	114	90.2	0.0052	0.83	8.6	2.54	3.9
3/12/05	Sd D	39	6.8	10.24	20.2	9	0.24	87	106	0.0052	0.85	9.3	3.77	3.8
3/12/05	Sd D	35	6.8	9.5	20.2	4	0.24	76	116	0.0052	0.79	9.3	3.54	2.7
3/12/05	CSC	19	7.3	9.99	19.4	0	0.12	75	79.3	0.0054	0.8	1.7	0.28	1.3
3/12/05	CSC	16	7.1	7.91	19.4	0	0.1	86	89.7	0.0057	0.98	0.4	0.27	1.2
3/12/05	CSC	16	6.4	8	19.4	0	0.1	83	92.2	0.0057	0.8	1.2	0.25	1.5
3/12/05	Sd d	17	8.3	11	21.7	302	0.11	72	110	0.0631	0.02	3.2	1.23	0.9
3/12/05	Sd d	17	7.9	10.11	21.5	310	0.11	74	112	0.0628	0.01	3.1	1	0.6
3/12/05	Sd d	17	7.7	9.08	21.5	280	0.11	76	130	0.0568	0.01	3.4	1.14	0.8
3/12/05	Sew U	41	7.4	10.27	22.7	8	0.26	-128	288	0.0764	0.01	9.7	4.95	7.8
3/12/05	Sew U	40	6.8	6.76	23	8	0.26	-142	331	0.0749	0.02	9.3	8.29	6.8
3/12/05	Sew U	40	6.8	8.84	22.6	8	0.26	-137	301	0.0813	0.02	8.9	4.86	7.5
3/12/05	Sew D	42	6.9	9.92	22.6	5	0.27	-121	391	0.0755	0.02	9.2	3.8	3
3/12/05	Sew D	42	6.7	6.45	22.7	6	0.27	-126	452	0.0759	0.02	10.1	2.28	5.1
3/12/05	Sew D	42	7.1	6.23	22.7	5	0.26	-117	485	0.0846	0.02	8.3	3.75	6.1
3/12/05	DW	23.7	7.2	5.67	21.1	33.1	0.16	46	339	1.25	0.02	1.8	0.08	0.62
3/12/05	DW	23.7	7.2	5.67	21.1	33.1	0.16	46	339	1.25	0.02	1.8	0.08	0.62
3/12/05	DW	23.7	7.2	5.67	21.1	33.1	0.16	46	339	1.25	0.02	1.8	0.08	0.62
3/12/05	IT	19.14	8.57	10.51	22.21	129	0.12	70.86	146	0.15	0.61	0.67	0.3	2.2
3/12/05	IT	19.14	8.57	10.51	22.21	129	0.12	70.86	146	0.15	0.61	0.67	0.3	2.2
3/12/05	IT	19.14	8.57	10.51	22.21	129	0.12	70.86	146	0.15	0.61	0.67	0.3	2.2
15/4/05	Ny D	6	6.4	12.68	20.4	760	0.04	88	19.8	0.12	6.88	0.4	0.07	0.63
15/4/05	Ny D	6	6.5	10.75	19.1	890	0.04	196	23.4	6.28	1.45	0.38	0.05	0.49
15/4/05	Ny D	6	6.1	10.89	19.1	840	0.04	146	34.8	5.09	73	0.41	0.04	0.59
15/4/05	Ny U	6	6.5	12.5	19	820	0.04	99	28	4.55	0.62	0.2	0.16	1.24
15/4/05	Ny U	6	5.7	11.98	19	960	0.04	90	29.6	4.12	0.68	0.3	0.22	1.12
15/4/05	Ny U	6	6.1	11.95	19	820	0.04	82	35.7	4.03	0.66	0.3	0.19	1.19
15/4/05	Ny T	0.007	6.3	9.66	20.5	0	0.04	58	89.7	0.138	3.39	0.8	0.04	0.47
15/4/05	Ny T	0.007	6.6	10.15	19.9	0	0.04	86	64.9	0.134	4.98	0.6	0.02	0.48
15/4/05	Ny T	0.007	5.9	10.02	19.8	0	0.04	94	58	0.121	0.15	0.9	0.03	0.47
15/4/05	Sd D	13	8	14.72	18.6	730	0.08	52	154	3.34	0.03	0.5	0.16	1.43
15/4/05	Sd D	13	7.5	13.61	18.3	820	0.08	73	145	3.36	0.03	0.3	0.15	0.74
15/4/05	Sd D	13	7.8	14.2	18.4	780	0.08	68	150	3.37	0.03	0.45	0.17	1.32
15/4/05	CSC	18	7.2	10.1	19.2	32	0.09	78	82.3	4.83	0.91	0.97	0.23	1.28
15/4/05	CSC	17	6.2	8.22	19.2	31	0.11	76	94.4	4.74	0.89	1.2	0.19	1.23
15/4/05	Sd d	16	8.1	13.2	19.2	292	0.1	73	150	3.55	16.2	0.29	0.9	0.75
15/4/05	Sd d	16	7.3	13.5	19.7	300	0.1	59	140	3.12	15.8	0.32	0.8	0.8

Actual date	Site	Con	Ph	DO	TEMP	Turb	TDS	ORP	Cl	NO_3	Ca	TotN	Orth P	Tot P
15/4/05	Sew U	37	6.9	8.86	22.9	6	0.21	-141	279	0.0742	0.01	7.21	4.03	5.5
15/4/05	Sew U	34	6.8	6.54	22.8	4	0.19	-148	327	0.0728	0.02	6.92	5.23	6
15/4/05	Sew U	35	7.2	9.92	22.9	4	0.19	-143	311	0.0683	0.02	6.46	3.45	5.74
15/4/05	Sew D	40	7.8	8.4	20.5	3	0.25	-110	42.3	4.4	0.01	8.5	3.13	3.4
15/4/05	Sew D	41	7.9	7.5	20.3	5	0.26	-99	19.8	5.6	0.02	8.7	2.87	4.1
15/4/05	Sew D	40	7.6	7.9	20.4	4	0.25	-112	48.2	4.9	0.01	8.4	2.46	3.23
15/4/05	DW	36.2	7.2	9.2	19.5	460	0.13	73	0.78	3.68	0.15	0.65	0.054	0.94
15/4/05	DW	36.2	7.2	9.2	19.5	460	0.13	73	0.78	3.68	0.15	0.65	0.054	0.94
15/4/05	DW	36.2	7.2	9.2	19.5	460	0.13	73	0.78	3.68	0.15	0.65	0.054	0.94
15/4/05	IT	17.75	7.89	11.42	20.21	793.75	0.12	94.63	0.4	3.62	0.06	1.07	0.28	1.11
15/4/05	IT	17.75	7.89	11.42	20.21	793.75	0.12	94.63	0.4	3.62	0.06	1.07	0.28	1.11
15/4/05	IT	17.75	7.89	11.42	20.21	793.75	0.12	94.63	0.4	3.62	0.06	1.07	0.28	1.11

APPENDIX C NUTRIENT LOADINGS

Nyambuya river	P loading				N loading	
Month	Mean m^3/s	Inflow (m^3)	Load (g)	Load (g/m^2)	Load (g)	Load (g/m^2)
Nov	0.001	2160.00	2224.80	0.003	9136.80	0.01
Dec	0.18	488039.00	697895.80	0.86	229378.30	0.28
Jan	0.27	714458.90	1836159.00	2.27	643013.00	0.79
Feb	0.42	1064526.00	968718.40	1.20	1596789.00	1.97
Mar	0.74	1989611.00	4436832.00	5.48	1532000.00	1.89
Apr	0.56	1445049.00	823677.70	1.02	578019.50	0.71
May	0.03	83783.81	122045.10	0.15	115482.00	0.14
June	0.01	18031.68	26266.15	0.03	24853.67	0.03
July	0.01	18411.84	26819.91	0.03	25377.65	0.03
Aug	0.004	11121.41	16200.18	0.02	15329.01	0.02
Sept	0.002	5533.06	8059.82	0.01	7626.40	0.01
Oct	0.002	5745.60	8369.42	0.01	7919.35	0.01
Mean	0.19	5856593.00	8973268.00	11.08	4784924.00	5.91
Sewage stream						
Nov	0.0002	561.60	1971.22	0.002	4509.65	0.01
Dec	0.21	574240.30	5093512.00	6.29	12937634.00	15.97
Jan	0.01	18000.58	58861.88	0.07	160205.10	0.20
Feb	0.10	241377.80	521376.00	0.64	2510329.00	3.10
Mar	0.86	2316643.00	10957722.00	13.53	21313117.00	26.31
Apr	0.16	421537.00	1509102.00	1.86	3595710.00	4.44
May	0.01	19293.12	83989.38	0.10	217337.00	0.27
June	0.003	7499.52	32647.91	0.04	84482.09	0.10
July	0.003	8225.28	35807.39	0.04	92657.78	0.11
Aug	0.002	6246.72	27194.05	0.03	70369.30	0.09
Sep	0.003	6704.64	29187.53	0.04	75527.77	0.09
Oct	0.001	2021.76	8801.40	0.01	22775.13	0.03
Mean	0.11	3622351.00	18360173.00	22.67	41084655.00	50.72
Storm drain						
Nov	0.0003	730.08	1890.91	0.00	12849.41	0.02
Dec	0.28	746512.40	1791630.00	2.21	395651.60	0.49
Jan	0.01	23400.75	85646.74	0.11	45163.45	0.06
Feb	0.13	324997.90	607746.10	0.75	1374741.00	1.70
Mar	1.12	3011636.00	2318960.00	2.86	9727585.00	12.01
Apr	0.21	547998.00	416478.50	0.51	158919.40	0.20
May	0.01	25081.06	50371.12	0.06	116250.70	0.14
June	0.004	9749.38	19580.00	0.02	45188.36	0.06
July	0.004	10692.86	21474.84	0.03	49561.42	0.06
Aug	0.001	8120.74	16309.14	0.02	37639.61	0.05

Month	Mean m^3/s	Inflow (m^3)	Load (g)	Load (g/m^2)	Load (g)	Load (g/m^2)
Sep	0.003	8716.03	17504.70	0.02	40398.81	0.05
Oct	0.001	2628.29	5278.48	0.01	12182.11	0.02
Mean	0.15	4720264.00	5352870.00	6.61	12016131.00	14.83

	PO_4 Loadings		NO_3Loadings	
Nyambuya river				
Month	**Load (g)**	**Load (g/m^2)**	**Load (g)**	**Load (g/m^2)**
Nov	**280.80**	**0.00**	**2440.80**	**0.00**
Dec	**112249.00**	**0.14**	**8555324.00**	**10.56**
Jan	**171470.10**	**0.21**	**8859290.00**	**10.94**
Feb	**681296.50**	**0.84**	**4172941.00**	**5.15**
Mar	**2049299.00**	**2.53**	**0.00**	**0.00**
Apr	**86702.92**	**0.11**	**7947768.00**	**9.81**
May	**32536.05**	**0.04**	**565261.40**	**0.70**
June	**7002.30**	**0.01**	**138533.40**	**0.17**
July	**7149.93**	**0.01**	**111236.50**	**0.14**
Aug	**4318.81**	**0.01**	**55405.04**	**0.07**
Sept	**2148.67**	**0.00**	**28543.98**	**0.04**
Oct	**2231.21**	**0.00**	**34580.53**	**0.04**
Mean	**3156685.00**	**3.90**	**2539277.00**	**3.13**
Sewage stream				
Month				
Nov	**3672.86**	**0.00**	**1061.42**	**0.00**
Dec	**5082027.00**	**6.27**	**8711226.00**	**10.75**
Jan	**50041.60**	**0.06**	**208806.70**	**0.26**
Feb	**531031.10**	**0.66**	**127930.20**	**0.16**
Mar	**7598590.00**	**9.38**	**185331.50**	**0.23**
Apr	**1188734.00**	**1.47**	**2095039.00**	**2.59**
May	**85114.81**	**0.11**	**110099.40**	**0.14**
June	**33085.38**	**0.04**	**42797.26**	**0.05**
July	**36287.19**	**0.04**	**46938.93**	**0.06**
Aug	**27558.45**	**0.03**	**35647.95**	**0.04**
Sep	**29578.64**	**0.04**	**38261.15**	**0.05**
Oct	**8919.33**	**0.01**	**11537.51**	**0.01**
Mean	**15980607.00**	**19.73**	**20671552.00**	**25.52**

Storm drain	PO_4 Loadings		NO_3Loadings	
Month	**Load (g)**	**Load (g/m^2)**	**Load (g)**	**Load (g/m^2)**
Nov	**3139.34**	**0.00**	**1379.85**	**0.00**
Dec	**164232.70**	**0.20**	**11220082.00**	**13.85**
Jan	**7488.24**	**0.01**	**276128.80**	**0.34**
Feb	**1049743.00**	**1.30**	**415997.30**	**0.51**
Mar	**3373032.00**	**4.16**	**180698.20**	**0.22**
Apr	**454838.40**	**0.56**	**1764554.00**	**2.18**
May	**41885.36**	**0.05**	**139116.30**	**0.17**
June	**16281.46**	**0.02**	**54076.54**	**0.07**
July	**17857.08**	**0.02**	**59309.75**	**0.07**
Aug	**13561.63**	**0.02**	**45043.02**	**0.06**
Sep	**14555.77**	**0.02**	**48344.92**	**0.06**
Oct	**4389.24**	**0.01**	**14578.24**	**0.02**
Mean	**430083.80**	**0.53**	**1184942.00**	**330.95**

APPENDIX D

PAMOLARE MODELLING RESULTS

Current Conditions

Simulation for : C:\Program Files\ILEC\Pamolare30\Rufaro 1 layer model.lk1

Simulated period	20.0 year(s)
Printing step	0.500 year
Integration step	0.020 year

Physical data

Lake depth	21.00 m
Water residence time	0.37 year(s)
Sedimentation constant	0.50 m/year
Reduction of nutrient outflow due to thermocline	0.00

Nitrogen data

Initial value of nitrogen in water	2.120 mg/l
Initial value of nitrogen in sediment	0.067 g/m2
Nitrogen loading	56.630 g/m2/year
Sediment release of nitrogen	0.600 /year
Fraction of nitrogen bound in sediment	0.006

Phosphorus data

Initial value of phosphorus in water	2.225 mg/l
Initial value of phosphorus in sediment	0.079 g/m2
Phosphorus loading	40.350 g/m2/year
Sediment release of phosphorus	0.600 /year
Fraction of phosphorus bound in sediment	0.005

Time (Years)	Water N (mg/l)	Sediment N (g/m2)	Water P (mg/l)	Sediment P (g/m2)	Limiting nutrient	Ch la (mg/l)	Secchi depth (m)	Zoopl. (mg/l)	Fish Prod. (mg/l)	Av. Prim. prim prod (g/l/day)	Av max. yield (g/l/day)	Av. Fish prod (g ww/m2/year
0.5	15.41	2.96	1.09	1.06	P	1.30	0.42	3.33	115.94	10.79	21.67	7.72
1.0	18.71	5.95	0.81	1.00	P	0.86	0.49	2.76	93.83	7.99	16.06	5.73
1.5	19.54	8.55	0.74	1.00	P	0.76	0.52	2.60	88.05	7.30	14.68	5.24
2.0	19.76	10.57	0.72	1.00	P	0.73	0.53	2.56	86.60	7.13	14.34	5.12
2.5	19.83	12.09	0.72	1.00	P	0.73	0.53	2.55	86.24	7.09	14.25	5.09
3.0	19.86	13.22	0.72	1.00	P	0.72	0.53	2.55	86.15	7.08	14.23	5.08
3.5	19.87	14.06	0.72	1.00	P	0.72	0.53	2.55	86.13	7.07	14.23	5.08
4.0	19.88	14.69	0.72	1.00	P	0.72	0.53	2.55	86.13	7.07	14.23	5.08
4.5	19.89	15.15	0.72	1.00	P	0.72	0.53	2.55	86.13	7.07	14.23	5.08
5.0	19.89	15.50	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
6.0	19.90	15.94	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08

Time (Years)	Water N (mg/l)	Sediment N (g/m2)	Water P (mg/l)	Sediment P (g/m2)	Limiting nutrient	Chla (mg/l)	Secchi depth (m)	Zoopl. (mg/l)	Fish Prod. (mg/l)	Av. Prim. prim prod (g/l/day)	Av max. yield (g/l/day)	Av. Fish productivity (g ww/m2/year
6.5	19.90	16.08	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
7.0	19.90	16.19	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
7.5	19.90	16.26	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
8.0	19.90	16.32	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
8.5	19.90	16.36	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
9.0	19.90	16.40	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
9.5	19.90	16.42	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
10.0	19.90	16.44	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
10.5	19.90	16.45	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
11.0	19.90	16.46	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
11.5	19.90	16.47	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
12.0	19.90	16.47	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
12.5	19.90	16.48	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
13.0	19.90	16.48	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
13.5	19.90	16.48	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
14.0	19.90	16.48	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
14.5	19.90	16.48	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
15.0	19.90	16.48	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
15.5	19.90	16.49	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
16.0	19.90	16.49	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
16.5	19.90	16.49	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
17.0	19.90	16.49	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
17.5	19.90	16.49	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
18.0	19.90	16.49	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
18.5	19.90	16.49	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
19.0	19.90	16.49	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
19.5	19.90	16.49	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08
20.0	19.90	16.49	0.72	1.00	P	0.72	0.53	2.55	86.12	7.07	14.23	5.08

Simulation for : C:\Program Files\ILEC\Pamolare30\Rufaro 1 layer model pop doubled.lk1
Simulated period 20.0 year(s)
Printing step 0.500 year
Integration step 0.020 year

Physical data
Lake depth 21.00 m
Water residence time 0.23 year(s)
Sedimentation constant 0.50 m/year
Reduction of nutrient outflow
due to thermocline 0.00

Nitrogen data
Initial value of nitrogen in water 2.120 mg/l

Initial value of nitrogen in sediment 1.940 g/m2
Nitrogen loading 89.900 g/m2/year
Sediment release of nitrogen 0.600 /year
Fraction of nitrogen bound in sediment 0.006

Phosphorus data
Initial value of phosphorus in water 2.225 mg/l
Initial value of phosphorus in sediment 1.360 g/m2
Phosphorus loading 64.640 g/m2/year
Sediment release of phosphorus 0.600 /year
Fraction of phosphorus bound in sediment 0.005

Time Years	Water N mg/l	Sediment N g/m2	Water P mg/l	Sediment P g/m2	Limiting nutrient	Chl a mg/l	Secchi depth m	Zoopl. mg/l	Fish mg/l	Av. Prim. Prod. mg/l/day	Av max. prim prod mg/l/day	Av. Fish yield mg ww/m2/year
0.5	17.79	4.19	0.87	1.29	P	0.95	0.48	2.88	98.69	8.58	17.25	6.15
1.0	19.39	7.17	0.73	1.12	P	0.74	0.52	2.58	87.17	7.20	14.47	5.17
1.5	19.57	9.51	0.71	1.00	P	0.72	0.53	2.54	85.90	7.05	14.17	5.06
2.0	19.60	11.26	0.71	1.00	P	0.72	0.53	2.54	85.75	7.03	14.14	5.05
2.5	19.61	12.56	0.71	1.00	P	0.72	0.53	2.54	85.74	7.03	14.14	5.05
3.0	19.62	13.52	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
3.5	19.63	14.23	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
4.0	19.63	14.76	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
4.5	19.63	15.15	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
5.0	19.64	15.44	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
5.5	19.64	15.66	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
6.0	19.64	15.82	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
6.5	19.64	15.93	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
7.0	19.64	16.02	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
7.5	19.64	16.09	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
8.0	19.64	16.13	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
8.5	19.64	16.17	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
9.0	19.64	16.20	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
9.5	19.64	16.21	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
10.0	19.64	16.23	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
10.5	19.64	16.24	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
11.0	19.64	16.25	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
11.5	19.64	16.25	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
12.0	19.64	16.26	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
12.5	19.64	16.26	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
13.0	19.64	16.26	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
13.5	19.64	16.27	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
14.0	19.64	16.27	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
14.5	19.64	16.27	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
15.0	19.64	16.27	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
15.5	19.64	16.27	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
16.0	19.64	16.27	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
16.5	19.64	16.27	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05

Time (Years)	Water N (mg/l)	Sediment N (g/m2)	Water P (mg/l)	Sediment P (g/m2)	Limiting nutrient	Chla (mg/l)	Secchi depth (m)	Zoopl. (mg/l)	Fish Prod. (mg/l)	Av. Prim. prim prod (g/l/day)	Av max. yield (g/l/day)	Av. Fish prod (g ww/m2/year
17.0	19.64	16.27	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
17.5	19.64	16.27	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
18.0	19.64	16.27	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
18.5	19.64	16.27	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
19.0	19.64	16.27	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
19.5	19.64	16.27	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05
20.0	19.64	16.27	0.71	1.00	P	0.72	0.53	2.54	85.73	7.03	14.14	5.05

2014 CONDITIONS

imulation for : C:\Program Files\ILEC\Pamolare30\Rufaro 1 layer model 2014 conditions.lk1

Simulated period 20.0 year(s)
Printing step 0.500 year
Integration step 0.020 year

Physical data
Lake depth 21.00 m
Water residence time 0.39 year(s)
Sedimentation constant 0.50 m/year
Reduction of nutrient outflow
due to thermocline 0.00

Nitrogen data
Initial value of nitrogen in water 2.120 mg/l
Initial value of nitrogen in sediment 1.940 g/m2
Nitrogen loading 56.630 g/m2/year
Sediment release of nitrogen 0.600 /year
Fraction of nitrogen bound in sediment 0.006

Phosphorus data
Initial value of phosphorus in water 2.225 mg/l
Initial value of phosphorus in sediment 1.360 g/m2
Phosphorus loading 40.350 g/m2/year
Sediment release of phosphorus 0.600 /year
Fraction of phosphorus bound in sediment 0.005

Time Years	Water N mg/l	Sediment N g/m2	Water P mg/l	Sediment P g/m2	Limiting nutrient	Chl a mg/l	Secchi depth m	Zoopl. mg/l	Fish Prod. mg/l	Av. Prim. prim prod mg/l/day	Av max. yield mg/l/day	Av. Fish prod mg ww/m2/year
0.5	15.87	3.71	1.15	1.34	P	1.40	0.41	3.45	120.38	11.38	22.85	8.14
1.0	19.53	6.65	0.86	1.20	P	0.94	0.48	2.87	98.14	8.52	17.12	6.10
1.5	20.52	9.26	0.78	1.07	P	0.82	0.50	2.70	91.81	7.75	15.57	5.56
2.0	20.80	11.31	0.76	1.00	P	0.79	0.51	2.65	90.03	7.53	15.15	5.41

Time (Years)	Water N (mg/l)	Sediment N (g/m2)	Water P (mg/l)	Sediment P (g/m2)	Limiting nutrient	Chla (mg/l)	Secchi depth (m)	Zoopl. (mg/l)	Fish Prod. (mg/l)	Av. Prim. prim prod (g/l/day)	Av max. yield (g/l/day)	Av. Fish prod (g ww/m2/year
2.5	20.89	12.87	0.76	1.00	P	0.78	0.51	2.64	89.55	7.48	15.03	5.36
3.0	20.93	14.03	0.75	1.00	P	0.78	0.51	2.64	89.42	7.46	15.00	5.35
3.5	20.94	14.89	0.75	1.00	P	0.78	0.51	2.64	89.39	7.46	15.00	5.35
4.0	20.95	15.53	0.75	1.00	P	0.78	0.51	2.64	89.38	7.46	14.99	5.35
4.5	20.96	16.01	0.75	1.00	P	0.78	0.51	2.64	89.38	7.46	14.99	5.35
5.0	20.97	16.36	0.75	1.00	P	0.78	0.51	2.64	89.38	7.46	14.99	5.35
5.5	20.97	16.62	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
6.0	20.97	16.82	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
6.5	20.97	16.96	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
7.0	20.98	17.07	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
7.5	20.98	17.15	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
8.0	20.98	17.21	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
8.5	20.98	17.25	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
9.0	20.98	17.29	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
9.5	20.98	17.31	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
10.0	20.98	17.33	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
10.5	20.98	17.34	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
11.0	20.98	17.35	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
11.5	20.98	17.36	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
12.0	20.98	17.36	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
12.5	20.98	17.37	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
13.0	20.98	17.37	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
13.5	20.98	17.37	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
14.0	20.98	17.37	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
14.5	20.98	17.38	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
15.0	20.98	17.38	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
15.5	20.98	17.38	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
16.0	20.98	17.38	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
16.5	20.98	17.38	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
17.0	20.98	17.38	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
17.5	20.98	17.38	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
18.0	20.98	17.38	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
18.5	20.98	17.38	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
19.0	20.98	17.38	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
19.5	20.98	17.38	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35
20.0	20.98	17.38	0.75	1.00	P	0.78	0.51	2.64	89.37	7.46	14.99	5.35

Simulation for : C:\Program Files\ILEC\Pamolare30\Rufaro 1 layer with bnr operating.lk1 BNR operating

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Simulated period 20.0 year(s)
Printing step 0.500 year
Integration step 0.020 year

Physical data
Lake depth 21.00 m

Water residence time 0.37 year(s)
Sedimentation constant 0.50 m/year
Reduction of nutrient outflow
due to thermocline 0.00

Nitrogen data
Initial value of nitrogen in water 2.120 mg/l
Initial value of nitrogen in sediment 1.940 g/m2
Nitrogen loading 46.100 g/m2/year
Sediment release of nitrogen 0.600 /year
Fraction of nitrogen bound in sediment 0.006

Phosphorus data
Initial value of phosphorus in water 2.225 mg/l
Initial value of phosphorus in sediment 1.360 g/m2
Phosphorus loading 29.020 g/m2/year
Sediment release of phosphorus 0.600 /year
Fraction of phosphorus bound in sediment 0.005

Time Years	Water N mg/l	Sediment N g/m2	Water P mg/l	Sediment P g/m2	Limiting nutrient	Chl a mg/l	Secchi depth m	Zoopl. mg/l	Fish Prod. mg/l	Av. Prim. prim prod mg/l/day	Av max. yield mg/l/day	Av. Fish prod mg ww/m^2/year
0.5	12.65	3.30	0.94	1.31	P	1.06	0.45	3.04	104.61	9.33	18.73	6.68
1.0	15.26	5.51	0.62	1.13	P	0.60	0.57	2.34	78.10	6.15	12.39	4.42
1.5	15.92	7.46	0.54	1.00	P	0.49	0.61	2.14	70.89	5.36	10.80	3.86
2.0	16.09	8.97	0.52	1.00	P	0.47	0.62	2.09	69.04	5.16	10.40	3.72
2.5	16.15	10.12	0.52	1.00	P	0.46	0.63	2.08	68.58	5.11	10.30	3.68
3.0	16.17	10.97	0.52	1.00	P	0.46	0.63	2.07	68.47	5.10	10.28	3.68
3.5	16.18	11.60	0.52	1.00	P	0.46	0.63	2.07	68.44	5.10	10.27	3.67
4.0	16.19	12.07	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
4.5	16.19	12.42	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
5.0	16.19	12.68	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
5.5	16.20	12.87	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
6.0	16.20	13.01	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
6.5	16.20	13.12	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
7.0	16.20	13.20	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
7.5	16.20	13.25	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
8.0	16.20	13.30	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
8.5	16.20	13.33	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
9.0	16.20	13.35	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
9.5	16.20	13.37	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
10.0	16.20	13.38	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
10.5	16.20	13.39	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
11.0	16.20	13.40	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
11.5	16.20	13.41	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
12.0	16.20	13.41	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
12.5	16.20	13.41	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
13.0	16.20	13.42	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67

Time (Years)	Water N (mg/l)	Sediment N (g/m2)	Water P (mg/l)	Sediment P (g/m2)	Limiting nutrient	Chl a (mg/l)	Secchi depth (m)	Zoopl. (mg/l)	Fish Prod. (mg/l)	Av. Prim. prim prod (g/l/day)	Av max. yield (g/l/day)	Av. Fish (g ww/m2/year)
13.5	16.20	13.42	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
14.0	16.20	13.42	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
14.5	16.20	13.42	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
15.0	16.20	13.42	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
15.5	16.20	13.42	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
16.0	16.20	13.42	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
16.5	16.20	13.42	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
17.0	16.20	13.42	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
17.5	16.20	13.42	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
18.0	16.20	13.42	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
18.5	16.20	13.42	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
19.0	16.20	13.42	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
19.5	16.20	13.42	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67
20.0	16.20	13.42	0.52	1.00	P	0.46	0.63	2.07	68.43	5.09	10.27	3.67

Simulation for : C:\Program Files\ILEC\Pamolare30\Rufaro 1 layer with storm drains diverted to BNR operating.lk1

Simulated period 20.0 year(s)
Printing step 0.500 year
Integration step 0.020 year

Physical data
Lake depth 21.00 m
Water residence time 0.37 year(s)
Sedimentation constant 0.50 m/year
Reduction of nutrient outflow
due to thermocline 0.00

Nitrogen data
Initial value of nitrogen in water 2.120 mg/l
Initial value of nitrogen in sediment 1.940 g/m2
Nitrogen loading 34.240 g/m2/year
Sediment release of nitrogen 0.600 /year
Fraction of nitrogen bound in sediment 0.006
Phosphorus data
Initial value of phosphorus in water 2.225 mg/l
Initial value of phosphorus in sediment 1.360 g/m2
Phosphorus loading 23.730 g/m2/year
Sediment release of phosphorus 0.600 /year
Fraction of phosphorus bound in sediment 0.005

Time (Years)	Water N (mg/l)	Sediment N (g/m2)	Water P (mg/l)	Sediment P (g/m2)	Limiting nutrient	Chl a (mg/l)	Secchi depth (m)	Zoopl. (mg/l)	Fish Prod. (mg/l)	Av. Prim. prim prod (g/l/day)	Av max. yield (g/l/day)	Av. Fish (g ww/m2/year)
4.0	12.02	9.02	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
4.5	12.03	9.27	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
5.0	12.03	9.45	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
5.5	12.03	9.58	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
6.0	12.03	9.68	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
6.5	12.03	9.76	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
7.0	12.03	9.81	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
7.5	12.03	9.85	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
8.0	12.03	9.88	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
8.5	12.03	9.90	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
9.0	12.03	9.92	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
9.5	12.03	9.93	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
10.0	12.03	9.94	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
10.5	12.03	9.95	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
11.0	12.03	9.95	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
11.5	12.03	9.96	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
12.0	12.03	9.96	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
12.5	12.03	9.96	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
13.0	12.03	9.96	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
13.5	12.03	9.97	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
14.0	12.03	9.97	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
14.5	12.03	9.97	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
15.0	12.03	9.97	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
15.5	12.03	9.97	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
16.0	12.03	9.97	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
16.5	12.03	9.97	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
17.0	12.03	9.97	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
17.5	12.03	9.97	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
18.0	12.03	9.97	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
18.5	12.03	9.97	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
19.0	12.03	9.97	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
19.5	12.03	9.97	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02
20.0	12.03	9.97	0.42	1.00	P	0.35	0.70	1.83	59.51	4.17	8.42	3.02

APPENDIX E

ZNWA + EPA REFERNCE CRITERIA FOR STREAMS AND RESERVOIRS

Parameter	EPA std (reservoirs)	EPA std (streams)	ZNWA std(discharge into surface waters)
Conductivity(µS/cm)	-	- -	200
Ph	6.5-8.5	-	6.0-7.5
TDS (mg/L)	-	-	100
Turbidity(NTU)	15	-	5
Chloride(mg/L)	250	-	200
Nitrate (mg/l)	10	-	10
Total N (mg/L)	0.963	2.62	10
Total P (mg/L)	0.06	0.12	0.5
DO(mg/L)	5	5	5
Secchi depth	1.23	1.23	-
Chlorophyll a	14.6	7.85	-