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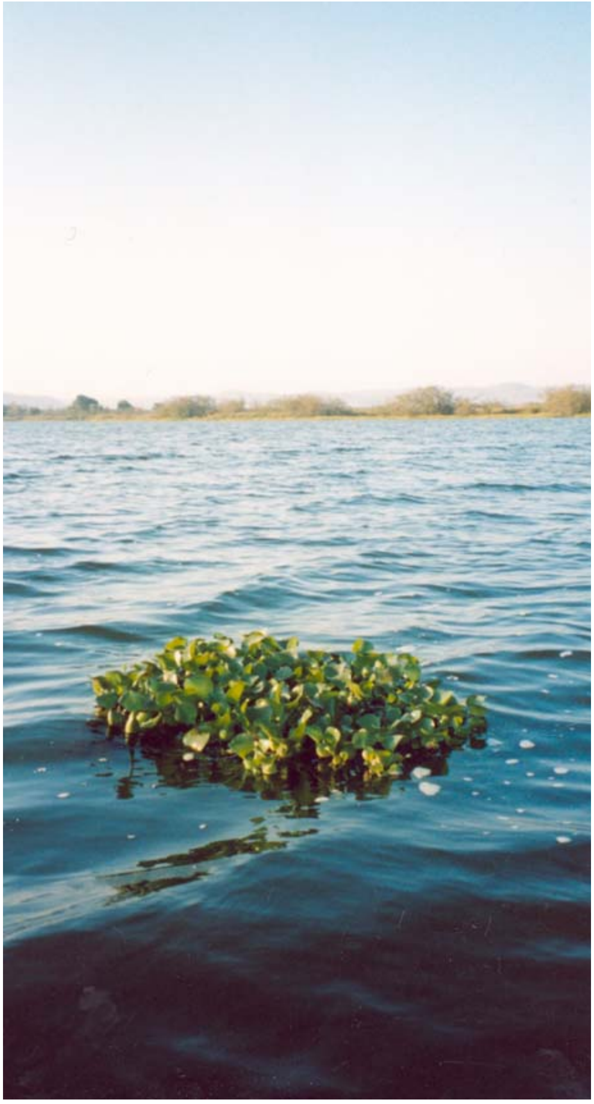
Nutrient Loading in the Kafue River between Mazabuka and Kafue Town, Zambia



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Cover picture: Water hyacinth on the Kafue River (Photo by Elin Alsterhag)

ABSTRACT

In Africa the water hyacinth has been a serious problem to many nutrient rich waters. One example of this is the Kafue River in Zambia which in the past has suffered severely from heavy water hyacinth infestations. The river is the largest tributary to the Zambezi with a basin hosting a third of Zambia's population and a variety of industrial, agricultural and municipal activities. To determine the nutrient situation in the lower Kafue River the Environmental Council of Zambia launched an extensive nutrient loading study in 1999.

This present study considers the lower Kafue River between Mazabuka and Kafue Town and was carried out during August and September in 2003. Nutrient levels in the river as well as possible impact from point sources was investigated by collecting and analysing water samples from effluents and river water. Point sources taken into account were Nakambala Sugar Estates, Kafue Sewage Treatment Plant, Nangongwe Maturation Ponds, Kafue Fisheries and the industrial area of Kafue Town. Obtained results from the analyses were compared with those from the ECZ study in 1999.

Overall, variations in nutrient concentrations along the river were difficult to detect. Nonetheless, river water samples generally showed phosphate-phosphorus concentrations about ten times greater compared to the ECZ study for the same season, which might be the result of the drastically reduced water hyacinth infestation. As the river has got a water low rate that is considerably greater than any of the discharges investigated, it follows that none of the point sources taken into consideration contributed with a significant load to the river. However, these results are applicable only during the short period of time when the study was carried out, hence the importance of continuing the monitoring of discharges into the Kafue River is stressed. The nutrient rich water in the Kafue River could possibly origin from diffuse outlets from the agricultural areas, the nutrient rich bedrock or point sources that were not included in this study.

Key words: Kafue River, Water hyacinth, Eutrophication, Point sources, Nutrient load

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LIST OF CONTENTS

APPENDICES

ABBREVIATIONS

DWA – Department of Water Affairs, Lusaka
ECZ – Environmental Council of Zambia
KSTP – Kafue Sewage Treatment Plant
m a s l – meters above sea level
NCZ – Nitrogen Chemicals of Zambia
NMP – Nangongwe Maturation Ponds
NSE – Nakambala Sugar Estates
Sida – Swedish International Development Cooperation Agency
Simb – Simbotwe Stream at Nakambala Sugar Estates
SLU – Swedish University of Agricultural Sciences, Uppsala
UNZA – University of Zambia
WWF – World Wide Fund for Nature
ZESCO – Zambia Electricity Supply Corporation

1 INTRODUCTION

High concentrations of nutrients in a water body cause eutrophication, which may lead to water hyacinth infestations. The water hyacinth was first introduced to Africa in the late 19th century and is today a threat to freshwaters all over the continent. In Zambia the problem became apparent in some parts of the Kafue River already in the early 1970's and in 1998 the government declared the situation a national disaster. The lower part of the river, with its many significant point sources, has had the most severe infestations.

This Minor Field study was an initiative from the Ministry of Agriculture and Cooperatives of Zambia. Their wish for this study was to determine the current state of the Kafue River in terms of nutrients and also to compare obtained results with those of an earlier study carried out by the Environmental Council of Zambia (ECZ) in 1998 - 1999. Since the time of the ECZ study there have been several changes that may have had an effect on the water quality in the river. Water hyacinths have been removed, higher penalty fees have been imposed on effluents exceeding the nutrient standards and a fertilizer plant has reopened after having been closed for several years.

The hypothesis behind this study was that agricultural, industrial and municipal activities have a great impact on nutrient levels in the Kafue River, but that the quality of the river has improved in recent years, thanks to stricter regulations on effluents from the commercial farms. This study therefore aims at determining the concentrations of nutrients in the lower Kafue River between Mazabuka and Kafue as well as to quantify nutrient discharges into the river from major point sources in the area. The collected data will be used by the Ministry of Agriculture and Cooperatives to, if necessary, make further adjustments in their agricultural policies.

2 BACKGROUND

2.1 Eutrophication

Both natural and anthropogenic emissons of nutrients such as nitrogen and phosphorus may give rise to eutrophication of water bodies. Generally, nitrogen is seen as a more significant problem in estuaries and marine water, and phosphorus in freshwater environments such as lakes and rivers. Initially, nutrient-poor waters benefit from eutrophication but as the nutrient loading continues the state of the water will decline. The increased biomass causes oxygen deficiency as oxygen is consumed when the organic matter is degraded. The river water will receive less sunlight where vegetation overgrowth occurs and also overgrowth prevents oxygen from mixing with the river water. Obviously, this will have a serious effect on aquatic life. In case of a totally oxygen-free aquatic environment the toxic substance of hydrogen sulphide, H_2S, is formed. In the end heavy eutrophication may lead to a decrease in biodiversity.

According to Sinkala et al. (2002) the values of nitrate for natural fresh waters should not exceed 5 mg/l whereas the phosphate concentration should be below 0.005 - 0.02 mg/l. The Environmental Council of Zambia has standards for effluents discharged into the aquatic system in catchment areas not including a lake, these are 50 mg/l for nitrate-nitrogen, 10 mg/l for ammonium-nitrogen and 6 mg/l for phosphate-phosphorus.

2.1.1 Nitrogen

Nitrogen is abundant in all living organisms and a large proportion of the total fixed nitrogen is locked up in living biomass and in dead organic matter. To support new growth plants assimilate nitrogen, mainly in the form of nitrate, NO_3^-, but to some extent also as ammonium, NH_4^+. As bacteria decompose, dead plants and other organic matter ammonium is again released to the soil. Another source of ammonium is the bacterial process of nitrogen fixation from the atmosphere. In two different steps nitrification bacteria convert ammonium into nitrate. First micro-organisms such as nitrosomonas convert ammonium into nitrite, NO_2^-, and then nitrobacter transform nitrite into nitrate. As these nitrifying bacteria are very common, the limiting factor for conversion from ammonium into nitrate is primarily the amount of oxygen available in a soil or a water body.

The positive charge of ammonium makes the ion willing to adsorb onto the negatively charged clay colloids and organic matter in the soil. This keeps ammonium from being washed out in event of heavy rainfall. Contrastingly, nitrate has got a negative charge, which makes the ion more likely not to adsorb and it will therefore be easily washed down to the groundwater and surrounding surface waters. As the groundwater often has a long residence time the problem with leaching would still continue a long time after the input of nitrates had ceased. In anaerobic environments microorganisms use nitrate as their source of oxygen, which reduces NO_3^- into NO_2^-, NO, N_2O and N_2, in the process of denitrification. This process encourages nitrogen losses to the atmosphere, hence closing the nitrogen cycle.

2.1.2 Phosphorus

The form of phosphorus that is taken up by plants is primarily phosphate, PO_4^{3-}, which naturally originates from weathering of bedrock and minerals. The ion easily forms strong complex with, or adsorbs to, humus and soil particles. Since there are no gases that contain phosphorus, recycling of the ion is by hydrological and geological processes. If phosphate occurs in excessive amounts, the soil gets saturated and the ion may be washed out to the aquatic system in event of heavy rainfall. Once the phosphate reaches the sea it will settle in the sediments and through geological processes it will gradually turn into rock. The recycling of phosphorus is complete when the bedrock after millions of years is raised and once again exposed to weathering.

2.1.3 Antropogenic impact

Excess of nutrients released into the environment from humans originates from different processes. Emissions from agriculture, industries, and municipal activities all add to the eutrophication. Large amounts of nitrogen and phosphorus applied on agricultural fields through fertilizers increase the risk of polluting groundwater through leaching and add to the nutrient load in the surface water when washed away by flush floods. Cultivated areas are more exposed to erosion, leading to a loss of nutrients to surrounding waters through overland flow. Another major source of phosphorus is domestic sewage, as phosphate is a component in faeces and is also commonly used as a water softener in detergents.

2.2 The water hyacinth

The water hyacinth, *Eichhornia crassipes*, originates from South America and was introduced to Africa in the late 1890's. It is a few decimetres in height above the water surface and the leaves have got spongy swollen petioles that keep it afloat, see Figure 1. Though a beautiful plant, the water hyacinth is regarded as a pest in tropical and subtropical regions since it reproduces very rapidly in the water environment the plant is adapted for. It responds quickly to enhanced nutrient concentrations, and is therefore abundant in eutrophicated water bodies.

The hyacinths may reproduce both sexually and asexually and according to some studies, they may increase their biomass by up to 12 % in one day only. Other reports show that the water hyacinths are capable to double its biomass or number in 6 to 15 days. According to Sinkala et al. (1997) seeds from the plant may germinate immediately, but have also got the ability to remain dormant for up to 15 years in the sediments. Conditions most favourable for plant growth are temperatures between 25 - 30° C and pH between 6 and 8, which makes the water bodies in Zambia almost optimal for the weed.
(Pest CABweb website, 2003)

Figure 1 The water hyacinth. (Photo by T. D. Center USDA, ARS.)

Among the effects of the water hyacinths are:
- Reduced nutrient levels in the water
- Interference with fishing and navigation
- Obstruction of installations such as water intake and hydroelectric turbines
- Limiting of water flow rates
- Decrease of oxygen due to degradation of dead plants
- Reduction of water resources available due to increased evapotranspiration
- Prevention of sunlight and oxygen from the air above to mix with the water mass
- Dispersal of diseases (the hyacinths act as a refuge for mosquitoes and snails that spread malaria, schistosomiasis, cholera and other diseases)

(Chola, 2001 and Pest CABweb website, 2003)

Different methods can be applied in order to clear water ways from the water hyacinths. Minimizing pollutants, the source of the eutrophication, in a water body is the only sustainable solution to the problem, though as it may be a long time before the actual result of this can be seen, also other complementary control measures can be used. For example these can be mechanical removal by hand or harvesters, chemical removal by herbicides or biological removal which involves introducing natural enemies that pose a threat to the plants. However, there are always risks involved when introducing new species into an ecosystem and use of chemicals might lead to pollution of the water body.

3 THE KAFUE RIVER

3.1 Geography

The Kafue River rises in the north western part of Zambia on the border to the Democratic Republic of Congo and passes through three provinces, namely the Copperbelt, the Central and the Southern Province, before its confluence with the Zambezi River. Figure 2 shows the river and its basin. In the upper reaches the river flows in a southerly direction through the extensive mining area of the Copperbelt before passing through the Ithezi-Tezhi Dam. Downstream of the reservoir the river runs towards the east through the Kafue Flats, passes Kafue Gorge Dam and then approaches its confluence with the Zambezi River, where the annual mean flow is 316 m^3. The total length of the Kafue River is approximately 1 200 km and the catchment area is estimated at 157 000 km^2 at the confluence with Zambezi River, accounting for about 21 % of the total land area in Zambia. This makes Kafue River the largest tributary to the Zambezi River.

Kafue Flats is a large grassland area with an elevation of about 1 000 m above sea level and a slope of less than 0.01 % in the flow direction. The flats are characterised by a myriad of open and closed lagoons and are more or less flooded throughout the year, with its water levels depending on rainfall and regulation at Ithezi-Tezhi Dam and Kafue Gorge Dam. Furthermore, the wetlands are considered to be one of the most biologically diverse in Africa (Mwase, unpublished 2003).

The downstream stretch of the river, from the Kafue Gorge Dam to the confluence with the Zambezi River, is very different from the flats. The river flows through a deep gorge with steep sides before proceeding through a hilly landscape. The drop on this relatively short stretch is 600 m, which makes the slope 0.9 %, a great contrast to the features of the flats.

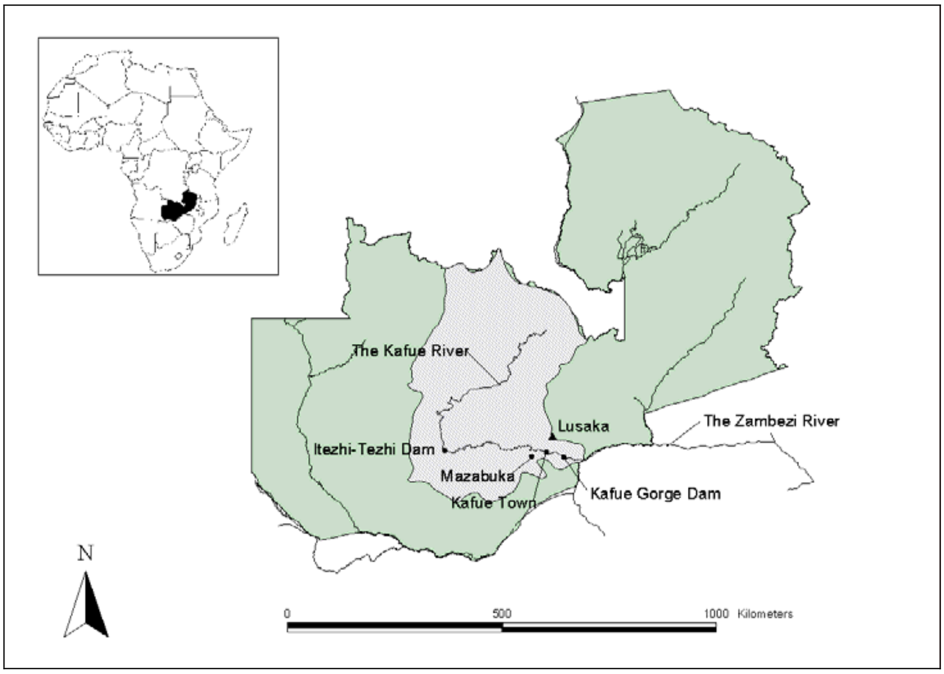

Figure 2 The Kafue River and its catchment.

3.2 Geology

The bedrock in Zambia consists of precambrian crystalline rocks in the east part with successively younger sedimentary formations towards the west (Pettersson and Ingri, 2001). Calcium rich carbonate rocks dominate the geology between Mazabuka and Kafue Town. In the area between Kafue Town and Kafue Gorge fine-grained muscovite schists, arkosic sandstones, granitic gneiss and biotitic gneiss with bands of feldspars can be found (ECZ, 1999). Characteristic for the soil profile of the study area is the occurrence of a clay horizon about five meters deep above a thick horizon of poorly sorted gravel (ECZ, 1999).

3.3 Climate

In Zambia the year can be divided into three seasons; the rainy season, the cool-dry season and the hot-dry season. The rainy season starts in November and ends in April with the maximum rainfall in January. In the northern part of the country the average annual rainfall is 1 500 mm, which is more than twice of what the south gets (ECZ, 1999). The study area receives an average of 793 mm a year and the annual potential evaporation is 2 122 mm. The cool-dry season follows the rainy season and continues until September when the temperature increases and the hot-dry season begins. In the study area July is the coldest month with an average temperature of 16.4° C and November the hottest with an average temperature of 24.4° C. The relative humidity in the lower Kafue River varies between 43 % in September and 80 % in February. (ZESCO, 1994)

3.4 Human impact

The Kafue River basin is the most developed area in Zambia in terms of mining, industries and agriculture. The river itself is the source of domestic water supply for e.g. Lusaka, Kafue and Mazabuka and the hydroelectric power station at Kafue Gorge generates more than half of Zambia's electricity requirements (ECZ, 1999). The basin is also the most populated part of the country with over 30 % of Zambia's 10 million people (Central Statistical Office, 2000).

The Copperbelt is one of the world's greatest stratiform metallogenic provinces (Pettersson and Ingri, 2000). In 1997 three percent of the world's production of copper and twenty percent of the production of cobalt were mined in Zambia, most of which were smelted within the country. Even though the production has declined due to a decrease in demand in recent years, mining is still Zambia's most important industry (Mwase et al., 2002). As a result of the mining activities in the Copperbelt, concentrations of heavy metals in the Kafue River upstream of Itezhi-Tezhi are very high compared to the Average World River (Norrgren et al., 1999). Also large cities like Kitwe in the Copperbelt can be expected to contribute with pollution to the river.

The Mazabuka area in the downstream part of Kafue Flats is Zambia's most important farming region with immense commercial agricultural activities, predominantly sugarcane cultivation. Among the farms, Nakambala Sugar Estates, Ceres Farms and Kaleya Smallholders are worth mentioning. The use of pesticides and fertilizers in this region is believed to affect the water quality of the river. In the town of Mazabuka, with its 130 000 people, the treatment of sewage mainly consists of septic tanks that are regularly emptied into sewage ponds. Further downstream Kafue Town, with approximately 100 000 inhabitants, hosts a variety of industries and the pollution is therefore mainly associated with industrial waste. (Figures on population were derived from Central Statistical Office Lusaka, 2000.)

As mentioned earlier the Kafue basin is home for a large portion of the Zambian people. The inhabitants keep livestock and practice fishing, vegetation burning, tree cutting and free-range ablution, all of which are activities likely to add to the pollution of the river. In addition riverine communities, which often lack proper sanitation facilities, are commonly located very close to the riverbank, thus increasing the risk of water contamination (Sinkala et al., 2002).

3.5 The water hyacinth in the Kafue River

Since the 1970's the water hyacinth has been present in the Kafue River. At times the river has suffered severely from infestations, causing nuisance such as interference with fishing, obstructing the turbines at Kafue Gorge Hydroelectric Plant and the hyacinths have also been a threat to physical structures such as the road and railway bridges.

Several methods have been used to extinguish the water hyacinth. Before 1991 spraying with herbicides was the main method used to eliminate the plant but in 1997 the ECZ introduced weevils to destroy the hyacinth. Though, according to Water Hyacinth News (2000), up to ten years is needed before result from the latter shows. At times when the problem has been acute local people have cleared the water manually and at Kafue Gorge Hydroelectric Power Plant water hyacinths are prevented from blocking the water intakes for the turbines by metal boom fencing structures. At the time when the EZC study was carried out during 1999 the water hyacinth was distributed irregularly along the river, some parts of the river were completely blocked by the water hyacinth while other places were free. When the infestation of the water hyacinth in the river reached its maximum, in 1999 and 2000, the Department of Water Affairs organized for a dredging machine to remove the weed mats. During the time of this study water hyacinths occurred irregularly along the fringes of the river and could occasionally be seen floating around on the water. (ECZ, 1999)

3.6 Kafue Gorge Hydroelectric Plant

The hydroelectric power station at Kafue Gorge, which was completed in 1973, is situated approximately 70 km upstream the confluence with Zambezi River, see Figure 2. With the 900 MW power station Zambia Electricity Supply Corporation (ZESCO) caters for 60 % of Zambia's electricity demand (ECZ, 1999) and also exports electricity to neighbouring countries such as Botswana, Zimbabwe and Namibia. To provide the reservoir at Kafue Gorge with water during the dry season a second dam was constructed in 1997 at Itezhi-Tezhi some 230 km upstream of Kafue Gorge.

In between the Itezhi-Tezhi and Kafue Gorge dams the huge flood plains of Kafue Flats spread out. Prior to the construction of the dams the seasonal flooding pattern was well defined with the normal flood starting in December and ending May. The average annual flooding at that time was significantly higher than today (WWF, 2002), consequently a large area that used to have annual floods during the rainy season is now dry all year round. Another result of the hydropower installations is the appearance of unnatural floods during the dry season, June to October, as a result of water release from the dam at Itezhi-Tezhi. The peak flow now occurs in July instead of March (WWF, 2002).

Because of the very small slope of the Kafue Flats, the backwater effect from Kafue Gorge Dam can reach as far upstream as Mazabuka. The backwater reduces water velocities in the river and also causes a permanent overflow of water onto earlier dry land just upstream from the gorge.

3.7 Earlier studies on the lower Kafue River

Since the problem with the water hyacinth and other aquatic weeds first occurred in the lower Kafue River, numerous studies have been carried out on water quality in the area. In 1973 the National Institute for Scientific and Industrial Research investigated the impact of industrial effluents from the Kafue area discharged into the Kafue River. In 1986 the same institute conducted a study on water quality in the river itself between Mazabuka and Kafue Town. The first study stated that none of the industries had sufficient treatment of their wastewaters while the second study concluded that microbiological contamination was the major pollution in the Kafue River. (ECZ, 1999)

Another study investigating the state of the river was carried out by Swedpower in 1991. With sampling sites at Mazabuka and downstream of Kafue Town this study pointed to the possible impact on the river from fertilizers applied in the agricultural areas. It also requested for a monitoring program on water quality during a full hydrological year.

In 1996 - 1997 the University of Zambia (UNZA) carried out an environmental impact assessment study in the lower Kafue. Besides an extensive chapter with sediment and water quality data, the study also included information on physical geography as well as impact of socio-economical activities on water quality. The study noted that the levels of nutrients in the wastewater from the industrial activities were high enough to contribute to aquatic weed proliferation.

Environmental Council of Zambia conducted an extensive study on nutrient loading in the lower Kafue River in 1998 - 1999. Since the present study aims to follow up the results of the ECZ study, Chapter 4 will give a closer presentation of it.

In 2002 Sinkala et al. carried out water sampling from the main river and the report that followed stated that except for nitrates and phosphates, all parameters measured did meet the standards set by the ECZ. The report also emphasized on the importance of engaging the local communities in the effort to reduce the nutrient load to the river.

One of the recommendations from earlier studies was a monitoring program covering all seasons. In 2003 ECZ therefore collected surface water samples from both discharge canals and the Kafue River itself. The conclusion drawn from these results was that effluents from all the industrial and agricultural activities included in the study exceeded the phosphate-phosphorus standard set by the ECZ.

4 ECZ NUTRIENT LOADING STUDY, 1999

Between April 1998 and February 1999, the Environmental Council of Zambia conducted an extensive study in the lower Kafue River covering all seasonal variations. Some 1 400 samples from surface water, ground water and sediments were collected and analysed for nutrients and a number of other parameters. At the time of the study the water hyacinths were present in the study area. At some places they covered the whole river while on other stretches free floating patches or fringes along the edges of the river were observed.

It was concluded that concentrations of nutrients in discharges were generally notably higher than the concentrations in the river, but several orders of magnitude less than concentrations observed in the groundwater. However, the concentration of nutrients in the Kafue River was high enough throughout the year to contribute to the rapid proliferation of the water hyacinths.

The study identified the major sources of nutrients to be agricultural activities (with Nakambala Sugar Estates as the most important contributor), industrial activities, municipal activities (of which the Kafue Sewage Treatment Plant was the main pollution source), Kafue Fisheries and riverine settlements. Yet another explanation to the high concentrations in the lower Kafue River was believed to be the nutrient rich bedrock in the area, but this hypothesis was not confirmed in the ECZ study.

Nutrients added to the Kafue River from the activities in the area, together with nutrient uptake by the water hyacinths, caused spatial variation along the river. The highest concentrations of nutrients were detected in the Mazabuka area where the commercial farms are located. Also the effluents from the industries in Kafue Town showed high concentrations of nitrates.

The study concluded that temporal variations of the nutrient concentrations in the river depend a lot on the life cycle of the water hyacinth, which in turn is influenced by weather, predominantly temperature. When the weather was cold (June to August), the water hyacinths withered and did not remove as much nutrients from the river, resulting in high concentrations of nutrients in the water. When the temperature increased (October), the water hyacinths were blooming, consuming a lot of nutrients, and consequently the nutrient concentrations in the river decreased. During the rainy season (November to April), more nutrients than the water hyacinths could remove were washed out from farms and settlements into the river, which caused the nutrient concentrations in the water to increase once again. Another factor ECZ took into account when looking at temporal variations was the water levels following the regulation at Itezhi-Tezhi Dam. Rise in water levels washed nutrients deposited on the banks into the river, causing high concentrations in the samples.

Since the water hyacinths consume a lot of nutrients, the ECZ's belief was that the water quality of the Kafue River would worsen if the water hyacinths were removed. ECZ recommended that mechanical, chemical and biological control of the weeds therefore must be combined with nutrient load reduction. ECZ recommended treatment and recycling of effluents discharged into the river and that lagoons and ponds should be lined with impermeable material in order to keep nutrients within. Since the study also showed that the ECZ effluent and wastewater regulations were regularly flouted, the ECZ suggested that the regulations should be enforced, that they must be expressed in terms of loads as well as concentration and that the current fine should be modified.

Sampling three times a year, representing the rainy season, the cool-dry season as well as the hot-dry season, was recommended for the future. In addition to the major plant nutrients, parameters such as temperature, pH, conductivity, dissolved oxygen and oxygen demand should be analysed. This ambitious plan has not yet been implemented, however the ECZ has employed more inspectors to monitor the activities. The study also pointed out the need for improved capabilities at the Environmental Engineering Laboratory at University of Zambia in order to inspire confidence in the results.

5 METHODS

With this background the Ministry of Agriculture of Zambia initiated the present study. Nutrient loading in the Kafue River and possible contributions from previously identified points sources were studied by interviews and field measurements. Surface water samples were combined with water flow estimations to quantify the nutrient loads in the river and from the point sources. This chapter gives a detailed description of the methods used.

5.1 Visits to stakeholders

Visits to major point sources identified in the ECZ study took place prior to field measurements. Informal interviews were conducted to get an overview of effluents, operational schemes, use of river water, monitoring programs etc, in order to choose suitable sites and days of sampling. Appendix 1 presents the time schedule that was prepared for this study.

5.2 Field measurements

5.2.1 Water samples

To get a picture of the state of the river, parameters analysed in this study were pH, nitrate-N, ammonium-N and phosphate-P. From each sampling point water samples were collected on two occasions. Every sample was divided into four bottles (500 or 1000 ml) provided and washed by UNZA. For analyses of nitrate-N, phosphate-P and pH two bottles were filled to the brim with water to minimize interaction with air. These samples were kept cool and dark until analyzed. The two bottles with water for analysis of ammonium were preserved with sulphuric acid to get the pH below two and were kept dark until analyzed. The duplicate samples were used for quality control of the analyses.

After interpretation of the results it was obvious that further sampling was needed. Therefore, a third round of sampling was carried out at some of the sampling sites. The field measurements were conducted during three weeks in August and September 2003. No sampling points were expected to show temporal variations, but to ensure the mean of the collected samples to be representative, sampling occasions at each point took place on different days of the week. The water was collected with a bottle attached to a stick.

5.2.1.1 The Kafue River

Sampling sites were chosen upstream and downstream suspected nutrient sources and, where possible, at the same sites as in the ECZ study from 1999. Exact positions of the river sampling sites were identified with GPS (Global Positioning System) equipment. A boat was used to reach the sampling points in the river between Mazabuka and Kafue, while the other samples were collected from the pontoon connecting Chirundu with Chiawa. At each sampling point in the Kafue River, water was collected from four different verticals, evenly distributed over the cross section, at depths of 0.5 and 1.5 m. The collected water was then mixed to form one sample.

5.2.1.2 Discharge channels

Where outlets from point sources were well defined, water samples were collected from the discharge points into the Kafue River. All discharge channels were small enough to collect the samples standing on the side of the channel, see Figure 3. At each sampling point, water was collected in the middle of the watercourse.

Figure 3 With assistance of the local children, Elin collects a water sample from Kasenje 2. (Photo by Liselott Petersson)

5.2.1.3 Methods of analyses

To be able to compare the results with the ECZ study from 1999 the same laboratory, the Environmental Engineering Laboratory at UNZA, carried out the analyses. For analysis of nitrate-nitrogen (NO_3^--N) the laboratory used the chromatographic acid method, for ammonium-nitrogen (NH_4-N) the phenate method and for phosphate-phosphorus (PO_4-P) the vanadomolybdophosphoric acid method, all of which are spectrofotometric methods. pH was measured with electronic equipment, also at UNZA.

The relative difference within each duplicate from each point was estimated as:

$$D = \frac{|C_a - C_b|}{C_m} \cdot 100 \qquad (1)$$

C_a, C_b = Concentration of samples within duplicates [mg/l]
C_m = Mean concentration [mg/l]
D = Relative difference [%]

For the low ammonium-nitrogen concentrations a comparatively large relative difference, up to 70 %, was accepted, while nitrate-nitrogen and phosphate-phosphorus duplicates with a relative difference exceeding 30 % were disregarded (Ulen, personal communication).

5.2.2 Water flow

5.2.2.1 The Kafue River

The water flow rates in the Kafue River between Mazabuka and Kaufe towns were assumed to be constant, Q_{River},. Most tributaries in the study area were dry and there was no precipitation during the time of the study. Neither were withdrawals large enough to affect the flow of the river. These factors together with a negligible relative increase in catchment area make this approximation reasonable. Q_{River} was estimated as the mean of the daily inflows to Kafue Gorge Dam, $Q_{in,}$ during September. These were obtained by water balance calculations for the reservoir, see Equation 2.

$$Q_{in} = Q_{out} + E_p \cdot A_{surface} + \frac{dh}{dt} \cdot A_{surface} + P \cdot A_{surface} \qquad (2)$$

Q_{in} = Inflow to the reservoir at Kafue Gorge [m^3/s]
Q_{out} = Discharge from Kafue Gorge Dam [m^3/s]
E_p = Potential evaporation [m/s]
$A_{surface}$ = Surface area of the reservoir at Kafue Gorge [m^2]
dh/dt = Change in water level at Kafue Gorge Dam [m/s]
P = Precipitation [m/s]

The Chirundu pontoon is located downstream of Kafue Gorge Dam. The flow rate at this point was approximated to the September mean discharge from the dam, for the same reasons as stated above for Q_{River}.

5.2.2.2 Discharge channels

Water flow rates in the discharge channels were measured on one or two occasions. The mean of the measurements at each point was assumed to be representative for the time of the study and was used for the days when water samples were collected but no flow measurements were carried out. At most sampling points a current meter was used for the measurements, but where this was not possible the floater method was practiced to get an approximation of the water flow rate.

At all samplings points the mean water velocity in a vertical of the canal was assumed to occur at 40 % of the total depth. Consequently, the current meter was used at verticals evenly distributed over the cross section at this depth. With knowledge of the cross section's dimensions, the water flow rate was calculated. A technician from the Provincial Water Engineering Office in Lusaka was hired to measure and calculate the flow rates in the discharge canals. The equipment used was a Mini Seba Current meter no 336. Figure 4 shows one of the flow measurements.

Figure 4 Flow measurements at 26 West at Nakambala Sugar Estates, Mr Chinonge and Liselott. (Photo by Elin Alsterhag)

With the floater method the mean velocity of the water was estimated at 70 % of the velocity of a stick floating on the water surface. The cross section area was measured and the flow rate calculated.

5.2.3 Calculation of load

When interpreting concentrations it is of great importance to combine these with the water flow in order to determine the actual amount of the substance. The obtained water flow rates were used together with the mean concentrations of nitrate-N, ammonium-N and phosphate-P to get nutrient load per day as masses in the river and discharge canals. The following equation was used.

$$L = 10^3 \cdot C \cdot Q \quad (3)$$

L = Load [mg/s]
C = Concentration [mg/l]
Q = Water flow [m^3/s]

6 POINT SOURCES

The significance of point sources' nutrient contributions with respect to the proliferation of the water hyacinths in the Kafue River has long been recognized (Sinkala et al., 2002). The ECZ study identified the major point sources of nutrients to be Nakambala Sugar Estates, Kafue Sewage Treatment Plant, Kafue Fisheries and Kafue industrial area. Consequently, these are the point sources taken into account in the present study. Figure 5 illustrates the locations of the point sources.

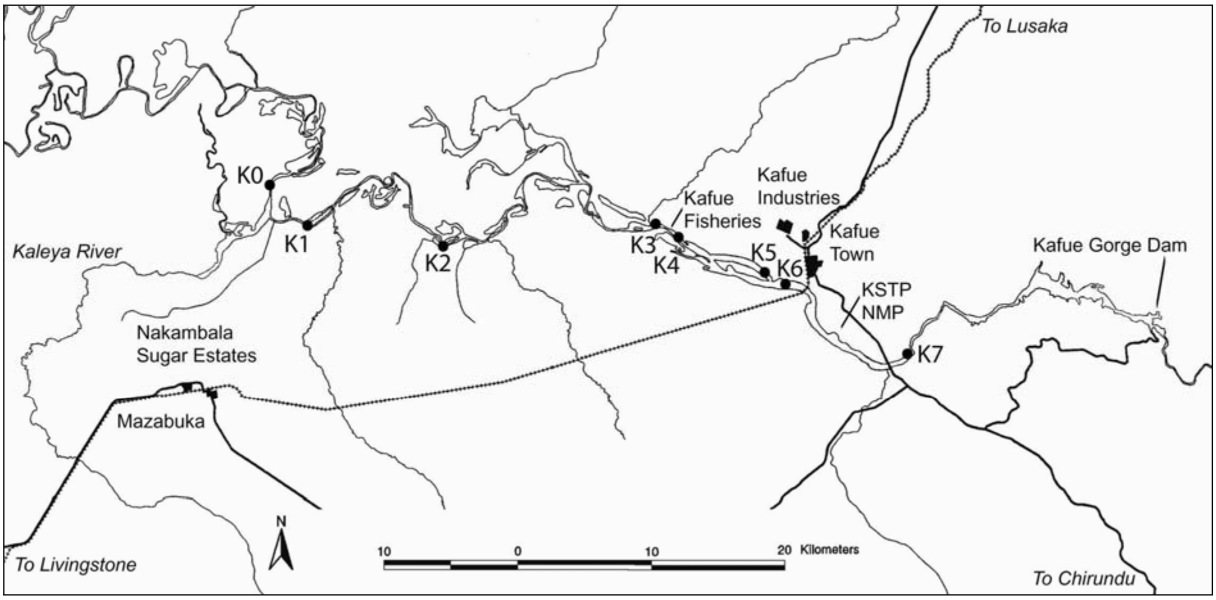

Figure 5 The Kafue River with investigated point sources and river sampling points.

6.1 Nakambala Sugar Estates

The commercial sugar cane plantation and sugar processing of Nakambala Sugar Estates (NSE) in Mazabuka was established in 1964 and today it covers an area of about 12 000 hectares. This makes NSE the main sugar producer in Zambia with a production large enough to export to neighbouring countries after supplying the Zambian market. The activities, such as use of fertilizers, harvesting and cane processing, are down between December and March since the fields are then inaccessible because of the rains. Between April and November NSE employs sugarcane cutters from the whole country who harvest approximately 1.12 million tonnes of sugar cane. (ECZ, 1999)

Nakambala Sugar Estates depends on irrigation and pumps water from the Kafue River. Monthly 16 million m^3 water is drawn from the river, of which 12.3 million m^3 is used for irrigation (Mwanza, personal communication). NSE also supplies the domestic areas within the estates as well as some of the surrounding farms with water. NSE uses flood irrigation method and recycles the water. The drainage water is collected in canals surrounding each field and is then reused for irrigation.

Fertilizers applied in the fields are diammonium phosphate, urea diammonium phosphate and murate potash (K_2CO_3). About 6 400 tonnes of fertilizers are used annually (ECZ, 1999), but since the drainage water from the fields is recycled, it is assumed that there are no major losses to the aquatic environment this way. Instead the biggest impact on the Kafue River from NSE is believed to originate from the factory, which uses more than 300 tonnes phosphorus in the purification process of the sugar cane during the eight months it is operating (Mwanza, personal communication).

There are three discharge points from NSE into the aquatic environment; 26 East, 26 West and Simbotwe. 26 East and 26 West drain the eastern and the western parts of the estates respectively. The wastewater from the processing factory passes through effluent ponds and filter reed beds before it reaches the stream of Simbotwe, which also receives drainage water from some surrounding fields. The three discharges enter Kaleya River which is a tributary to the Kafue.

6.2 Kafue Sewage Treatment Plant

Kafue Sewage Treatment Plant (KSTP) was constructed in 1972 and is based on biological treatment. The wastewater goes through primary and secondary treatment and a succession of four lagoons before it finally enters the Kafue River through a well-defined discharge canal. The estimated retention time through the full system is four months. Though, in the area several small-scale farmers operate who might drain water from the system, thus interrupting the cleaning process of the wastewater.

Roughly 15 % of the town’s residential areas are connected to the sewage treatment plant while the rest use pit latrines and septic tanks. Normally the wastewaters from industries that lack own facilities for purification is treated at Kafue Sewage Treatment Plant. However, at the time of the study the pipes connecting these industries with KSTP had been vandalised resulting in untreated wastewater being discharged into the nature. (Mukuka, personal communication)

6.2.1 Nangongwe Maturation Ponds

The Nangongwe Maturation Ponds (NMP) consists of a series of four ponds, which treat the sewage from the small residential area of Nangongwe. The total retention time is approximately 14 days. Under normal circumstances the naturally treated water from the ponds is pumped into KSTP, but when this study was carried out the water was discharged directly into the Kafue River since the pump was out of order.

6.3 Kafue Fisheries

Kafue Fisheries, 15 km west of Kafue Town, was established 22 years ago. It is an integrated pig and fish farm where the pigsties are located adjacent to the fishponds. The idea is to wash pig manure into the ponds to feed the plankton, which in turn feed the fish. Annually 200 tonnes of fish and 3 200 tonnes of pork are produced at Kafue Fisheries. There are 72 fishponds in total covering an area of 50 hectares. The nutrient load into the Kafue River is assumed to be constant throughout the year since harvesting of fish is carried out during the full year. When harvesting the fish, the pond is totally emptied on water. The water passes through six hectares of reed beds before it enters the Kafue River. Consequently, there is no defined canal for effluents. (Flynn, personal communication)

6.4 Kafue industrial area

The small stream of Kasenje runs through Kafue industrial area where among others Nitrogen Chemicals of Zambia (NCZ), Bata Tannery, Lee Yeast, Kafue Chemicals and Kafue Textiles are located. Kasenje Stream enters Chirumba Lagoon which is a part of the Kafue River upstream of the Kafue Railway Bridge. Special attention was paid to NCZ in this study since the factory recently reopened.

6.4.1 Nitrogen Chemicals of Zambia

Nitrogen Chemicals of Zambia produced ammonium nitrate, NPK-fertilizers and sulphuric acid starting from 1970 up until the 1990's when it closed due to financial problems. Though the last few years NCZ has had sporadic production and at the time of the study only the NPK-fertilizer production was operating. The NPK plant only produces gaseous waste and does not discharge any liquid effluents. When the other productions are running their wastewaters are pre-treated and then pumped to man made lagoons for further treatment before being discharged into the Kafue River. However, water is pumped from the pipe connecting NCZ with the lagoons, and from the lagoons themselves, to irrigate illegal farms in the area. As a result not fully treated wastewater might reach the river. Storm water from the area is collected in drains and joins the Kasenje Stream, a tributary of the Kafue River.

7 SAMPLING POINTS

A sketch map of the points of sampling can be viewed in Figure 6, and a short description of the sites and what they are believed to represent is found below. A more detailed description of the sampling points can be found in Appendix 2.

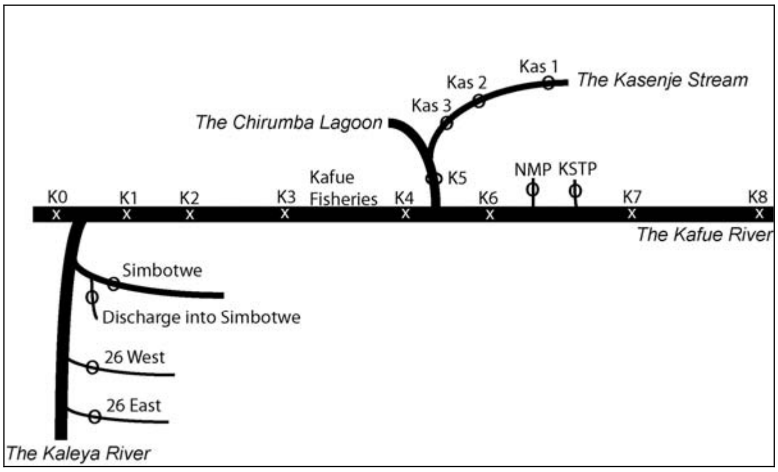

Figure 6 Sketch map of the sampling points.

7.1 The Kafue River

K0 through K8 are points in the main watercourse of the Kafue River, except K5 which is located in a lagoon. The map in Figure 5 illustrates the exact locations of the river sampling points. Several of these correspond to sampling points in the ECZ study and matching sample identities and GPS positions are found in Appendix 2. The landscape along the 70 km long stretch of the river between sampling points K0 and K7 is characterized by flat grassland with numerous open and closed lagoons. Downstream at sample point K8 the landscape is hillier and the vegetation consists of trees and bushes.

K0: Water samples from K0 were collected from the Kafue River upstream the confluence of Kaleya River. The point is considered unaffected by the activities in the study area and is therefore regarded as a reference point.

K1: This sampling point is located just upstream Shimungalo fishing village in the farming area.

K2: K2 river samples were collected at Nanga fishing village. At this sample point impact from most of the farming activities is expected to show.

K3: To study the impact from all the commercial farms upstream, including NSE, and at the same time get a sample unaffected by Kafue Fisheries, K3 was chosen.

K4: K4 samples were collected downstream of Kafue Fisheries to show its possible impact. Furthermore, K4 represents the river unaffected by the industrial activities in Kafue Town.

K5: This sampling point is located in Chirumba Lagoon downstream of the Nitrogen Chemical's pump station. Some of the wastewater from the industrial activities might be discharged into the lagoon through Kasenje Stream.

K6: Water samples from this site were collected upstream of the Kafue Railway Bridge. Most of the nutrient load from the industrial activities has entered the river at this point.

K7: Downstream the road bridge all pollution from Kafue Town, including KSTP and NMP, is assumed to have entered the river.

K8: Located some 80 km downstream from Kafue Town, these water samples were collected from the pontoon connecting Chirundu and Chiawa. Samples at this point show the condition of the river water before the confluence with the Zambezi River.

7.2 Nakambala Sugar Estates

Simbotwe: Simbotwe receives wastewater from the factory and drainage water from fields close by and has its outlet in the Kaleya River. It is a rather small stream but compared to the other discharges within the estates it is considerably larger.

Discharge into Simbotwe: This small stream receives wastewater from Kaleya compound as well as drainage water from surrounding fields. It enters Simbotwe just upstream where Simbotwe has its exit from the estates and downstream the sampling point of Simbotwe.

26 West: The fields in the western parts of the estates drain into 26 West which finally enters the Kaleya River. Downstream this sampling point the fields are assumed to have no impact on the stream.

26 East: Drainage water from the fields in the eastern parts of the estates is collected in 26 East and is eventually discharged into Kaleya River. This sampling point is located downstream of the fields and upstream of a residential compound adjacent to the stream.

7.3 Kafue Town and industrial area

Kafue Sewage Treatment Plant: This sampling point is in the covered canal which transports the treated water from the lagoons of KSTP to the Kafue River.

Nangongwe Maturation Ponds: The samples from this site were collected just downstream the last pond, in the discharge channel that is used when the pump station is out of order.

Kasenje 1: Kasenje 1 is situated within the properties of the Nitrogen Chemicals of Zambia, in the upstream part of the industrial area of Kafue Town. At the time of the study the pipe transporting wastewater from the residential area Kafue Estates to KSTP was broken, leading to pollution of Kasenje Stream upstream of this point.

Kasenje 2: This sampling point is assumed to represent the impact of the industrial activities in the area, but as there is a confused heap of fields and irrigation canals all along Kasenje Stream downstream from the industries it is close to impossible to know the exact catchment of this point.

Kasenje 3: Located just upstream Kasenje's discharge into Chirumba Lagoon, samples from this point should represent contributions from the industrial area.

8 RESULTS

8.1 Water samples

Appendix 3 shows the complete list of results from the analysis of pH, phosphate-P, nitrate-N and ammonium-N. Some of the concentrations were unrealistic and were therefore not included in the study (further explanation in Chapter 9), others were discarded because of great relative differences between samples within one duplicate as explained in 5.2.1.3. The relative differences of all duplicates are presented in Appendix 4. Tables 1 and 2 present the modified list of results based on means of the duplicates. Bold figures denote samples with concentrations exceeding the ECZ standards for effluents discharged into aquatic systems not including a lake.

Table 1 pH, phosphate-P, nitrate-N and ammonium-N in the Kafue River.

		pH	Phosphate-P (PO_4^{3-}-P mg/l)	Nitrate-N (NO^{3-}-N mg/l)	Ammonium-N (NH_4^+-N mg/l)
Kafue River					
K0	04-Sep	6.7	1.17	2.80	0.015
	08-Sep	7.8	1.54	4.14	0.610
K1	04-Sep	6.8	2.31	2.95	<0.010
	08-Sep	7.8	0.46	5.17	0.535
K2	04-Sep	6.9	2.08	4.00	0.010
	08-Sep	7.5	0.78	6.09	0.575
	22-Sep	-	1.01	2.64	-
K3	04-Sep	6.9	2.40	4.10	0.015
	08-Sep	7.7	1.73	7.63	0.445
K4	04-Sep	7.1	2.28	2.95	0.015
	08-Sep	7.6	1.83	5.53	1.220
K5	04-Sep	7.0	1.69	2.90	0.025
K6	04-Sep	7.2	1.89	3.20	0.010
	08-Sep	7.5	1.31	3.89	0.560
K7	04-Sep	7.1	2.98	3.05	<0.010
	08-Sep	8.3	2.84	6.74	0.455
K8	28-Aug	8.0	0.72	-	0.325
	09-Sep	7.5	3.41	1.08	0.400
	17-Sep	-	1.10	12.30	-

Table 2 pH, phosphate-P, nitrate-N and ammonium-N in discharges. Bold figures indicate samples that exceed the ECZ-standards.

		pH	Phosphate-P (PO_4^{3-}-P mg/l)	Nitrate-N (NO^{3-}-N mg/l)	Ammonium-N (NH_4^+-N mg/l)
ECZ-standard[1]		6 to 9	6 mg/l	50 mg/l	10 mg/l
Nakambala Sugar Estates					
Simbotwe	03-Sep	7.6	1.72	4.07	0.045
	11-Sep	7.5	4.48	-	0.020
	22-Sep	-	2.71	4.64	-
Discharge into Simbotwe	03-Sep	7.6	3.37	1.78	<0.01
	11-Sep	7.9	**6.65**	-	<0.01
	22-Sep	-	1.51	2.96	-
26 West	03-Sep	7.6	-	2.91	<0.01
	11-Sep	7.8	-	-	<0.01
	22-Sep	-	1.28	3.25	-
26 East	03-Sep	7.7	0.71	2.50	<0.01
	11-Sep	8.2	-	-	<0.01
	22-Sep	-	1.04	2.80	-
Kafue Town					
Kafue Sewage Treatment	01-Sep	6.8	2.39	2.70	0.270
	10-Sep	7.3	-	19.33	0.035
	17-Sep	-	1.34	14.05	-
Nangongwe Maturation Ponds	01-Sep	7.2	4.10	3.15	3.670
	10-Sep	6.6	1.98	19.55	5.225
	17-Sep	-	2.82	11.75	-
Kasenje 1	01-Sep	7.5	4.15	4.30	3.795
Kasenje 2	10-Sep	7.5	**6.02**	26.40	3.800
Kasenje 3	08-Sep	7.8	4.91	6.58	3.575

No sample exceeds the ECZ standards for nitrate-nitrogen and ammonium-nitrogen, while two phosphate-phosphorus samples did, namely the discharge into Simbotwe at Nakambala Sugar Estates and Kasenje 2 downstream Kafue industrial area. The lowest mean phosphate-phosphorus concentration recorded was 0.46 mg/l, which was collected from Kafue River at K1, i.e. at Shimungalo fishing village, while the highest concentration, 6.65 mg/l, was from the discharge into Simbotwe. One of the samples at K8 showed 1.08 mg/l of nitrate-nitrogen, which was the lowest mean recorded, whereas one of the Kasenje 2 samples had the highest contents of nitrate-N, 26.40 mg/l. Several samples had concentrations of ammonium-nitrogen below the detection limit of 0.01 mg/l. Nangongwe Maturation Ponds had the highest ammonium-N concentration, 5.23 mg/l.

8.2 Water flow rates

The approximated river flow rate between Mazabuka and Kafue Town, Q_{River}, was 201 m^3/s (see Appendix 5 for calculations). Note that K5 is located in Chirumba Lagoon and not in the main river channel. As a result this sampling point was not included in the calculations on water flow rates and load representing the Kafue River, and neither was Q_{River} applicable at this point. The river flow rate at Chirundu (K8) was 147 m^3/s. Table 3 presents the measured

[1] ECZ standards for effluents discharged into aquatic systems not including a lake.

flow rates in the discharge channels. A current meter was used at all sites except at Kasenje 1 where the floater method was practiced. At Kasenje 3 no flow rate was obtained since the site was covered with water hyacinths obstructing the measurements.

Table 3 Water flow rates in the discharge channels together with calculated means.

Site	Date	Flow rate (m^3/s)	Mean flow rate (m^3/s)
Simbotwe	03-Sep	0.163	0.212
	11-Sep	0.261	
Discharge into Simbotwe	03-Sep	0.030	0.022
	11-Sep	0.014	
26 West	03-Sep	0.034	0.031
	11-Sep	0.027	
26 East	03-Sep	0.009	0.009
Kafue Sewage Treatment Plant	01-Sep	0.008	0.006
	10-Sep	0.003	
Nangongwe Maturation Ponds	01-Sep	0.005	0.007
	10-Sep	0.008	
Kasenje 1	01-Sep	0.182	0.182
Kasenje 2	10-Sep	0.094	0.094

8.3 Load of phosphate-P, nitrate-N and ammonium-N

The mean loads of phosphate-phosphorus, nitrate-nitrogen and ammonium-nitrogen per day based on the concentrations and flow rates obtained in the study can be seen in Table 4. Loads of 0.1 kg or less per day were regarded as no load.

Table 4 Mean load of phosphate-P, nitrate-N and ammonium-N per day.

	Mean load PO_4^{3-}-P (kg/day)	Mean load NO^{3-}-N (kg/day)	Mean load[2] NH_4^+-N (kg/day)
Kafue River			
K0-K3	26000	76000	<220; 9400
K4, K6, K7	38000	73000	<210; 12500
K8	22000	85000	4600
Nakambala Sugar Estates			
Simbotwe	58	71	1
Discharge into Simbotwe	7	5	0
26 West	4	9	0
26 East	1	2	0
Kafue Town and Industries			
Kafue Sewage Treatment Plant	1	5	0
Nangongwe Maturation Ponds	2	7	3
Kasenje 1	65	68	60
Kasenje 2	49	214	31

[2] When two figures, the left-hand ones denote the loads corresponding to concentrations of ammonium-N from the first day of sampling, wheras the ones to the right show the load based on the concentrations from the second day of sampling, see Table 1.

9 DISCUSSION

Along the Kafue River no temporal variations were expected because of the limited period of time sampling was carried out and the river's great water flow rate. This study was conducted during the dry season, hence there was no rain that could affect either concentrations or flow rates. Neither were any of the point sources expected to show any differences in concentrations from one time of sampling to another, except for the sites in Kasenje Stream, where exact discharge patterns were not considered.

Throughout the dry season the main polluter at Nakambala Sugar Estates was expected to be the factory, which during the time of the study was in operation 24 hours a day seven days a week. Furthermore, the fields in the plantation always are at different stages, which results in a constant leakage. These two factors should eliminate any variations in concentrations and water flow rates at each point within the estates during this study. Also at Kafue Sewage Treatment Plant the results from the sampling occasions were assumed to be comparable concerning both concentrations and water flows, since the retention time for sewage water passing through the plant and lagoons is approximately four months. Moreover, no variations in effluents were expected at neither Nangongwe Maturation Ponds, as the origin of the sewage is a domestic area, nor at Kafue Fisheries, due to constant production throughout the year. In contrast, exact patterns of discharges from the industrial area into Kasenje Stream have not been taken into account in this study and the concentrations in the stream might be subject to change during the weeks of sampling.

However, in spite of the situation described above, results from the analyses differ between different days of sampling, see Appendix 3. Firstly, the Chirundu (K8) sample from the first occasion of sampling was discarded as it showed concentrations of nitrate-nitrogen below 0.01 mg/l whereas the other samples at the same site, and the majority of other samples collected from the river, had nitrate-nitrogen concentrations at least 100 times greater. This variation cannot possibly be ascribed to natural fluctuations and neither was there any change in effluents upstream from Chirundu during the time of the study.

Secondly, all river samples between the towns of Mazabuka and Kafue showed temporal variations in ammonium-nitrogen. Although there were only four days between the rounds of sampling and there was no precipitation or change in discharge patterns, the results from the second day of sampling were more than 30 times higher than those of the first day. As there was no obvious indication on which of the two sampling occasions were the more probable, none of the results on ammonium-N were discarded. If one considers the fact that water samples were collected at depths of 0.5 and 1.5 m in the river, where the water most likely should be rich in oxygen due to mixing with the above air, low concentrations of ammonium-N could be expected in the water, as was the case on the first day of sampling. At the same time, the high concentrations of phosphate-P in the river could be the sign of oxygen deficit, which prevents ammonium to convert into nitrate. In this case high concentrations of ammonium-N, like the result from the second sampling occasion, could be the result. To fully understand the NH4-N situation in the river also the oxygen condition should have been studied. Furthermore, nitrate-N samples from the second sampling occasion at Nakambala Sugar Estates were ignored since these showed considerably different values than the other days of sampling, without discharge patterns being changed.

Sampling was consistently carried out in the same manner, the above described uncertainties can thus only be assigned to the laboratory and its routines. This demonstrates the risk in drawing conclusions for a longer period of time from one sample only. However, the samples within duplicates were well correlated, which is pointed out by the relative differences in Appendix 4.

When comparing the results of this study with the corresponding figures from the ECZ study in 1999 it can be stated that obtained phosphate-phosphorus concentrations in the Kafue River samples were in general ten times higher in 2003. This may be explained by the drastically reduced water hyacinth infestation. As discussed above, interpretation of the situation on ammonium-nitrogen in the river at the time of this study was difficult to make, therefore no comparisons with earlier ammonium-N-results have been possible. For nitrate-nitrogen no conclusions could be drawn due to significant variability in the 1999 results. According to Sinkala et al. (2002) the concentrations of nitrate in natural fresh waters should not exceed 5 mg/l, equivalent of 1.1 mg NO_3-N/l, whereas the phosphate concentration should be below 0.005-0.02 mg/l, i.e. 1.6-6.5 µg PO_4-P/l, to prevent eutrophication. Using this definition, the Kafue River was exceeding both limits at the time of the present study. Especially remarkable is phosphate-phosphorus where even the lowest recorded concentration at 0.46 mg/l, is more than 70 times the limit!

The concentrations of nutrients were generally higher in the discharges than in the river itself, still all but two were within the ECZ limits[3]. The sites that did not meet the regulations were the discharge into Simbotwe and Kasenje 2 concerning phosphate-phosphorus. Simbotwe is the main discharge from NSE while Kasenje drains the industrial area of Kafue Town. For nitrate- and ammonium-N all samples showed concentrations far below the ECZ standards, several of the ammonium-N concentrations were even below the detection limit of 0.01 mg/l. Parameters analysed from NSE were generally lower than those from Kafue Town and industries, but without considering the water flow rate at a site, the concentration does not provide sufficient knowledge about the amount of nutrients that in fact is released into the aquatic system.

This study shows that the daily loads of phosphate-phosphorus were 70 kg from the NSE and 50 kg from Kafue Town and industrial area. These figures are to be compared with the transport in the river itself between Mazabuka and Kafue, which was estimated at more than 26 tonnes per day. The corresponding loads of nitrate-nitrogen were 90 kg from NSE and almost 230 kg from Kafue Town and industrial area, compared with the river’s transport of more than 73 tonnes per day. For ammonium-nitrogen, NSE contributed with only 1 kg per day, while the industries in Kafue added some 35 kg per day to the Kafue River, which itself carried approximately 200 kg per day. Summarizing these figures, during the time of this study, industries in Kafue Town contributed with more nitrogen, and NSE with more phosphate, than the other point sources. Though comparing the point sources with the river itself, the difference in load is enormous.

[3] See Table 2.

The significant difference between load from the point sources and the Kafue River itself implies that the point sources do not have a great impact on the quality of the river water. Let us take Simbotwe as an example to illustrate how much higher the phosphate-phosphorus concentration must be, for Simbotwe to have an impact on the Kafue River. The example demonstrates the situation at all discharges. Using continuity, Equation 3 gives:

$$C_{Kafue,downstream} - C_{Kafue,upstream} = C_{Simbotwe} \cdot \frac{Q_{Simbotwe}}{Q_{Kafue}} \qquad (4)$$

$C_{Kafue,downstream}$ = Phosphate-P concentration in the Kafue River downstream Simbotwe [mg/l]
$C_{Kafue,\ upstream}$ = Concentration of phosphate-P in the Kafue River upstream Simbotwe [mg/l]
$C_{Simbotwe}$ = Concentration of phosphate-P in Simbotwe [mg/l]
$Q_{Simbotwe}$ = Water flow rate in Simbotwe [m^3/s]
Q_{Kafue} = Water flow rate in the Kafue River [m^3/s]

The magnitude of error when carrying out the analysis of phosphate-phosphorus according to Standard Methods (APHA 1998) is estimated at 0.2 mg PO_4-P/l. In the example this concentration, i.e. the smallest difference needed to see a change in phosphorus-concentration, will be used for the left-hand side of Equation 4. The average water flow rate in Simbotwe was 0.2 m^3/s during the time of the study and it should be reasonable to assume that it would not exceed 1 m^3/s in the dry season, thus $Q_{Simbotwe}$ was given this value. These figures, together with the calculated Q_{Kafue} of approximately 200 m^3/s, would make Equation 4:

$$0.2 = C_{Simbotwe} \cdot \frac{1}{200} \qquad (5)$$

According to this example, $C_{Simbotwe}$ must be at least 40 mg/l to have an impact on the Kafue River, which is six times higher than the highest concentration recorded during the time of the study. Though, it should be emphasized that this study only covers a few weeks during the dry season.

The small impact of the investigated point sources is also highlighted by the difficulty to distinguish any spatial variations along the river. Though possibly a slight increase of concentration in phosphate-phosphorus was discernible as the river has run through Kafue Town. However, downstream of this point, it is possible that vegetation removed phosphate from the water as the modest rise in phosphate-phosphorus concentration was gone by the time the water reached the confluence with the Zambezi River. The total load of phosphate-phosphorus in the Kafue River just before it enters Zambezi River was estimated at approximately 22 tonnes a day and for nitrate- and ammonium-nitrogen the figure were 85 and 5 tonnes respectively.

It is noteworthy that the river reference sample of this study (K0) had high concentrations of the parameters analysed at the time of the study. As mentioned earlier, concentrations in discharges were generally higher than in the river itself. Still for phosphate-phosphorus, K0 had a concentration that was even exceeding the ECZ standard for effluents discharged into aquatic systems in drainage areas including a lake[4].

[4]The ECZ standard for phosphate for effluents discharged into an aquatic system including a lake (which is not the case with Kafue River) is 1 mg/l.

The high concentrations of nutrients along the river from Mazabuka down to Kafue could originate from activities upstream, but vegetation would probably have absorbed nutrients from the Copperbelt by the time the water reaches the study area and there are no other major settlements or industries upstream of the reference point. The small fishing villages were not expected to contribute with a significant amount of nutrients. Another potential explanation of the high concentrations in the river water might be the diffuse leakage from agricultural activities or from the naturally nutrient rich bedrock in the area of lower Kafue River, but the impacts are not yet confirmed. Possibly point sources that were not taken into consideration in this study could be the cause of the high concentrations of nutrients. The modest increase in phosphate-phosphorus downstream Kafue Town could be a sign of this. Though it should be kept in mind that through the backwater effect from Kafue Gorge Dam, a point source could possibly have an effect also on areas upstream of its location.

10 CONCLUSIONS AND RECOMMENDATIONS

Today the nutrient levels in the Kafue River are higher than in 1999, probably due to the removal of the water hyacinth and its nutrient absorbing capacity. During the period of this study, none of the point sources considered contributed with a significant load to the river. The available data imply that neither the agricultural, industrial nor the municipal activities included in the study had a great impact on the river during this time. Nevertheless, it is of great importance to emphasize that many effluents together, however small, will have an impact on the environment. Therefore, it is essential to continue the monitoring of effluents into the Kafue River.

From this study it is evident that the uncertainty in the analyses makes it impossible to draw conclusions for a longer period of time based on only one sample. To be able to rely on the results from the laboratory it is also important that its routines will be reviewed. Further analysis on the effect of the nutrient rich bedrock is suggested, as well as an inspection on diffuse discharges and possible significant point sources not taken into account in this study. It should be pointed out that this study was based on samples from a very short period of time, during one season only. To be able to draw more reliable conclusions a study covering all seasons is recommended.

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Images

T. D. Center USDA, ARS. © Invasive.org, Image no. UGA0002074
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APPENDIX 1: TIME SCHEDULE

Activities	Schedule (weeks)								
	w 0	w 1	w 2	w 3	w 4	w 5	w 6	w 7	w 8
1 Preparation for field work									
1.1 Meetings with stakeholders									
1.1.1 Ministry of Agriculture and Cooperatives									
1.1.2 Department of Water Affairs									
1.1.3 Provincial Water Engineering Office									
1.1.4 Environmental Council of Zambia									
1.1.5 Environmental Engineering Laboratory, UNZA									
1.1.6 ZESCO									
1.1.7 WWF									
1.1.8 Nakambala Sugar Estates									
1.1.9 Kafue Sewage Treatment Plant									
1.1.10 Nitrogen Chemicals of Zambia									
1.1.11 Kafue Fisheries									
1.3 Recognition of study site									
1.3.1 Nakambala Sugar Estates									
1.3.2 Kafue Sewage Treatment Plant									
1.3.3 Nangongwe Maturation Ponds									
1.3.4 Nitrogen Chemicals of Zambia									
1.3.5 Kafue Fisheries									
1.4 Literature and data studies									
1.4.1 Environmental Council of Zambia									
1.4.2 Provincial Water Engineering Office									
2 Field work									
2.1 First sampling occasion and analysis of samples									
2.1.1 Kafue River									
2.1.2 Chirundu									
2.1.3 Nakambala Sugar Estates									
2.1.4 Kafue Town									
2.1.4.1 Kafue Sewage Treatment Plant									
2.1.4.2 Nangongwe Maturation Ponds									
2.1.4.3 Kafue Industrial Area									
2.2 Second sampling occasion and analysis of samples									
2.2.1 Kafue River									
2.2.2 Chirundu									
2.2.3 Nakambala Sugar Estates									
2.2.4 Kafue Town									
2.2.4.1 Kafue Sewage Treatment Plant									
2.2.4.2 Nangongwe Maturation Ponds									
2.2.4.3 Kafue Industrial Area									
2.3 Preliminary interpretation of results									
2.4 Additional sampling occasions									
3 Summarizing study									
3.1 Interpretation of results									
3.2 Collecting additional information									
4 Presentation of preliminar results									

Week 0: 16/06/2003 - 20/06/2003

Week 1 - 8: 18/08/2003 - 10/10/2003

APPENDIX 2: DESCRIPTION OF SAMPLING SITES

The Kafue River

K0 through K8 are samples from the main channel of the Kafue River, except K5 which is located in a lagoon. The landscape in the area between sample point K0 and K7 is characterized by flat grassland with several open and closed lagoons. Downstream at sample point K8 the landscape is hillier and the vegetation consists of trees and bushes. The depth at each sampling point was estimated as the mean of the depths measured at the four different verticals where samples were collected, while the width was approximated with the naked eye.

K0

Latitude: 15°43'22
Longitude: 27°48'20
Altitude: 976 m a s l
Approximate depth: 8 m
Approximate width: 70 m
Water samples from K0 were collected in the Kafue River upstream from the confluence of Kaleya River. The sample is considered unaffected by the activities in the study area and is therefore regarded as a reference sample. K0 corresponds to sample 8 in the ECZ study from 1999.

K1

Latitude: 15°44'39
Longitude: 27°49'47
Altitude: 977 m a s l
Approximate depth: 6 m
Approximate width: 200 m
This sampling point is located just upstream Shimungalo fishing village in the farming area. K1 corresponds to sample 11 in the ECZ study from 1999.

K2

Latitude: 15°45'32
Longitude: 27°55'32
Altitude: 978 m a s l
Approximate depth: 9 m
Approximate width: 150 m
K2 river samples were collected opposite the power line at Nanga fishing village. At this sample point impact from most of the farming activities is expected to show. This sample point corresponds to sample 14 in the ECZ study from 1999.

K3

Latitude: 15°44'40
Longitude: 28°04'09
Altitude: 980 m a s l
Approximate depth: 4 m
Approximate width: 180 m
To study the impact from all the commercial farms upstream, and at the same time get a sample unaffected by Kafue Fisheries, K3 was chosen. K3 is located downstream from Mungu Stream and corresponds to number 22 in the EZC study from 1999.

K4
Latitude: 15°45'25
Longitude: 28°05'43
Altitude: 980 m a s l
Approximate depth: 7 m
Approximate width: 180 m
K4 samples were collected 1 km downstream of Kafue Fisheries, opposite the bird watch tower, to show Kafue Fisheries possible impact. At the same time K4 represents the river unaffected by the industrial activities in Kafue Town. K4 corresponds to sample 23 in the EZC study from 1999.

K5
This sampling point is located in Chirumba Lagoon downstream of the Nitrogen Chemical's pump station. Some of the wastewater from the industrial activities might be discharged into the lagoon through Kasenje Stream.

K6
Latitude: 15°46'51
Longitude: 28°09'47
Altitude: 975 m a s l
Approximate depth: 5 m
Approximate width: 200 m
Water samples from this site were collected underneath the power lines upstream of Kafue Railway Bridge, in the southern river channel. Most of the nutrient loading from the industrial activities have entered the river at this point.

K7
Latitude: 15°49'59
Longitude: 28°14'36
Altitude: 978 m a s l
Approximate depth: 5 m
Approximate width: 100 m
K7 is located downstream from the road bridge and corresponds to sample point 28 in the ECZ study from 1999. All pollution from Kafue Town is assumed to have entered the river at this point.

K8
Located roughly 80 km downstream from Kafue Town, these water samples were collected from the pontoon on the road between Chirundu and Chiawa. This sample point was chosen to study the condition of the river water before its confluence with the Zambezi River.

Nakambala Sugar Estates

Simbotwe

Location: Approximately 50 m upstream of where Simbotwe exits the estates.
Average depth: 0.3 m
Width: 2 m
Mean flow rate: 0.2 m^3/s
Simbotwe receives wastewater from the factory and drainage water from fields close by before it enters the Kaleya River. It is a rather small stream but compared to the other discharges within the estates it is considerably larger. Fields surround the sampling point and the slope down to the watercourse had a lot of vegetation at the time for this study. The floor of the stream was muddy and free from vegetation.

Discharge into Simbotwe

Location: The discharge from Kaleya compound, approximately 20 m upstream of confluence with Simbotwe Stream.
Average depth: 0.25 m
Width: 1.6 m
Mean flow rate: 0.02 m^3/s
This small stream receives wastewater from Kaleya compound as well as drainage water from surrounding fields. It enters Simbotwe just upstream where Simbotwe has its exit from the estates and downstream the sampling point of Simb. The physical features were similar to those of the Simbotwe sampling point.

26 West

Location: Upstream of the bridge at ECZ's 26 West sampling point.
Average depth: 0.15 m
Width: 1 m
Mean flow rate: 0.03 m^3/s
The fields in the western parts of the estates drain into 26 West which finally enters the Kaleya River. Downstream of the sampling point the fields are assumed to have no impact on the stream.

26 East

Location: Water samples were collected just downstream of the weir at ECZ's 26 East sampling point, whereas parameters below were measured approximately 50 m downstream from this point.
Average depth: 0.1 m
Width: 0.5 m
Mean flow rate: 0.01 m^3/s
Drainage water from the fields in the eastern parts of the estates is collected in 26 East and is eventually discharged into Kaleya River. The sampling point is located downstream of the fields and upstream of the residential compound adjacent to the stream. The water was during the study slightly turbid and algae were present.

Kafue Town and industrial area

Kafue Sewage Treatment Plant

Location: In the discharge channel downstream of the lagoons.
Average depth: 0.1 m
Width: 0.5 m
Mean flow rate: 0.005 m^3/s
The treated water is transported through a covered concrete canal from the lagoons to the Kafue River. The samples were collected at a point where the canal is not covered.

Nangongwe Maturation Ponds

Location: Just after the last pond in the discharge channel that is used when the pump station is out of order.
Average depth: 0.1 m
Width: 0.5 m
Mean flow rate: 0.007 m^3/s
Even though the ponds are cleaned from weeds and sediments annually, they were almost completely covered with weeds at the time of this study. The floor of the small channel was covered with black particles and the water had a sulphuric smell.

Kasenje 1

Location: Sampling point SW2 at the northern road bridge at Nitrogen Chemicals of Zambia.
Average depth: 0.2 m
Width: 12 m
Mean flow rate: 0.18 m^3/s
At the time of the study the pipe transporting wastewater from Kafue Estates to KSTP was broken, leading to pollution of Kasenje stream upstream of this point. The sample was collected from the eastern side of the stream since weeds cover the western side. On the day of sampling the water was very turbid and dirty (faeces were visible) and had a smell of sewage.

Kasenje 2

Location: Just downstream the confluence of Kasenje Stream coming from NCZ and the stream from Bata Tannery, Lee Yeast, Kafue Chemicals, Kafue Textiles and others.
Average depth: 0.25 m
Width: 3.2 m
Mean flow rate: 0.1 m^3/s
This sampling point is assumed to represent the impact of the industrial activities in the area, but as there is a confused heap of fields and irrigation canals all along Kasenje Stream downstream from the industries, it is close to impossible to know the exact catchment of this point. The water had a dark brown colour and the floor is muddy and free from vegetation.

Kasenje 3

Location: In a small irrigation canal connected to Kasenje Stream just upstream its discharge in Chirumba Lagoon.
At this site, Kasenje is very shallow, slow and completely covered with water hyacinths. Therefore the sample was collected from an irrigation canal that takes its water from the stream, which might not make it a representative sample for Kasenje at the outlet into Chirumba Lagoon.

APPENDIX 3: RESULTS FROM CHEMICAL ANALYSES

The tables below present results from all analyses of pH, phosphate-P, nitrate-N and ammonium-N. Some of the concentrations were unrealistic and are therefore not included in the study, others were discarded because of high relative difference, see Appendix 4. The excluded samples are indicated with bold figures in the tables.

Table A3.1 Phosphate-P, nitrate-N, ammonium-N and pH from the Kafue River. Bold figures indicate discarded samples.

	Date	pH	Phosphate-P PO_4^{3-}-P (mg/l)			Nitrate-N NO_3^--N (mg/l)			Ammonium-N NH_4^+-N (mg/l)		
			Duplicates		*Mean*	Duplicates		*Mean*	Duplicates		*Mean*
The Kafue River											
K0	04-Sep	6.7	1.02	1.32	*1.17*	2.60	3.00	*2.80*	0.01	0.02	*0.015*
	08-Sep	7.8	1.53	1.55	*1.54*	4.06	4.21	*4.14*	0.57	0.65	*0.61*
K1	04-Sep	6.8	2.33	2.29	*2.31*	3.00	2.90	*2.95*	0.01	<0.01	*<0.01*
	08-Sep	7.8	0.44	0.47	*0.46*	5.13	5.20	*5.17*	0.52	0.55	*0.54*
K2	04-Sep	6.9	2.16	1.99	*2.08*	3.70	4.30	*4.00*	0.01	0.01	*0.01*
	08-Sep	7.5	0.76	0.80	*0.78*	6.06	6.12	*6.09*	0.59	0.56	*0.58*
	22-Sep	-	1.07	0.95	*1.01*	2.70	2.57	*2.64*	-	-	-
K3	04-Sep	6.9	2.41	2.39	*2.40*	3.90	4.30	*4.10*	0.02	0.01	*0.015*
	08-Sep	7.7	1.79	1.67	*1.73*	7.62	7.64	*7.63*	0.44	0.45	*0.445*
K4	04-Sep	7.1	2.30	2.25	*2.28*	2.80	3.10	*2.95*	0.01	0.02	*0.015*
	08-Sep	7.6	1.82	1.84	*1.83*	5.49	5.56	*5.53*	1.26	1.18	*1.22*
K5	04-Sep	7.0	1.68	1.70	*1.69*	2.80	3.00	*2.90*	0.02	0.03	*0.025*
K6	04-Sep	7.2	1.91	1.86	*1.89*	3.40	3.00	*3.20*	0.01	0.01	*0.01*
	08-Sep	7.5	1.33	1.28	*1.31*	3.98	3.79	*3.89*	0.54	0.58	*0.56*
K7	04-Sep	7.1	2.91	3.04	*2.98*	3.30	2.80	*3.05*	<0.01	<0.01	*<0.01*
	08-Sep	8.3	2.89	2.79	*2.84*	6.82	6.66	*6.74*	0.45	0.46	*0.455*
K8	28-Aug	8.0	0.73	0.70	*0.72*	**<0.01**	**<0.01**	***<0.01***	0.32	0.33	*0.325*
	09-Sep	7.5	3.43	3.39	*3.41*	1.05	1.10	*1.08*	0.39	0.41	*0.40*
	17-Sep	-	1.12	1.08	*1.10*	12.50	12.10	*12.30*	-	-	-

Table A3.2 Phosphate-P, nitrate-N, ammonium-N and pH from Nakambala Sugar Estates and Kafue Town and industries. Bold figures indicate discarded samples. The underscored duplicate was ignored due to great relative differences within duplicates.

	Date	pH	Phosphate-P PO_4^{3-}-P (mg/l)			Nitrate-N NO_3^--N (mg/l)			Ammonium-N NH_4^+-N (mg/l)		
			Duplicates		***Mean***	**Duplicates**		***Mean***	**Duplicates**		***Mean***
Nakanbala Sugar Estates											
Simbotwe	03-Sep	7.6	1.76	1.68	*1.72*	4.14	3.99	*4.07*	0.04	0.05	*0.045*
	11-Sep	7.5	4.77	4.19	*4.48*	**27.04**	**25.73**	***26.39***	0.04	<0.01	*<0.03*
	22-Sep	-	2.75	2.67	*2.71*	5.01	4.27	*4.64*	-	-	-
Discharge into Simbotwe	03-Sep	7.6	3.46	3.28	*3.37*	1.87	1.69	*1.78*	<0.01	<0.01	*<0.01*
	11-Sep	7.9	6.60	6.70	*6.65*	**15.88**	**15.85**	***15.87***	<0.01	<0.01	*<0.01*
	22-Sep	-	1.62	1.40	*1.51*	3.00	2.92	*2.96*	-	-	-
26 West	03-Sep	7.6	**<u>1.34</u>**	**<u>0.99</u>**	-	2.94	2.88	*2.91*	<0.01	<0.01	*<0.01*
	11-Sep	7.8	**7.10**	**7.12**	***7.11***	**10.36**	**11.01**	***10.69***	<0.01	<0.01	*<0.01*
	22-Sep	-	1.31	1.24	*1.28*	3.32	3.17	*3.25*	-	-	-
26 East	03-Sep	7.7	0.68	0.74	*0.71*	2.44	2.56	*2.50*	<0.01	<0.01	*<0.01*
	11-Sep	8.2	**8.50**	**8.45**	***8.48***	**22.03**	**23.02**	***22.53***	<0.01	<0.01	*<0.01*
	22-Sep	-	1.00	1.08	*1.04*	2.94	2.65	*2.80*	-	-	-
Kafue Town											
KSTP	01-Sep	6.8	2.40	2.38	*2.39*	2.70	2.69	*2.70*	0.28	0.26	*0.27*
	10-Sep	7.3	**<u>0.34</u>**	**<u>0.55</u>**	-	18.61	20.04	*19.33*	0.04	0.03	*0.035*
	17-Sep	-	1.37	1.30	*1.34*	15.10	13.00	*14.05*	-	-	-
NMP	01-Sep	7.2	4.00	4.20	*4.10*	2.90	3.40	*3.15*	3.69	3.65	*3.67*
	10-Sep	6.6	1.85	2.10	*1.98*	19.81	19.28	*19.55*	5.06	5.39	*5.23*
	17-Sep	-	2.84	2.80	*2.82*	11.50	12.00	*11.75*	-	-	-
Kasenje 1	01-Sep	7.5	4.30	3.99	*4.15*	4.30	4.30	*4.30*	3.79	3.80	*3.795*
Kasenje 2	10-Sep	7.5	5.48	6.55	*6.02*	27.04	25.75	*26.40*	4.08	3.52	*3.80*
Kasenje 3	08-Sep	7.8	4.89	4.92	*4.91*	6.67	6.48	*6.58*	3.58	3.57	*3.575*

Appendix 4: Relative Differences

The relative differences within duplicates were estimated with Equation 1. Table A4.1 shows the obtained relative differences for all duplicates, where bold figures indicate duplicates that have been disregarded.

Table A4.1 Calculated relative differences for duplicates, bold figures indicate samples that were discarded due to difference being too great.

Site	Date	Phosphate-P D (%)	Nitrate-N D (%)	Ammonium-N D (%)
K0	04-Sep	26	14	67
	08-Sep	1	4	13
K1	04-Sep	2	3	>0
	08-Sep	7	1	6
K2	04-Sep	8	15	0
	08-Sep	5	1	5
	22-Sep	12	5	-
K3	04-Sep	1	10	67
	08-Sep	7	0	2
K4	04-Sep	2	10	67
	08-Sep	1	1	7
K5	04-Sep	1	7	40
K6	04-Sep	3	13	0
	08-Sep	4	5	7
K7	04-Sep	4	16	0
	08-Sep	4	2	2
K8	28-Aug	4	0	3
	09-Sep	1	5	5
	17-Sep	4	3	-
Simb	03-Sep	5	4	22
	11-Sep	13	5	>120
	22-Sep	3	16	-
DS	03-Sep	5	10	0
	11-Sep	2	0	0
	22-Sep	15	3	-
26 W	03-Sep	**30**	2	0
	11-Sep	0	6	0
	22-Sep	5	5	-
26 E	03-Sep	8	5	0
	11-Sep	1	4	0
	22-Sep	8	10	-
KSTP	01-Sep	1	0	7
	10-Sep	**47**	7	29
	17-Sep	5	15	-
NMP	01-Sep	5	16	1
	10-Sep	13	3	6
	17-Sep	1	4	-
Kasenje 1	01-Sep	7	0	0
Kasenje 2	10-Sep	18	5	15
Kasenje 3	08-Sep	1	3	0

APPENDIX 5: CALCULATIONS OF WATER FLOW RATES

The water flow rates at the river sampling points upstream Kafue Gorge Dam, Q_{River}, were approximated to be equal. Q_{River} was estimated to the mean of the inflow at Kafue Gorge Dam, Q_{in}, during September.

Q_{in} was obtained through the equation:

$$Q_{in} = Q_{out} + E_p \cdot A_{surface} + \frac{dh}{dt} \cdot A_{surface} + P \cdot A_{surface}$$

Q_{in} = Inflow to the reservoir at Kafue Gorge [m^3/s]
Q_{out} = Discharge from Kafue Gorge Dam [m^3/s]
E_p = Potential evaporation [m/s]
$A_{surface}$ = Surface area of the reservoir at Kafue Gorge [m^2]
dh/dt = Change in water level at Kafue Gorge Dam [m]
P = Precipitation [m/s]

Since there was no rain during the time of the study, the precipitation term was ignored. Data on daily water levels, h, and outflows, Q_{out}, from Kafue Gorge was received from ZESCO and can be viewed in Table A5.2. Due to uncertainty in the reading of water levels and the great effect an error in reading has got, a polynomial regression was made and used to calculate dh/dt. ZESCO also provided a conversion table from water levels to reservoir surface areas at Kafue Gorge, an excerpt is shown in Table A5.1. Through interpolation of the figures in the conversion table surface areas for the approximated water levels were obtained. The potential evaporation was approximated to the pan evaporation normal, which is 7.73 mm/day ($8.95 \cdot 10^{-8}$ m/s) for September (ZESCO 1994).

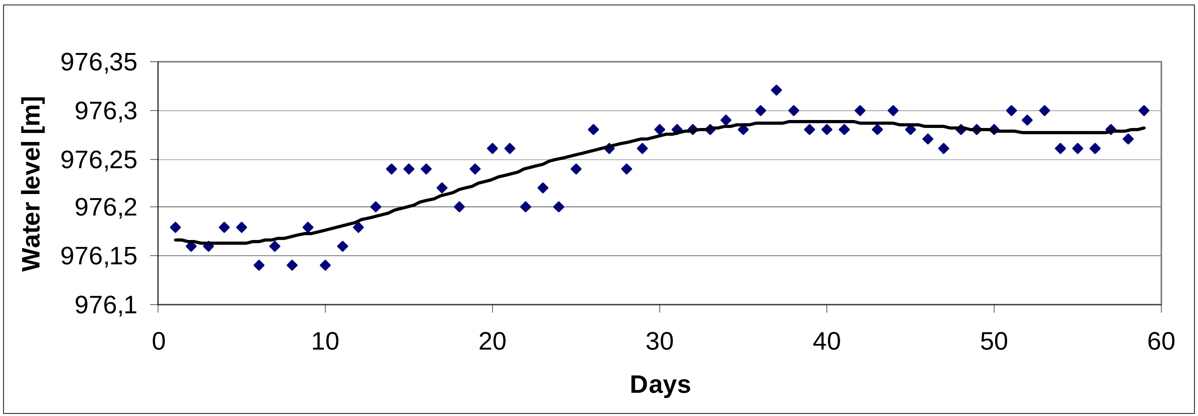

Figure A5.1 Polynomial regression of grade four, based on water levels at Kafue Gorge in August and September 2003.

Table A5.1 An excerpt from ZESCO's table for conversion from water level to reservoir surface area at Kafue Gorge Dam.

h (m)	$A_{surface}$ (10^6 m^2)
976.00	430
976.25	565
976.50	725

Table A5.2 Water balance at Kafue Gorge Dam.

Date	Q_{out} (m^3/s)	h Water level at Kafue Gorge (m)	h Polynomial approximation (m)	dh/dt (10^{-8} m/s)	$A_{surface}$ (10^6 m^2)	Q_{in} (m^3/s)
01-Sep	138	976.28	976.279		582.39	208
02-Sep	145	976.28	976.281	2.60	583.74	212
03-Sep	143	976.29	976.283	2.21	584.89	208
04-Sep	146	976.28	976.285	1.82	585.84	209
05-Sep	145	976.30	976.286	1.44	586.59	206
06-Sep	151	976.32	976.287	1.07	587.15	210
07-Sep	148	976.30	976.288	0.71	587.52	205
08-Sep	146	976.28	976.288	0.37	587.71	201
09-Sep	154	976.28	976.288	0.05	587.74	207
10-Sep	152	976.28	976.288	-0.25	587.61	203
11-Sep	152	976.30	976.287	-0.52	587.33	202
12-Sep	143	976.28	976.287	-0.76	586.94	191
13-Sep	154	976.30	976.286	-0.96	586.43	201
14-Sep	152	976.28	976.285	-1.13	585.84	198
15-Sep	151	976.27	976.284	-1.26	585.19	196
16-Sep	146	976.26	976.283	-1.34	584.49	190
17-Sep	148	976.28	976.281	-1.37	583.77	192
18-Sep	147	976.28	976.280	-1.36	583.07	191
19-Sep	150	976.28	976.279	-1.28	582.40	195
20-Sep	150	976.30	976.278	-1.15	581.80	195
21-Sep	145	976.29	976.277	-0.96	581.30	191
22-Sep	148	976.30	976.277	-0.70	580.94	196
23-Sep	153	976.26	976.276	-0.37	580.75	203
24-Sep	154	976.26	976.276	0.04	580.77	206
25-Sep	153	976.26	976.277	0.51	581.03	208
26-Sep	151	976.28	976.278	1.06	581.58	209
27-Sep	118	976.27	976.279	1.70	582.47	180
28-Sep	138	976.30	976.281	2.43	583.73	204