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An investigation of nutrient levels along the Mbuluzi River

- A background for sustainable water resources management

A Minor Field Study (MFS) conducted in Mozambique and Swaziland
Master of Science Thesis in Environmental Engineering

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Resumo

Título: Investigação do nível de nutrientes ao longo do Rio Umbeluzi – Base para uma gestão sustentável dos recursos hídricos

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Definição do Problema: O rio Umbeluzi nasce na Suazilândia e no seu percurso atravessa Moçambique desaguando no Oceano Índico. Devido à escassez de água, aumento populacional e crescimento dos sectores industrial e agrícola, tem se colocado uma grande pressão sobre a qualidade de água. A importância de manter água de boa qualidade é acentuada pelo facto de o Rio ser partilhado entre dois países para além de ser a fonte de abastecimento de água para as duas capitais. O incremento verificado nas actividades agrícolas na bacia tem levantado preocupações quanto à migração de nutrientes, especialmente vindos da farmas comerciais. Devido à relativa escassez de água na região, o principal assunto relativamente ao rio Umbeluzi tem sido a quantidade ao invés da qualidade de água. Esta situação combinada com os constrangimentos económicos levou à limitação do monitoramento e coordenação de programas de qualidade de água.

Objectivos: O principal objectivo deste estudo é descrever a forma como a qualidade de água varia (sazonal e espacialmente) ao longo do Rio Umbeluzi e propor melhorias para futuro monitorameto. A ênfase é dada aos nutrientes e ao risco de eutrofização. As questões específicas a serem respondidas são:

- Será que o massivo cultivo da cana de açúcar na Suazilândia e outras fontes de poluição influenciam a qualidade de água que entra em Moçambique? Se for o caso, qual é a dimensão?
- Como é que as barragens de Mnjoli e Pequenos Libombos influenciam a qualidade de água do rio?
- Qual é a capacidade de auto-purificação do Rio?
- Será possível detectar diferenças sazonais na qualidade de água?
- Existe algum risco eminente de eutrofização?
- Como é que se pode tornar o monitoramento da qualidade de água mais eficiente?

Método: Os dados de qualidade de água foram obtidos de diferentes instituições responsáveis pelo monitoramento. Foram, igualmente levadas a cabo medições de qualidade de água em oito locais ao longo do Rio em Setembro-Outubro de 2005. No campo foram feitas medições de Condutividade, pH, TDS, turvação, temperatura e NO_3^- (incluíndo NO_2^-) enquanto o N-tot e P-tot foram analisados no laboratório. Para os pontos de amostragem localizados em Moçambique, o PO_4^{3-} foi analisado uma única vez. Os dados foram analisados usando métodos estatísticos.

Para recolha de informação relativa às actividades ao longo do rio Umbeluzi, foram visitados e entrevistados os principais *stakeholders* desta área. Foram também visitados os laboratórios envolvidos em análises de amostras de água para colher informação sobre análises actuais (métodos, conservação de amostras, manuseamento de dados etc). A informação sobre o monitoramento actual da qualidade de água foi obtida através de entrevistas aos principais participantes.

Conclusões: O cultivo de cana de açúcar na Suazilândia influencia a qualidade de água nos troços de jusante através do aumento de condutividade eléctrica, fosfatos, fósforo nitrato e nitrito. Contudo, no troço que vai desde Goba (na fronteira) à barragem dos Pequenos Libombos, o Rio parece ter uma considerável capacidade auto-purificadora, levando a que, duma forma geral, a água tenha uma qualidade aceitável nos troços de jusante (durante o período de realização deste estudo). Isto poder ser constatado pela redução dos níveis de fósforo, nitrogénio e nitratos/nitritos. Todavia, é muito provável que esta auto-purificação seja limitada e que no caso dum aumento na carga poluente possa ocorrer uma deterioração severa da qualidade de água.

Medições efectuadas durante o presente trabalho de campo mostram níveis de fósforo, nitrogénio e nitratos mais baixos antes da entrada para a albufeira dos Pequenos Libombos que à jusante, o que pode ser uma indicação de que a barragem não funciona como unidade de retenção de nutrientes. Todavia, visto que a água é descarregada a partir do fundo da barragem, foi feita uma comparação entre a água de superfície do caudal afluente e a água de fundo do caudal efluente. Isto pode servir de explicação para os altos valores de jusante. Embora não tenham sido feitas medições de oxigénio pensa-se que a água do fundo seja anaeróbica. As condições anaeróbicas e o facto de o caudal efluente ter um elevado pH do que o caudal afluente indicam que tem lugar uma desnitrificação na barragem. Aquando deste estudo de campo, o efeito da desnitrificação não era notado nas concentrações de nitratos visto que as concentrações no caudal afluente eram raramente baixas e o caudal descarregado da barragem originada de um período de tempo relativamente longo, durante o qual a concentração do fluxo afluente provavelmente era mais alta do que a actual. Numa perspectiva de longo prazo (vários anos), o efeito resultante da barragem é por conseguinte, a redução de nitrogénio mesmo que assim não o pareça durante as condições de seca. Os dados da Barragem de Mnjoli mostram resultados similares.

Geralmente, as concentrações de nutrientes são elevadas durante a época das chuvas, o que implica que o efeito da carga de nutrientes é mais alto que o efeito de diluição dos grandes caudais.

Os dados mostram que no final de 2005 (época seca) o fósforo era um factor limitante de crescimento no Rio e assim não havia riscos de eutrofização, nem nas Barragens nem no Rio. Contudo, isto pode mudar durante a época chuvosa quando as concentrações de nutrientes (tanto N e P) são susceptíveis de crescer. Segundo informações a espécie não indígena *Salvinia Molesta* está a espalhar-se na parte Moçambicana do Rio e quantidades crescentes de flores de algas nas Barragens, foram relatadas, indicando que as condições eutróficas podem ocorrer ocasionalmente.

Para melhorar o monitoramento da qualidade de água, é necessária melhor coordenação entre diferentes actores. Além disso, os objectivos dos programas de monitoramento precisam de ser bem definidos. Os métodos de análise também precisam de ser verificados e avaliados numa base regular. Em relação ao armazenamento de dados, recomenda-se a implementação de um sistema uniforme para todos os participantes envolvidos no monitoramento da Bacia Hidrográfica.

Palavras chave: Qualidade de água do rio, nutrientes, eutrofização, monitoramento da qualidade de água, Moçambique, Suazilândia

Summary

Title: An investigation of nutrient levels along the Mbuluzi River – A background for sustainable water resources management

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Problem Definition: The Mbuluzi River runs through Swaziland and Mozambique into the Indian Ocean. Due to water shortage, population increase and growing industrial and agricultural sectors, high stress is being put on the water quality. The importance of keeping good water quality is accentuated by the fact that the River is shared between two countries and that it supports both capitals with drinking water. The increased agricultural activities in the basin have raised concerns regarding leakage of nutrients, especially from commercial farming. Because of the general water scarcity in the region, the main issue regarding the Mbuluzi River has been water quantity rather than water quality. This, together with economical constraints has lead to limited monitoring and coordination of water quality programmes.

Objectives: The main objective of this study is to describe how the water quality varies (seasonally and spatially) along the Mbuluzi River and to propose improvements for future monitoring. The focus is on nutrients and the threat of eutrophication. Specific questions are:

- Does the intense sugar farming in Swaziland or other pollution sources influence the quality of the water entering Mozambique? If so, to what extent?
- How do the Mnjoli and Pequenos Libombos Dams influence the river water quality?
- How is the River's self-purification capacity?
- Can any seasonal differences be detected in the water quality?
- Is there an impending risk of eutrophication?
- How can water quality monitoring become more efficient?

Method: Water quality data was obtained from different actors responsible for monitoring. Also, the water quality was measured at eight sites along the River in September-October 2005. Conductivity, pH, TDS, turbidity, temperature and NO_3^- (including NO_2^-) were measured in field whereas N-tot and P-tot were analysed in laboratory. Further, flow data was obtained from different stakeholders. For the Mozambiquean sampling locations, PO_4^{3-} was also analysed once. Data was analysed using statistical methods.

In order to gather information regarding activities in the area along the Mbuluzi River, the main stakeholders in the area were visited and interviews were conducted. Also, laboratories involved in analysing water samples were visited to collect information on current analyses (methods, storage of samples, handling of data etc). Information about current water quality monitoring was obtained by interviews with the main participants.

Conclusions: The sugar farming in Swaziland influences the water quality in the downstream stretches by increased levels of conductivity, phosphate, phosphorous, nitrate and nitrite. However, on the stretch between Goba (at the border) and the Pequenos Libombos Dam, the River seems to have a considerable self-purifying capacity, leading to generally acceptable water quality in the downstream reaches (during the time of this field study). This can for example be seen in decreased levels of phosphorous, nitrogen and nitrate/nitrite. It is, however, likely that the self-purifying capacity is limited and if pollution loads increases it may lead to severe water quality deterioration.

Measurements during this field study show that levels of phosphorous, nitrogen and nitrate are lower before the Pequenos Libombos Dam than after. This indicates that the Dam does not function as a nutrient trap, as would be expected. However, since water is released from the bottom of the Dam, inflowing surface water has been compared to outflowing bottom water. This might be one explanation of the higher downstream values. Although no measurements of oxygen have been made, the bottom water is thought to be anoxic. The anoxic conditions and the fact that the outflowing water has a higher pH than the incoming water indicates that denitrification takes place in the Dam. At the time of this field study, the effect of the denitrification is not seen in the nitrate concentrations since the concentrations in the inflowing water were unusually low and the water released from the Dam originates from a relatively long time period, during which the inflowing concentration probably were higher than at present. However, in a longer time perspective (several years), the net effect of the Dam is thought to be a reduction of nitrogen even though this does not appear during drought conditions. Data from the Mnjoli Dam show similar results.

Generally, the concentrations of nutrients are found to be higher during rainy seasons, implying that the effect of nutrient loads is higher than the dilution effect of the higher flows.

Data show that in late 2005 (dry season) phosphorous is the growth limiting factor in the River and there were no risks of eutrophication, neither in the Dams nor in the River. This may however change during rainy seasons when nutrient concentrations (both N and P) are likely to increase. Information gives that the alien specie *Salvinia Molesta* is spreading in the Mozambiquean part of the River and increased amounts of algal blooms have been reported in the Dams, indicating that eutrophic conditions may occur occasionally.

To improve water quality monitoring, better coordination between different actors is needed. Further, the objectives of the monitoring programmes need to be better defined. The analysis methods also need to be checked and evaluated on a regular basis. Regarding data storage, a uniform system for all participants involved in the River basin monitoring is recommended to be implemented.

Keywords: River water quality, nutrients, eutrophication, water quality monitoring, Mozambique, Swaziland

Sammanfattning

Titel: Undersökning av näringshalter längs Mbuluzi-floden – En bakgrund för hållbar vattenresurshushållning

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Problem-beskrivning: Mbuluzi-floden rinner från Swaziland via Moçambique ut till Indiska oceanen. På grund av vattenbrist, befolkningsökning och ökande industri- och jordbruks-sektorer är belastningen på floden hög. Vikten av att bibehålla god vattenkvalitet förstärks av att floden delas mellan två länder, vars båda huvudstäder försörjs av vatten från floden. Det ökande jordbruket i Moçambique har gett upphov till oro beträffande läckage av näringsämnen, särskilt från kommersiellt jordbruk. Tidigare har den huvudsakliga frågan rörande vattenresursen Mbuluzi varit kvantitet snarare än kvalitet. Detta, tillsammans med ekonomiska begränsningar, har lett till begränsad övervakning och koordination av vattenkvalitetsprogram.

Syfte: Det huvudsakliga syftet med denna studie är att beskriva hur vattenkvaliteten varierar (i tid och rum) längs Mbuluzi-floden samt att föreslå förbättringar för framtida övervakning. Tyngdpunkten är lagd på näringsämnen och övergödnings-risk. Frågeställningen är:

- Påverkas vattenkvaliteten i Moçambique av det omfattande sockerrörs-odlandet (eller andra föroreningskällor) i Swaziland? Om så är fallet, i vilken omfattning?
- Hur påverkas flodens vattenkvalitet av dammarna Mnjoli och Pequenos Libombos?
- Hur är flodens självrenande förmåga?
- Kan årstidsvariationer uskiljas i vattenkvaliteten?
- Finns det en överhängande risk för övergödning?
- Hur kan vattenkvalitetsövervakningen effektiviseras?

Metod: Vattenkvalitetsdata erhölls från olika aktörer ansvariga för övervakning i avrinningsområdet. Vidare gjordes vattenkvalitetsmätningar i september och oktober 2005 vid åtta mätpunkter längs floden. Konduktivitet, pH, TDS, turbiditet, temperatur och NO_3^- (inclusive NO_2^-) mättes i fält medan N-tot och P-tot analyserades i laboratorium. Flödesdata erhölls från olika intressenter längs floden. För mätpunkterna i Moçambique analyserades även fosfat vid ett tillfälle. Erhållen data utvärderades med statistiska metoder.

För att samla information rörande aktiviteter i området gjordes studiebesök och intervjuer med de viktigaste aktörerna. Även laboratorier inblandade i vattenanalys besöktes för att erhålla information rörande nuvarande analyser (metoder, förvaring av vattenprover, behandling av data etc). Vidare erhölls upplysningar angående nuvarande vattenkvalitetsövervakning.

Slutsatser: Sockerrörsodlingarna I Swaziland påverkar vattenkvaliteten nedströms genom högre konduktivitet samt ökade halter av fosfat, fosfor, nitrat och nitrit. Dock har floden en betydande självrenande förmåga på sträckan mellan Goba (gränsen) och Pequenos Libombos Dam. Detta leder till en generellt sett acceptabel vattenkvalitet i Moçambique (åtminstone vid tiden för denna fältstudie). Den självrenande förmågan kan t.ex. ses genom minskande halter av fosfor, kväve och nitrat/nitrit. Emellertid är det troligt att den självrenande förmågan är begränsad – detta vill säga att om gränsen överskrids kan resultatet bli en betydande vattenkvalitets-försämring.

Mätningar under denna fältstudie påvisar lägre halter av fosfor, kväve och nitrat före Pequenos Libombos Dam än efter. Detta tyder på att dammen inte fungerar som en näringsfälla, vilket förväntades. Som en följd av att dammutsläppet är placerat nära dammens botten, har inflödande ytvatten jämförts med utflödande bottenvatten i denna studie. Detta kan vara en förklaring till de högre halterna nedströms dammen. Även om inga mätningar gjorts på syrehalt är det rimligt att anta att bottenvattnet är anoxiskt. De anoxiska förhållandena och det faktum att utflödande vatten har ett högre pH än det inflödande vattnet indikerar att det sker denitrifikation i dammen. Vid tidpunkten för denna fältstudie framgår inte effekten av denitrifikationen särskilt tydligt eftersom nitrathalterna i det inflödande vattnet var ovanligt låga. Dessutom härrör vattnet i dammen från en relativt lång tidsperiod, under vilken nitratkoncentrationen sannolikt varit högre än vid mättillfällena under denna studie. Sett i ett längre tidsperspektiv (ett flertal år) anses netto-effekten av dammen dock vara reducerande med avseende på kväve även om detta inte märks under torra förhållanden. Data från Mnjoli Dam visar liknande resultat som för Pequenos Libombos Dam.

I allmänhet är koncentrationerna av näringsämnen högre under regnperioder än under torrperioder, vilket tyder på att effekten av den extra näringtillförseln via avrinning är större än utspädningseffekten av det högre flödet.

För senare delen av år 2005 visar data att fosfor är den tillväxtbegränsande faktorn i floden. Vidare var övergödningsrisken inte överhängade, vare sig i floden eller i dammarna. Dessa förhållanden kan dock förändras under regnperioder då koncentrationerna av näringsämnena sannolikt ökar. Enligt källor sprider sig den främmande arten *Salvinia Molesta* i den moçambikanska delen av floden. Vidare rapporteras ökande förekomst av algblomningar I dammarna, vilket tyder på tillfälliga eutrofa förhållanden.

För att förbättra vattenkvalitetsövervakningen krävs bättre koordination mellan olika aktörer. Syftena med övervakningsprogrammen måste också klargöras. Vidare bör analysmetoderna kontrolleras, utvärderas och kalibreras kontinuerligt. Beträffande lagring av data rekommenderas implementering av gemensamma system och rutiner för alla involverade aktörer.

Nyckelord: Flodvattenkvalitet, näringsämnen, övergödning, vattenkvalitetsövervakning, Moçambique, Swaziland

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The MFS Scholarship Programme offers Swedish university students an opportunity to carry out two months' field work, usually the student's final degree project, in a Third World country. The result of this work is presented in an MFS report which is also the student's Master of Science Thesis within engineering and natural sciences. Minor Field Studies are primarily conducted within subject areas of importance from a development perspective and in a country supported by Swedish international development assistance.

The main purpose of the MFS Programme is to enhance Swedish university students' knowledge and understanding of developing countries, their problems and opportunities. An MFS should provide the student with initial experience of conditions in such a country. Overall goals are to widen the human resource base for recruitment into international co-operation and to promote scientific exchange between univeristies, research institutes and similar authorities in developing countries and in Sweden. A further purpose is to widen the human resource base for recruitment into international co-operation.

The responsibility for the accuracy of the information presented in this MFS report rests entirely with the authors and their supervisors.

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Anna Gustafsson *Maria Johansson*

List of abbreviations

AdM	Águas de Moçambique
ARA-Sul	Administração Regional de Águas do Sul (Regional Water Administration for Southern Mozambique)
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DNA	Direcção Nacional de Águas (National Directorate of Water), Mozambique
DO	Dissolved Oxygen
DWAF	Department of Water Affairs and Forestry, South Africa
EC	Electrical Conductivity
ETA	Estação de Tratamento de Água (Water treatment plant)
GDP	Gross Domestic Product
INIA	Instituto Nacional de Investigacao Agronomia
JURBS	Joint Umbeluzi River Basin Study
MAP	Mean Annual Precipitation
MFS	Minor Field Study
MISAU	Ministério da Saúde (Ministry of Health), Mozambique
RSSC	Royal Swaziland Sugar Corporation
SADC	Southern Africa Development Community
SAWQG	South African Water Quality Guidelines
SS	Suspended Solids
SWSC	Swaziland Water Services Corporation
TDS	Total Dissolved Solids/Salts
TPTC	Tripartite Permanent Technical Committee
TSS	Total Suspended Solids
TWQR	Target Water Quality Range
UEM	Eduardo Mondlane University, Mozambique
UNDP	United Nations Development Programme
U.S. EPA	U.S. Environmental Protection Agency
WHO	World Health Organization of the United Nations
WRB	Water Resources Branch, Swaziland
WRM	Water Resources Management
WTP	Water Treatment Plant
WWTP	Waste Water Treatment Plant

Glossary

Afforestation	The establishment of a forest, stand or tree crop on an area not previously forested, or on land from which forest cover has very long been absent.
Baseflow	The continous contribution of groundwater to rivers. An important source of flow between rainstorms.
Benthic algae	Algae living on, or very near, the bottom of a waterbody.
Benthic chlorophyll	Chlorophyll deriving from benthic algae.
Bio-accumulate	The increase in the concentration of a substance, especially a contaminant, in an organism or in the food chain over time.
Bioturbation	The disturbance of sediment by organisms.
Cover crops	Crops that serve to prevent erosion, control weeds, and conserve water in the soil (from losses due to evaporation).
Drip irrigation	Continuous (slow) irrigation close to the roots of a plant, making evaporation losses minimal.
Estuary	The section where the river meets the ocean. Often characterised by brackish water.
First flush	A flush (e.g. of nutrients) which derives from a rainfall event after a period of dry conditions. The first flushes are often high in pollutants.
Floodplain	The land bordering a river, built up of sediments from overflow of the river.
Furrow irrigation	The method of surface irrigation in which narrow furrows very close to one another are used to guide water across a field.
Macrophytes	Large aquatic plants
Nutrient bioassays	Research method where a delimitated area of a waterbody is exposed to different nutrient concentrations whereupon the consequences are analysed.
Phytoplankton	Free-floating planktonic algae with a photosynthesizing ability.
Phytoplanktonic chlorophyll	Chlorophyll deriving from phytoplankton.
Riparian zone	The banks of a river.
Saltwater weir	A weir built to prevent intrusion of saltwater into fresh water systems.
Secchi depth	A measurement of visibility in water.
Stratification	Creation of layers in a water body due to density differences.
Wetland	A lowlying area which are saturated with water most or all of the time.

Map of the Mbuluzi River basin

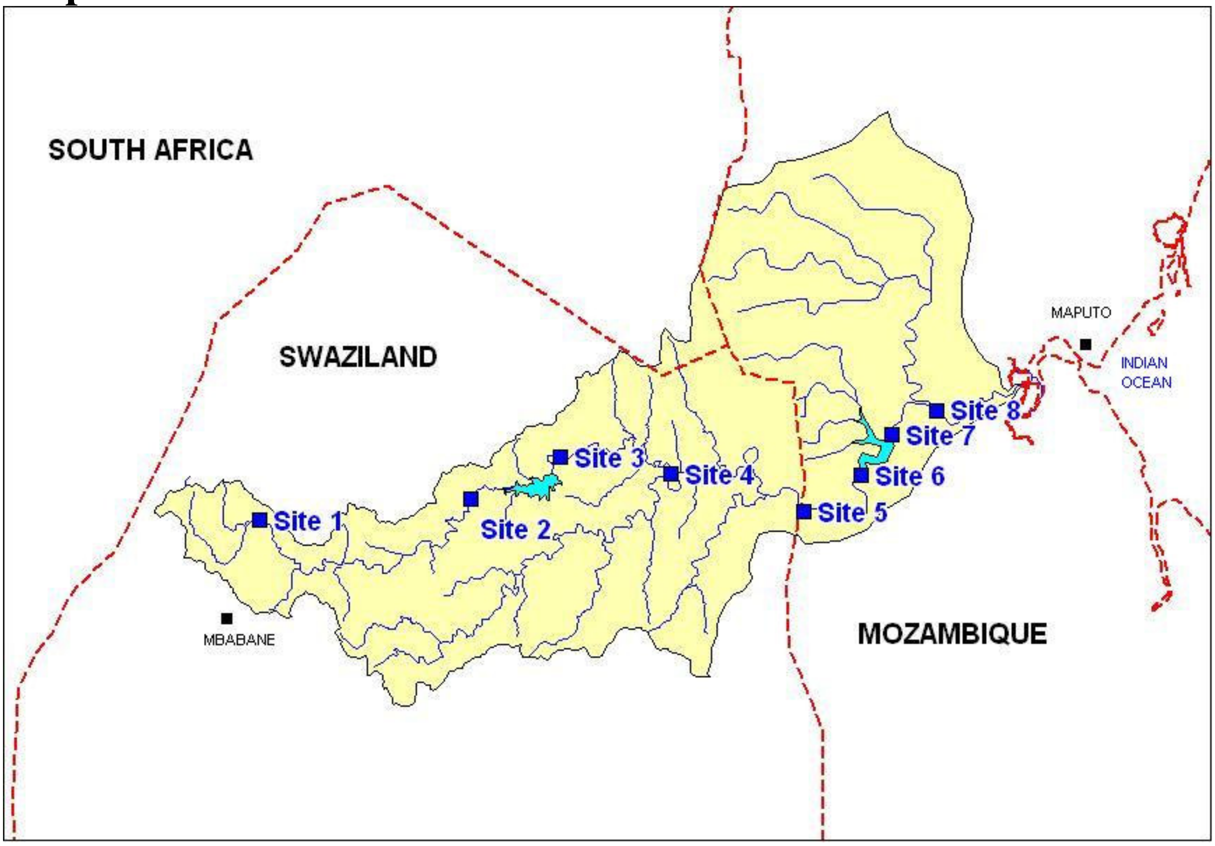

Figure 1 Basin map showing the sampling sites used in this study. The distance from the westernmost to the easternmost edge is about 150 km.

1 Introduction

1.1 Background

The Mbuluzi River runs from the north-western part of Swaziland via Mozambique to the Indian Ocean. Although the River is relatively small, it supplies almost 2 million people with water. The River is the water source for both Mbabane and Maputo, the capitals of the two countries.

In the beginning of the 1990's, after a devastating civil war, Mozambique was placed amongst the world's poorest countries. Also Swaziland is a developing country, striving towards a better economical situation. As the industrial sector grows, the commercial agriculture expands and the living standard of the population increases, the water demand augments while the quality of the waters in the countries deteriorates.

Having to share a water resource in a region with very unevenly distributed rainfall requires sustainable management practices. To facilitate equitable and sustainable usage of the Mbuluzi River, the two countries are in the process of formulating a bilateral agreement regarding the future usage of the River. When water scarcity prevails, the water quality issue becomes as important as the issue of water quantity. If there is only little water available, it needs to be of sufficiently good quality. Presently, there are signs of water quality impairment, especially in the Mozambiquean stretch of the River. However, little information is available on the current water quality situation. Even though there are many parties on both sides of the border monitoring the water quality, the data are rarely presented in the format of reports, studies etc. Also, few previous studies have been made including the entire River. Water quality studies in the River basin present knowledge, data and descriptions of present and previous water quality and are essential tools in the development of future activities in a basin when it comes to agricultural, domestic and environmental needs.

The main factors influencing the water quality in the Mbuluzi catchment are commercial agriculture and untreated wastewater. This study hence focuses on nutrient leakages. Due to rapid development, eutrophication is a rising problem in many developing countries.[1] Eutrophic conditions in the Mbuluzi would negatively affect the ecological system in the River itself as well as the estuary.

This study was performed as a Minor Field Study financed by the Swedish Agency for International Development Cooperation (Sida). The work was supervised by the Department of Water Resources Engineering at the faculty of Engineering, Lund University, Sweden as well as the Department of Civil Engineering at Eduardo Mondlane University, Maputo, Mozambique.

1.2 Objective

The main objective of this study is to describe how the water quality varies (seasonally and spatially) along the Mbuluzi and to propose improvements for future monitoring. Throughout the study, the focus is put on nutrients and the threat of eutrophication.

Based on old water quality data and supplementing measurements from this study, the main questions to be answered are:

- Does the intense sugar farming in Swaziland or other point sources influence the quality of the water entering Mozambique? If so, to what extent?
- How do the Mnjoli and Pequenos Libombos Dams influence the river water quality?
- How is the River's self-purification capacity?
- Can any seasonal differences be detected in the water quality?
- Is there an impending risk of eutrophication?
- How can water quality monitoring become more efficient?

[1] Brönmark et al. 2002

As more detailed and deeper studies are needed, the results from this study should mainly be regarded as indications. The intention of the study is partly to gather and utilise as much information as possible regarding the Mbuluzi water quality, partly to stress the importance of well functioning water quality monitoring programmes and to be aware of the problems of eutrophication that easily follow rapid development. The report is primarily written to act as a source of information for the people working with water quality in the Mbuluzi.

1.3 Scope and outline

The field work of this study comprised 8 weeks in Mozambique and Swaziland in September and October 2005. The River was monitored at 8 sites evenly distributed along the River. Measurements of general parameters and nutrients were made in field and samples were taken for laboratory analyses. Due to limited time and budget only 9 parameters were sampled, each parameter measured 3-5 times at every sampling site. When using the results, consideration should be taken to the fact that these measurements were taken during a drought period. Apart from the samples, study visits were made to the main stakeholders along the River (authorities, agricultural companies and water treatment facilities). The study visits focused on obtaining water quality data, finding information about water monitoring practices, general observations about the River and information regarding possible pollutions sources. Data from previous monitoring (obtained from the different parties) has further been used to determine how the water quality parameters change along the River.

This report begins with general descriptions of Mozambique, Swaziland and the Mbuluzi Basin. Thereafter follows a chapter outlining the methodology. Chapter 5 deals with water quality and eutrophication in rivers, whereas chapter 6 presents the results. Discussion (including recommendations on improved water quality management) is placed in chapter 7 and finally a conclusion can be found in chapter 8. To facilitate the reading of this report, a list of abbreviations and a glossary are enclosed. Words in the glossary are underlined in the text. Further information is placed in the appendixes.

2 Country descriptions

Swaziland and Mozambique are situated in the eastern part of Southern Africa (see Figure 2). Both countries have a history of colonisation and have only been independent for less than half a century.

Figure 2 Map over Mozambique. Swaziland is located in the south-western corner, between Mozambique and South Africa.[2]

[2] The Guardian, undated

2.1 Mozambique

The Republic of Mozambique is situated on the eastern coast of Southern Africa between South Africa and Tanzania. The country has a size of about 800 000 km^2 (approximately the size of Sweden, Norway and Denmark together) and has a 2500 km long coastline along the Indian Ocean. The total population in 2003 was estimated by the UNDP to be 19 millions[3], a dramatic increase from the 6,5 million population in 1960[4]. About 1,5 million people live in the capital Maputo (formerly Lorenço Marques) in the southernmost part of the country.

Mozambique was early recognized by Arab traders as an important location for commerce. From the 8th century, ivory, gold and slaves were the most important merchandise that was shipped to the countries of the Far East. In the end of the 15th century, the first Europeans arrived. Different European nationalities competed with each other and the Arabs over the control of the trade. The Portuguese colonised Mozambique (then known by the name Portuguese East Africa) and ruled the country until its independence in 1975.

In the late 70's, a civil war broke out between the ruling Marxist party FRELIMO and the guerrilla movement RENAMO. 1992 a peace agreement between the parties ended the fighting. The civil war together with a vulnerability to natural disasters (mainly droughts and floods) and a period of socialist mismanagement had then placed Mozambique amongst the poorest countries in the world.

Multi-party elections and the advent of peace have led to a significant increase in industrial and agricultural development in Mozambique. The country has been going through an extensive privatisation of formerly state owned property, making way for foreign investors (mainly from South Africa and Portugal).[5] Between 1996 and 1999, the GDP increased about 8% every year.[6] However, the severe floods in early 2000 reduced the economic growth. Presently 38% of the population lives below 1 US$ per day and 58% do not have access to an improved water source (water that has been treated). [7] In total, the foreign economic aid to Mozambique amounts to one fourth of the GDP.[8] During the first years of this century, Mozambique has been one of the countries receiving the highest financial aid from Sweden.[9]

The long civil war with recurrent droughts in the hinterlands have resulted in increased migration to urban and coastal areas with adverse environmental consequences such as desertification and pollution of surface and coastal waters.

2.2 Swaziland

The Kingdom of Swaziland is a landlocked country almost entirely surrounded by South Africa except in the east where the country borders Mozambique. The size of the country is little more than 17 000 km^2 (almost the size of Israel) and the total population is slightly more than one million. About 50% of the population lacks sustainable access to an improved water source and according to the Swaziland Environmental Action Plan about 80% of all sicknesses and diseases in Swaziland can be traced to unsafe water.[10]

Swaziland was colonised in the 19th century by the Boers and the British looking for grazing land for their livestock. The actual power was initially taken by the Boers, but in the beginning of the 20th century the British seized the rule of country. In 1968 independence was granted and the internal battle for power began.

[3] UNDP, 2006
[4] Sundström 1992
[5] Utrikespolitiska institutet 2006
[6] Sida 2006
[7] UNDP 2006
[8] CIA a 2006
[9] Sida 2006
[10] JTK Associates 2003

The country is a monarchy, the present king (and also chief of state) being King Mswati III. The head of the government is the prime minister which is appointed by the monarch. The government is recommended by the prime minister and confirmed by the monarch, all political parties are banned by the government.[11] Due to the current political structure, Swaziland does not receive any financial aid from Sweden.

Swaziland recently surpassed Botswana as the country with the world's highest known rates of HIV/AIDS infection. The ongoing HIV/AIDS pandemic is the major factor causing the recent decline in average life length. During the last 30 years the average life expectancy has decreased from 50 to 33 years.[12]

Sugar is amongst the most important export goods in Swaziland. Of the world's sugar 2% is of Swazi origin. The nation's economy is thus vulnerable to the global sugar prices which have gradually slumped as a consequence of the agricultural politics within the EU.

80% of the population depend on agriculture for their survival. Small-scale farming for domestic usage is common, maize being the most common crop.[13] Further, Swaziland is one of the countries in Africa with the highest density of cows (in average, 48 cows/km^2).[14] About 40% of the arable land is covered with commercial farming, the main crops being sugarcane, citrus, cotton and pineapple.[15]

Almost entirely surrounded by South Africa, Swaziland is heavily dependent on South Africa from which it receives about nine-tenths of its imports and to which it sends nearly three-quarters of its exports. Apart from the devastating AIDS pandemic, overgrazing, soil depletion, drought, and sometimes floods persist as problems for the future.[16]

3 Characteristics of the Mbuluzi River basin

The Mbuluzi River is an international river whose catchment is primarily shared between Mozambique and Swaziland. As in most cases when a resource is shared between countries/stakeholders, conflicts and disagreements sometimes occur. Naturally, sufficient access to water of an adequate quality is a necessity for the economic development of both countries as well as for fostering good relations between the countries.

When discussing the Mbuluzi River, it is important to know that the name of the river differs in the two countries. In Mozambique, *Umbeluzi* is the name used, but also the spelling *Mbeluzi* can be found. Since this report is written in the English language, it seems reasonable to use the spelling used in the English-speaking Swaziland, i.e. Mbuluzi. In the Swaziland stretch of the river, the name *Black Mbuluzi* is sometimes used for the main River whereas the major Swazi tributary – the Mbuluzane is sometimes called the *White Mbuluzi*.

3.1 Geography

The sources of the River are located in the northwestern part of Swaziland close to the border with South Africa (see Figure 1, page viii). From here, the River flows principally in an easterly direction into Mozambique where it eventually (some 300 km later) joins the Indian Ocean in the Espirito Santos estuary south of Maputo. The size of the catchment is 5400 km^2 of which 58% is located in Swaziland, 40 % in Mozambique and a mere 2 % in South Africa.[17]

[11] CIA b 2006
[12] UNDP 2006
[13] Utrikespolitiska institutet 2006
[14] Hirji et al. 2002
[15] Utrikespolitiska institutet 2006
[16] CIA b 2006
[17] SWECO & associates 2005

The major tributaries are the Mbuluzane in Swaziland and the Movene River in Mozambique. The former joins the main River in the Swazi lowveld within the sugar cane farming area whereas the confluence of the latter river is downstream the Pequenos Libombos Reservoir close to the estuary. The Movene River is perennial as opposed to the other tributaries which only flow seasonally. In the mountainous parts of the catchment, ephemeral streams are common. At most times they do not flow at all but during/after rain events they show quick responses resulting in flashing flows.

3.2 Topography and landscape

The River originates in the Ngwenya hills in the highlands of Swaziland (so called highveld) at an altitude of about 1600 m.a.s.l. From here, the altitude declines as the River flows through the middleveld in central Swaziland and into the lowveld. It flows through the Grandes Libombos (also called *Lebombo*) mountain range (which constitutes the border with Mozambique) before it flows through the littoral plain into the Indian Ocean. The main physiographic units of the Basin can be seen in Figure 3. The dominant land cover of the Mbuluzi River basin is bush and thickets followed by woodlands, grasslands and cultivated areas. The amount of afforestation within the catchment is very small.[18]

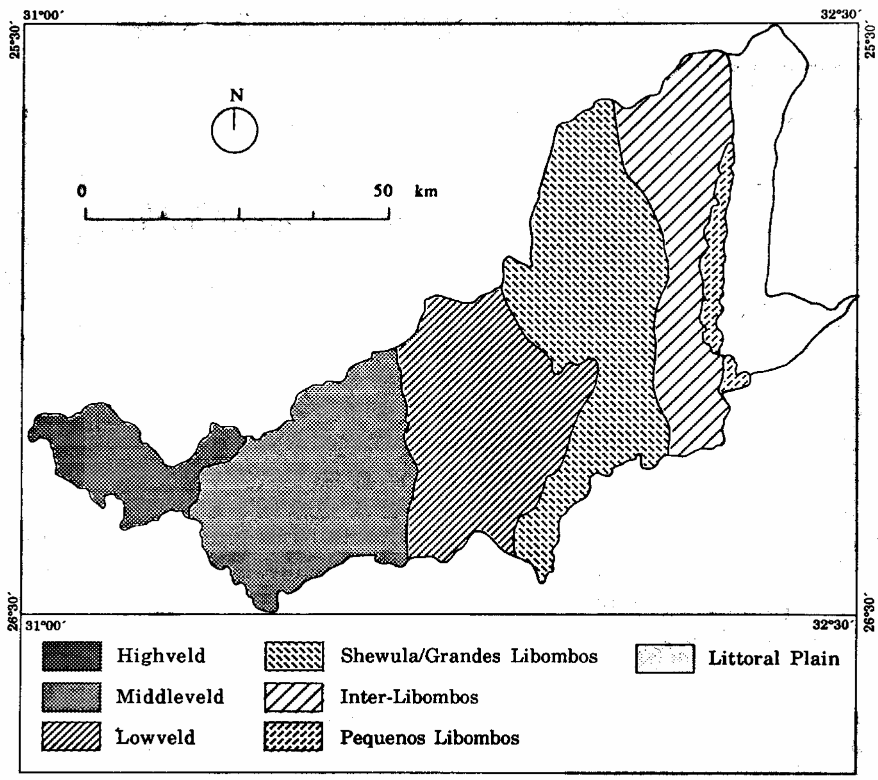

Figure 3 Map over the major physiographic units of the Mbuluzi Basin.[19]

The *highveld* is a mountainous area characterised by steep slopes with an average gradient of 18%.[20] Due to heavy erosion in the past, the hilly areas are now dominated by rock outcrops and stony ground. Most streams are perennial and the riverbeds are generally stony as a consequence of the floods of the rainy seasons. The natural vegetation of the highveld consists of short grassland covered with bushes and small trees interspersed with rock-outcrops. Wet grassland systems and spots of temperate forests can also be found, especially in the valleys. The land has been inhabited for a long

[18] SWECO & associates 2005
[19] Chonguiça 1995
[20] Naah (undated)

time, implying that the present vegetation is a consequence of earlier land use (with long term grazing and fires).[21]

The *middleveld* comprise rocky hills with granite outcrops, rounded ridges and hills with frequent steep valley slopes. The average elevation is about 700 m.a.s.l. The River bed generally consists of pebbles, gravel and sand. The vegetation is a mixture of temperate and tropical elements. In the mountainous terrain, woodland and savannah vegetation is predominant whereas riparian forest can be encountered in the larger valleys.[22]

In the *lowveld*, the main topographic feature is rounded ridges with gentle slopes. Around the River, narrow terraces composed of river alluvium occur frequently. The riverbed mainly contains sand, but patches of gravel, pebbles and hard rock outcrops occur occasionally. The natural lowveld vegetation consists mainly of woodland, dominated by large trees.

The *Libombo Mountains* have an average altitude of 600 m.a.s.l. and consist of rhyolitic lava plateaux. The sides of the mountains are generally steep with incised gorges which become ephemeral streams during/after rain events. In-between the mountains, stream channels and small terraces occur. The vegetation of the Libombo region is similar to that of the middleveld, consisting of acacia savannah, broad-leaved savannah, patches of open grassland and thick tropical forest in the river valleys. The *Grandes Libombos* constitute the border between the countries whereas the *Pequenos Libombos* mainly lie in the Mozambiquean part of the basin. The *Inter-Libombos Depression* is the plain area between the mountain ranges.

Downstream the Pequenos Libombos Reservoir the River flows through the *Littoral Plain* towards the estuary. The alluvial plains along the River are composed of sand, clay and loam with an average slope gradient < 2%. The vegetation is very diverse, incorporating forest, woodland, grassland and swamps. The coastal plain inhabits a very large population and is to a very large extent anthropogenically modified.[23]

3.3 Climate

The climate is tropical wet and dry in the western highlands and semi-arid in the middle- and lowveld. The year can be divided into two distinct seasons, hot and rainy (Nov-Apr) and dry and cool (May-Oct). In general, the climate gets warmer and drier with eastwards direction. Mean rainfall figures vary from 500 mm/year in the lower parts of the catchment up to 1500 mm/year in the mountainous areas. The mean annual temperatures generally decrease in a westerly direction from approximately 26º C on the coast to 19º C on the Swazi highveld (which is occasionally struck by frost). Figure 4 shows average rainfall as well as deviation from longterm mean annual precipitation.

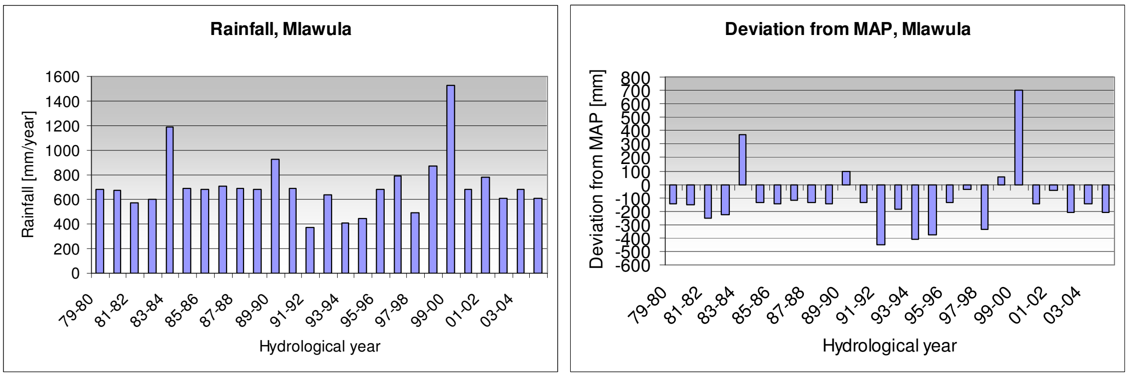

Figure 4 a,b Average yearly rainfall (a) and deviation from mean annual precipitation (b) at Mlawula weather station in the middle of the catchment.

[21] SWECO & associates 2005
[22] Ibid
[23] Ibid

Values in the rainfall figures supplied from RSSC from Mlawula weather station (station number 33309105), located south of the River in easternmost Swaziland (rainfall data originates from RSSC).

Extreme meteorological conditions that cause floods and droughts strike the region on a regular basis. The most recent cyclone occurred in the beginning of 2000 and caused major floods in the area. At the time of this field study (late 2005), the region was experiencing drought conditions. For several years the rainfall has been noticeably less than expected (in some areas less than half of the normal rainfall).[24] As seen in Figure 4b, rainfall at this location has been less than normal during the last years. The drought condition prevailed over the entire catchment, however to different extent. For parts of the Mbuluzi catchment it is reported that there has been no surface runoff during the last five years.[25]

3.4 Geology

The geology of the Basin belongs to four major geological formations. These formations mainly follow the topographical landform regions in roughly parallel bands running in a north-south direction. From west to east, they were created during the Archaean, the Jurassic, the Cretaceous and the Quaternary eras. This implies that the western parts of the catchment can be as old as 3 billion years. The age of the geologic formations decreases when moving towards the ocean.

The Archaean formation characterises the highveld and parts of the middle- and lowveld. It is dominated by ancient rocks of volcanic origin (for example amphibolites, granodiorites and granite) and Precambrian era sediments.[26] [27]

The Jurassic formation covers part of the area between the middleveld and the Inter-Libombos depression. Mainly, the geology consists of old glacial deposits, sandstones and rhyolites. Geological unities that can be found are Dwyka tillite (rock formed from glacial deposits), claystone, shale and Stormberg basalt. Underneath the glacial deposits, the bedrock consists of granite and granitic gneisses. In the Libombo Mountains, rhyolite-dominated intrusions (originating from the break-up of Gondwanaland) can be found as well as porphyritic rhyolites, breccias and volcanic tuffs and ashes. The Inter-Libombos depression is dominated by basalt rocks.[28] [29]

The Cretaceous formation is mostly a sedimentary complex originating from the end of the volcanic activity and in line with successive altitude changes due to tectonic uplift and sea transgression. The formation is integrated by two spots of igneous rocks (the Pequenos Libombos rhyolites and the basalt of the Movene depression). Sedimentary deposits (of marine and continental origin) have accumulated above the Karoo lavas in portions of the catchment. The deposits are generally composed of calcareous sandstone.[30] [31]

The Quaternary formation (located by the Mbuluzi floodplain) has been formed by erosion and deposits. The erosion has partly been caused by the River and its tributaries and partly by wind and surface runoff. As the River has been flooded, it has generated extensive alluvial deposits along the floodplains. [32] [33]

[24] Southern African Development Community 2006
[25] Personal communication, Ndlovu 2005
[26] SWECO 2005
[27] Chonguiça 1995
[28] SWECO 2005
[29] Chonguiça 1995
[30] SWECO 2005
[31] Chonguiça 1995
[32] SWECO 2005
[33] Chonguiça 1995

3.4.1 *Soils*

In the highveld, the surface layer is dominated by rock outcrops, occasionally interrupted by zones of ferrisolic clay, ferralitic loam (both highly susceptible to erosion) and shallow black hill peat. Further down, in the middleveld, the rock outcrops decreases and lithosolic shallow sand or sandy loam takes over.

The soil in the lowveld varies considerably in size fraction (from clayey to sandy) and in layer thickness (from shallow to deep). In this part of the basin, the clay fractions are characterised by having a relative high cation exchange capacity. Dominant soils are clay soils (Vertisols and Luvisols), duplex soils (Planosols or Mananga soils which are highly sodic and easily eroded), alkaline soils (Solonetz, also highly sodic and easily eroded) and shallow soils (Leptosols) as well as Phaeozems. Other soils are alluvial soils (Fluvisols), poorly drained soils (Gleysols) and sandy soils (Arenosols).

In the Libombo Mountains, red clays (Nitisols) are dominant on the non-eroded plateux whereas the eroded slopes are covered by shallow, unconsolidated soils (Regosols) and shallow soils (Leptosols). Shallow and stony Lithosols over rhyolites are also found. In the Inter-Libombos depression and Movene valley, heavy textured soils (Ferric Lixisols, Chromic Luvisols, Eutric Leptosols and Calcic Vertisols) and fine textured Managa occur over the basalts.

Downstream the Pequenos Libombos Dam, soils formed from four different parent materials can be found. The lacrustine soils (Fluvisols, Solonchaks, Vertisols, Gleysols), which in general are saline and sodic. The soils from estuarine sediments (Eutric Fluvisols, Solonchaks, Cambisols) are calcareous, sodic and saline. The alluvial soils are more recent and hence overlie the estuarine sediments. They are non-saline and non-sodic (except when they are very shallow). The final group is the basaltic soils which are also non-saline and non-sodic. On the active floodplain and the higher terraces of the river, the dominant soil types are: coarse alluvial sands, medium textured soils, clayey loam, sandy clay loam and silty clay loam (Eutric Fluvisols).[34]

3.4.2 *Erosion*

Erosion intensities in the catchment have been determined by using satellite images to classify the erodability in the basin. According to Chonguiça, moderate erosion intensity is predominant within the Mbuluzi Basin (45% of the catchment area), particularly around the Swazi-Mozambiquean border and by the sugar cane plantations of RSSC.[35] High erosion intensities account for 25% of the area, of which the main part is within the Swazi high- and middleveld.[36] Areas with low erosion intensity come at third level of importance (22%).[37] These areas are mainly located in the areas immediately downstream the Mnjoli Dam, to the south of the major sugar farming area and north of the Pequenos Libombos Dam. The areas classified with very high erosion risk (7%) occur almost exclusively within the Swazi middleveld, the remaining parts are located in the highveld. [38] The combination of large erosion risk and heavy rainstorms makes erodability an important factor to include when discussing surface water quality, especially in the upper part of the river basin. Steep slopes, poor cultivation practices and overgrazing further enhance erosion in these reaches.

3.5 Hydraulic infrastructure

The major structures influencing the flow in the River are the Mnjoli Dam in Swaziland and the Pequenos Libombos Dam in Mozambique. Following the River from its source towards the ocean, the following constructions will be encountered.

[34] SWECO & associates 2005
[35] Chonguiça 1995
[36] Ibid
[37] Ibid
[38] Ibid

Hawane Dam
This minor reservoir was commissioned in 1984 and is situated in the uppermost reaches of the River north of Mbabane. The main purpose of the reservoir is to secure the water supply for Mbabane City. Water is transported 20 km through a pipeline from the dam to the water treatment plant.

Mnjoli Dam
The Mnjoli Dam is situated upstream the major sugarcane growing area (Royal Swaziland Sugar Corporation – RSSC), some 70 km upstream the Mozambiquean border. The Reservoir was completed in 1978 during a time of large expansion of the RSSC to secure water supply for irrigation of the sugar fields. Besides extraction of irrigation water the reservoir is used to provide domestic water for the settlements in the vicinity (most importantly Siteki and Mpaka). [39] The maximum storage capacity of the Dam is about 150 Mm^3.[40] At the time of this field study (October 2005), after several years of drought, the Reservoir was only filled to 25%. The released flow to the River is determined by domestic (mainly to the Maputo area) and ecological demands downstream. During the time of the field study, the average release from the Dam was about 6 m^3/s of which roughly 50% was released into the River. The remaining 50% was transferred via a canal to irrigate the sugar fields.

Pequenos Libombos Dam
This Reservoir is situated some 35 km west of Maputo City. It was built 1983-1987 with the principal function of providing the ever growing city with water. Other important reasons for building the reservoir were flood mitigation and water supply for irrigation. There are also plans to construct a hydro-power plant by the Dam. The storage capacity of the Dam is about 400 Mm^3 which corresponds to a dam level of about 47 m.a.s.l.[41] The filling of the Dam started in 1986 by reducing the discharge to the downstream areas to almost zero. The Dam reached its maximum level in 1989. The average dam level is about 42 m, corresponding to a volume of 220 Mm^3.[42] Average water retention time is 2,5-3 years. The outlet of the Dam is placed close to the reservoir bottom, which implies that the water quality of the effluent is likely to differ from the water quality at the dam surface. During the floods in 2000 the downstream damage was limited by the Dam which was then filled almost to its maximum. The Mbuluzi is the only perennial inflow to the Dam. The second largest tributary is the intermittent river Calichane entering the Reservoir in its northern end. At the time of the field study of this project (Sept-Oct 2005), no flow was evident in any of the Reservoir tributaries apart from the Mbuluzi. The average dam release in September/October 2005 was about 3 m^3/s.

Saltwater weir
Close to the estuary, downstream the Boane water treatment plant, a saltwater weir has been constructed to prevent saltwater intrusion at low river flows and high tide. Since the construction of the weir, the salt water transfer from the estuary has ceased and no problems have been reported. After the floods in 2000, the weir had to be re-constructed due to damage caused by the extreme flows.

3.6 Flows and water resources

Due to the large anthropogenic influence on the River, natural flow variations can hardly be observed in the Mbuluzi River anymore. The effluent flows from the Dams are determined by the demand downstream (primarily by agricultural, domestic and ecological needs). At times of water scarcity only the minimum required flow is released. The only occasion when more water than necessary is released from the dams is before and during periods with much rain. Water is then released gradually to prevent floods and overloading of dam capacities. Just after the confluences with the major tributaries (Mbuluzane and Movene) semi-natural flows can be observed since the flows of these two rivers are not significantly altered by humans.

[39] JTK Associates 2003
[40] SWECO & associates 2005
[41] Ibid
[42] Chonguiça 1995

The natural flow within the drainage basin is characterized by high rainfall/runoff during the wet season, the wettest months account for more than 70% of the total runoff. [43] Figure 5 shows average monthly rainfall at the Mlawula weather station in the centre of the catchment. The graph shows the division of the year into two seasons (wet and dry).

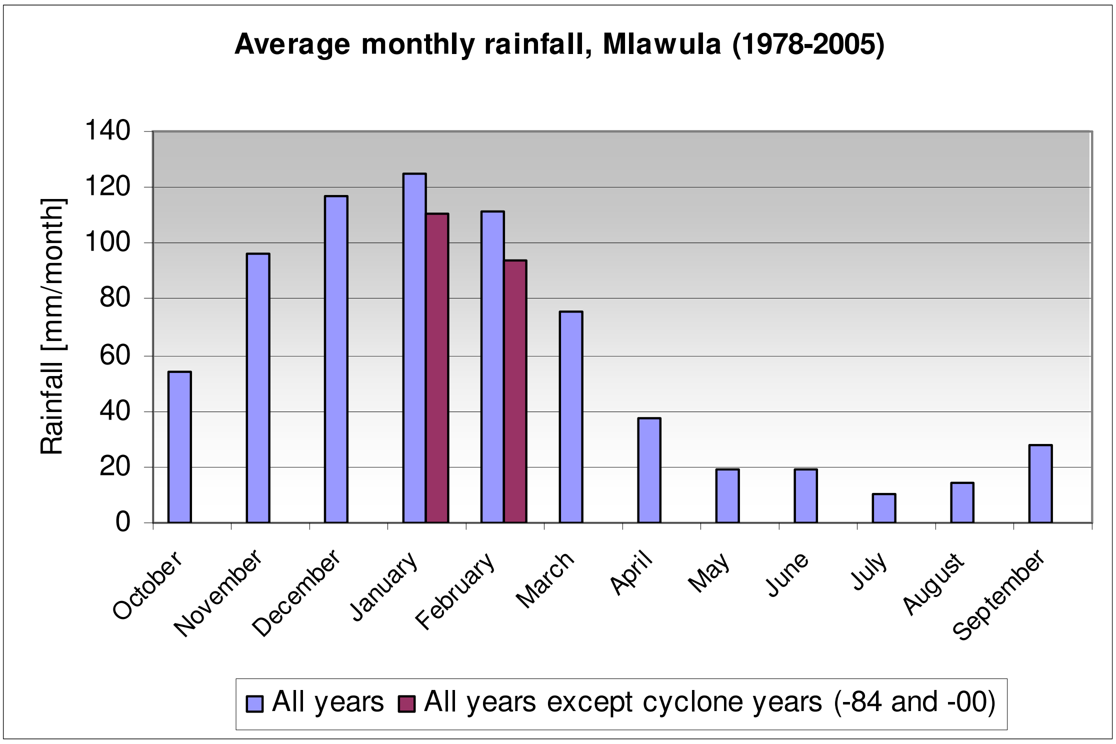

Figure 5 Average mothly rainfall at Mlawula weather station based on rainfall data from 1978 to 2005. Rainfall data has been obtained from RSSC.

Tropical cyclones occasionally cause extreme flood events in the region. The major floods during the last century have occurred 1925, 1966, 1984 (cyclone Demoina) and in early 2000 (cyclone Eline). During the flood in 1984, river flows of about 5600 m^3/s (compared to 2-3 m^3/s at the time of this field study) were recorded at the flow station in Goba.[44]

Due to the large climatic variability (causing floods and droughts on a regular basis) and the high likeliness of extreme weather conditions, it is crucial that the water resources are managed in an efficient way. The Dams in the catchment have two main purposes; to store water for periods with little or no rainfall and to control flood conditions. The storage of the Pequenos Libombos Dam is sufficient to provide the downstream area with water for about three years.[45]

For the purpose of irrigating the areas of the sugar cane estates in northeastern Swaziland, water is transferred via a canal from the adjacent Komati River Basin (north of the Mbuluzi Catchment) as the Mbuluzi water is not sufficient. Most of the water from this transfer is used by the crops (i.e. lost by evapotranspiration) but some water is believed to contribute to the flow of the Mbuluzi via groundwater return flow. Further downstream, another water transferring scheme is taking place. Close to the River mouth, the Matola aluminium plant (Mozal) abstracts water for its processes. The industry is situated outside the Mbuluzi Catchment, and its effluent does not flow back into the River.

According to recent reports, a severe water shortage is expected in the Mbuluzi Basin. This makes it even more important to protect the water quality and to optimise the water usage without causing

[43] Chonguiça 1995
[44] JTK Associates 2003
[45] Personal communication, Mateus 2005

environmental problems.[46] The major increases are expected to be expansions of agriculture and increased population (mainly in greater Maputo). Because of climatic variability and the impossibility of collecting and using all water efficiently, the future scenario poses a large risk of water scarcity – especially for the downstream areas. The situation pleads for a sustainable solution, regarding water quantity as well as water quality.

In order to secure sufficient water supply for future development, water saving schemes are being implemented. Within the Royal Swaziland Sugar Corporation the irrigational sprinkler systems are being gradually exchanged to drip-irrigation systems which make the evaporation losses minimal. Other major water losses occur within the pipe network in Maputo City where as much as 60% of the water is assumed to be lost through leakage.[47]

3.7 Demography

Of the population depending on the Mbuluzi River, the majority (91%) is distributed within the urban centres of Mbabane (capital of Swaziland) and Maputo (capital of Mozambique). Included in the population of Maputo is the population of its suburb Matola. The mentioned urban areas are all situated outside the catchment of the Mbuluzi; however they get their water from the River. 95% of the population of the Basin lives in Mozambique.[48]

The population within the catchment is expected to increase by approximately 2,6-3,2% during the coming 15 years.[49] The extent of the population increase is however difficult to estimate due to the ongoing epidemic of HIV/AIDS. Swaziland has one of the highest HIV/AIDS infection rates in the world, 39% of the population between 15 and 49 years of age are infected according to the 2005 Human Development Report, UNDP. Also Mozambique is severely struck by the disease with an infection rate of 12%.[50] The future population in the area thus depends much on the measures taken to prevent HIV/AIDS. Regardless of the medical success, a future water deficit is likely.

The poverty situation in the basin is very severe. According to the UNDP Human Development Report (2005), the percentage of the population living below the national poverty line is 40% in Swaziland and 69% in Mozambique. [51] The percentages of undernourished people are 19% and 47% respectively.

The rural population generally practices agriculture at subsistence level. Access to potable water for human consumption, livestock and agriculture is a necessary condition for survival. Inadequate access to clean water and sanitation combined with malnutrition threatens the health of the people in the basin. This is especially hazardous for the poorer part of the population which is more vulnerable.

3.8 Activities in the catchment

The most significant water usage in the Mbuluzi Basin is agricultural irrigation. At present, the water demand of the sugar cane estates in eastern Swaziland is more than 60% of the total demand.[52] The second most important water use is domestic water supply where the population of Maputo/Matola is the major user. Since the end of the Mozambiqan civil war and the since the privatisation process of agricultural land started, commercial (large-scale) farming has increased and is likely to increase further on the Mozambiquean side of the border.

In the following section the major usages along the River are presented, from upstream to downstream.

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[46] SWECO & associates 2005
[47] Lindqvist et al. 2005
[48] SWECO & associates 2005
[49] Ibid
[50] UNDP 2006
[51] Ibid
[52] SWECO & associates 2005

The highveld

In the westernmost areas of the Basin, the land use is not very intense due to the steep slopes and the cooler climate. The main activities in this area are small scale farming on the hill slopes, small scale cattle keeping and spots of forest plantations.[53] In the upper reaches of the River, Hawane Dam and the water treatment plant for Mbabane are situated.

The middleveld

This area is dominated by traditional communal farming in a small scale, intermixed with extensive areas of controlled grazing land for cattle. The population in the area is scattered and there are no major towns.[54] Around the Mnjoli Dam, local farmers are farming sugar cane (this cultivation started in 2000). These farmers can use water for irrigation from the Dam providing that they sell their harvested sugar to the sugar mills of RSSC.[55]

The lowveld

The lowveld downstream the Mnjoli Dam is dominated by large scale irrigated commercial farming. Since 2002, the *Royal Swaziland Sugar Corporation (RSSC)* in the main stakeholder, comprising the two sugar estates formerly known by the names Simunye and Mhlume estates. Together these areas cover an area of about 20 000 ha. In the vicinity lies also the Tabankulu Estate (3 000 ha), but due to its smaller size, the environmental impact from this estate has not been comprised in this study. Previously the Tambankulu land has been used extensively for citrus farming and other crops. The RSSC is partly (~50%) owned by the Swazi government, and the sugar export is a central part of the country's economy. The sugar farming in the area went through a major expansion in the late 70's and early 80's, at the time the Mnjoli Dam was built. Within the sugar estates two sugar mills are situated, one in Mhlume and one in Simunye. The treatment of the effluent from the mills is continuously improving; their major impact on the River is at present the high levels of organic material entering the river system. The larger settlements (Simunye, Mhlume and Tabankulu) are connected to small waste water treatment plants. Apart from the sugar farming, Tambankulu Estate also has cattle farms. In the area there is also a piggery (of a relatively small scale).

This part of the catchment further includes areas of protected bushland in status of natural/game reserves and national parks.

The Grandes Libombos Mountains

After the sugar farming, the River flows through a sparsely populated area (where it is flanked by nature reserves), pass the forested mountains and into Mozambique. About 10 km downstream the border, the small town of Goba is situated. This is the largest settlement in Mozambique upstream the Pequenos Libombos Dam. Before the war, the area was extensively used for grazing. During the war, agricultural activities ceased due to the security situation, but since then they have resumed.

Plantations by the Pequenos Libombos Dam

Around the Pequenos Libombos Dam, the presence of commercial and irrigated fruit plantations have increased since the end of the war. Presently, the major ones are *Bananalandia*, *Citrum* and *Libombos Macadamia*.

As indicated by its name, *Bananalandia* is a banana plantation. It is located on the southern shore of the Pequenos Libombos Dam and at the moment comprises a little less than 300 ha. The farm was started in 1999.[56]

The *Citrum* Company grows grapefruit and oranges for export. The farm has two locations for plantations, which together cover about 700 ha. One of the locations is by the dam wall and one is

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[53] Chonguiça 1995
[54] Ibid
[55] Personal communication, White 2005
[56] Personal communication, Wessecs 2005

south of the Dam, close to Bananalandia. Formerly, the farm was run by the government, but since 2002 it is run in private regime.[57]
Since 2004, *Libombos Macadamia*, a macadamia nut plantation, also exists in the proximity of the Pequenos Libombos Dam. In late 2005 the farm comprised little more than 100 ha, but it is still expanding. To secure continuous income, bananas (who have a relatively short growth cycle) are grown in-between the nut trees.[58]

Downstream the Pequenos Libombos Dam
As for the situation in Goba, the activities in this area decreased during the civil war. However, the agricultural activities in this area have increased continuously since the end of the war. The population density is high in most of the area between the Dam and the estuary. The major settlement is the town of Boane with a population of 65 000.[59] Due to its proximity to the capital, Boane was fairly safe (and thus not entirely unpopulated) during the years of the civil war. The area around Boane is dominated by farming for both commercial and private purposes as well as by animal keeping (mainly cattle and goats). There is also an agricultural school downstream Boane. Common crops are maize, oranges and bananas.

Roughly 5 km downstream Boane town is the *water treatment plant* (WTP, ETA in Portuguese) for Maputo city, which is run by AdM (Águas de Moçambique). The WTP abstracts water from the River with an average quantity of 2,2m^3/s.[60] The outtake at the WTP is one of the main factors determining the flow released from the Pequenos Libombos Reservoir. The WTP was first constructed during the Portuguese rule in the early 1900's and has since then has been rebuilt several times. Additionally there is another small treatment plant (run by AdM) in the small town of Namaasha in the northern part of the Basin.

3.9 Current river management and legal framework

The water resource management structure in both Swaziland and Mozambique is built on sound principles of sustainable water utilisation. Together, the institutions and legal frameworks on both sides of the border create a base for joint water resources planning and management at basin level. Common aspects for the water legislations of the two countries are:

- 'best use' of the available water resources aiming to satisfy the needs of the population and the national economic development
- prevention and minimisation of adverse effects (such as pollution)
- application of the 'polluter pays' principle
- priority of water usage for domestic purposes
- sustainable usage of resources and ecosystems
- priority to the prevention of activities that may damage the environment (the precautionary principle)
- participation of the water users in water management at various levels
- striving for a basin approach in water resources management

Both countries apply *water tariff systems* forcing water users (for other than domestic use) to register and pay for water concessions. The making of river basin plans for the shared river basins in co-ordination with the other riparian countries is an issue that is given high priority in both countries.[61]

The main co-operative instrument between the countries is the Joint Water Commission, which was also the client for the Joint Umbeluzi River Basin Study. The Joint Water Commission has monthly

[57] Personal communication, Negrão 2005
[58] Personal communication, Gomes 2005
[59] SWECO & associates 2005
[60] Personal communication, Gildo 2005
[61] SWECO & associates 2005

meetings where common issues are discussed.[62] Another important institution for the international co-operation between the countries is the Tripartite Permanent Technical Committee (TPTC) that was established in 1983 by an agreement between South Africa, Mozambique and Swaziland. The current agreement regulating the management of the Mbuluzi Basin is the agreement between Mozambique and Swaziland signed in 1976, but a new agreement is currently being created. The SADC Protocol on Shared Watercourse Systems is an important guiding policy for river basin co-operation in the region.[63]

3.9.1 Water management in Swaziland

In early 2003, the Swazi government and King Mswati III approved the new *Water Act* to replace the older version from 1967. The implementation of the new Water Act is still in its initial stages; therefore it has not been easy to get information about the institutions involved in WRM, their responsibilities and authorities. A focus in the new Water Act is to establish that all water found naturally in Swaziland is "… a national resource", with "no private right of property".[64]

The ultimate decision power in water related issues rests with the Minister responsible for water affairs. Presently, the *Water Resources Branch* is responsible for monitoring the water quality of the surface waters of the country. As a consequence of the "polluter pays principle", possible polluters (for example sugar mills and waste water treatment plants) are required to monitor their effluents and report to the government to assure that the concentrations of pollutants are within the limits.[65]

The *Swaziland Water Services Corporation* is the company which owns most of the water treatment facilities in Swaziland. Amongst its assets are 30 water treatment plants, 11 wastewater treatment plants and one of the few accredited water laboratories within the country.[66]

The new administrative structure involves a *National Water Authority* consisting of members from the government, from the private sector and from each of the five established *River Basin Authorities*. Further, the *Environment Management Act* of 2002 establishes Swaziland Environment Authority with the duty to provide for and promote the protection, conservation and enhancement of the environment and the sustainable management of natural resources.[67]

3.9.2 Water management in Mozambique

The *Water Law* of 1991 is the most important legal document for the management of Mozambiquean water resources. The Law puts a special focus on the shared river basins. Due to the country's vulnerable downstream position, the need to cooperate with the other watercourse states is given particular attention. Other objectives to be attained are: the importance of coordinated management, the equitable utilisation of common water resources, the exchange of information on issues of common interest and water quality control as well as the prevention of pollution and soil erosion.

Another important feature in the water law is that it establishes the difference between water usages as common or private use. Waters of common use are those consumed by a family, e.g. for domestic purposes, cattle and small-scale irrigation, with no use of mechanisation. By this law, these uses shall be prioritized and free of charge whereas water for private use (such as commercial irrigated agriculture) needs a license from the water managing authority and the private user will be charged for the water that he uses. The fee is based on the irrigated area. The law also stipulates that water for private use will not be allowed if its use is in conflict with the water needs for ecological conservation.

[62] Personal communication, Ndlovu 2005
[63] SWECO & associates 2005
[64] Ibid
[65] Personal communication, Mthimkhulu 2005
[66] Personal communication, Fakudze 2005
[67] SWECO & associates 2005

In a water conflict, the right to use the water will be given to the activity which implies the highest socio-economic value.[68]

The governmental authority which is responsible for water management in Mozambique is the *Ministry of Public Works and Housing*. The ministry is structured into several National Directorates with different responsibilities, amongst them the *National Directorate of Water* (Direcção Nacional de Águas, DNA). The DNA is the main institution responsible for the management of the water sector of the country and until the management de-centralisation during the 1990's, it was also the executive authority. At present, the responsibility of DNA is mainly to make national water policies, promote inventories of the water resources, gather and store data, deal with planning, conservation and development (short- and longterm) and to influence the legislation in the area of water resources. One of the sub-sectors within the DNA is the International Rivers Office which was created to facilitate the water resource management within the internationally shared river basins. Its responsibilities include connections with the corresponding institutions in the other watercourse states and with the SADC Water Sector Division.[69]

As a consequence of the Water Law, the operational part of the water management was de-centralised. This was to be achieved by forming Regional Water Administrations (ARAs) which were created in the early 90's. In total there are five ARAs in Mozambique, the Mbuluzi belongs to the ARA-Sul (Administração Regional de Águas do Sul). The responsibilities of the ARAs are mainly operational, for example the ARAs are responsible for water quality monitoring, administration of licences and payments from private users, management of hydraulic works (for example the Pequenos Libombos Dam) and collection of hydrological data from the basins. Previous to the formation of the ARAs, most of their duties (such as water quality monitoring) were under the responsibility of DNA.[70]

The water supply to Maputo (and several other major towns in the country) is managed by the private operator Águas de Moçambique (AdM) since 1999. [71] Before the privatisation, the urban water supply to Maputo was managed by the governmental Águas de Maputo. AdM owns and runs the WTP in Boane and is responsible for the distribution of potable water within the city.

4 Methodology

The purpose of the field work in this study was to:

- collect and analyse water samples along the Mbuluzi River - N and P being the main focus
- gather old data (mostly regarding N and P) and find out how this data had been obtained (sampling-, storage- and analysis methods)
- find information about possible pollution sources by visiting major farms and activity areas in the River basin

4.1 Sampling methodology

Samples were collected once a week for 3-5 weeks (Sept-Dec 2005) at eight different sampling points along the River (see Figure 1 page 10). The analyses of total nitrogen, total phosphorus and nitrate from the first sampling trip have not been included in the results of this study since the samples were not preserved properly and the equipment was unfamiliar. Table 1 presents the dates for collection and analysis of nitrogen, phosphorus and nitrate. General parameters were additionally measured during sampling trip one (September 15th and 16th). Short descriptions of the sampling points can be found in chapter 4.2.

[68] SWECO & associates 2005
[69] Personal communication, Juizo 2005
[70] SWECO & associates 2005
[71] Matsinhe (undated)

Table 1 Sampling and analysis dates for the parameters analysed in laboratory (sampling trip 1 is eliminated since only general parameters were measured and those were measured in field).

Sampling point	Sampling trip 2		Sampling trip 3			Sampling trip 4			Sampling trip 5		
	Collected	*Analysed*	*Collected*		*Analysed*	*Collected*		*Analysed*	*Collected*		*Analysed*
	21 Sep	*22 Sep*	*5 Oct*	*6 Oct*	*7 Oct*	*11 Oct*	*13 Oct*	*14 Oct*	*17 Oct*	*18 Oct*	*19 Oct*
1			X		X		X	X	X		X
2			X		X		X	X	X		X
3			X		X		X	X	X		X
4			X		X		X	X	X		X
5	X	X		X	X	X		X		X	X
6	X	X		X	X	X		X		X	X
7	X	X		X	X	X		X		X	X
8	X	X		X	X	X		X		X	X

Due to the size of the catchment, sampling had to be done during two days. Usually the sites in Swaziland were sampled during the first day followed by the Mozambiquean sites during the next day. For all sampling trips, the aim was to sample the River from source to mouth (i.e site 1 was sampled first and site 8 last). Due to logistical problems this was not possible during sampling trip 4, meaning that the Mozambiquean sites were sampled the day before the Swazi sites. Further, the sites in Swaziland were visited in the opposite order during the last sampling trip.

Samples were taken in running water, perpendicular to the flow, at a depth of 5-10 cm below the surface and as close to the middle of the River as possible. At all but one sampling point (site 4) water was collected with help of a half 1,5 l plastic water bottle fastened to a stick. At site number 4, water was collected with a "throw bottle", i.e. a bottle with a string attached to it and with a stone stuck on the outside. The bottles used for sampling (the half 1,5 l plastic bottle and the throw bottle) were rinsed three times with river water before taking the sample. From the sampling utensils, water brought to laboratory for nitrogen analyses were poured into 0,5 l plastic bottles. These bottles were rinsed once with distilled water and three times with river water and were only used at the same location as during last sampling (i.e. bottle No.1 was only used for sampling at site No.1). Samples for phosphorus analysis were poured into small glass bottles of different sizes. The reason for using glass bottles is that phosphate ions can bind to plastic and thereby cause misleadingly low phosphorus concentrations.[72] The effect of this binding is quite evident in studies where the phosphate concentration is low, such as in this study. Just as for the nitrogen bottles, phosphorus bottles were first rinsed with distilled water and then with river water three times. All sampling bottles were filled completely to avoid air bubbles. This is important especially for nitrogen analysis since nitrogen can be released to or dissolved from the air.

After sampling, the samples were stored on ice in a cool box during sampling trips and then in fridge (nitrogen samples) and freezer (phosphorus samples) until analysis - this in compliance with recommendations in the "Standard Methods for the Examination of Water and Wastewater".[73] If analysis were made more than one day after sampling, nitrogen samples were also stored in freezer or on ice in fridge.

Prior to sampling trips 4 and 5 all bottles were rinsed with hydrochloric acid as recommended by Bydén, Larsson and Olsson.[74] However, lack of hydrochloric acid made it impossible to do it prior to all sampling trips.

Discharge data were obtained for all sampling occasions and locations except for site 1 and site 8. For sites 2, 3 and 4, daily flow measurements were obtained from the water department at the RSSC. The

[72] *Standard Methods for the Examination of Water and Wastewater.* 16th ed.
[73] Ibid
[74] Bydén et al. 1996

flow at site 3 was assumed to be the same as the discharge from the Mnjoli Dam *into the River*. About half of the total outflow from the Dam is transferred to the sugar fields via a canal immediately after the Dam. Since site 3 is located only a few kilometres downstream the Dam and no water abstractions take place on this stretch of the River, the flow at site 3 can be assumed to be the same as the flow released from the Dam to the River. For site 5, the flow was obtained by reading the scale (showing the water level) at the E10 station and by using rating curves provided in the JURBS report.[75] For site 6, before the Pequenos Libombos Dam, an approximated flow was obtained from ARA-Sul. The total daily inflow to the Dam is calculated using an equation including evaporation losses (temperature dependent), precipitation and the known outflow. Since all other tributaries to the reservoir were dry at the time of the field study, the calculated inflow corresponds to the flow in the Mbuluzi. However, there might be an uncertainty in the calculations which should be kept in mind. At site 7, the flow was assumed to be the same as the outflow of the Dam, since the sampling location is located only a short distance downstream and since no abstractions take place between the Dam and the sampling site. For site 8, no flow could be determined because of the very unstable river section making it impossible to determine which (if any) rating curve to use.

4.2 Sampling locations

In this field study, eight sampling locations were chosen along the course of the River; four in each country (see Figure 1 page viii). Important criteria for choosing sampling points were conformity with earlier studies/ongoing monitoring, accessibility to the River and proximity to flow measuring devices. The sampling points were also chosen to be before and after areas likely to influence the water quality. Geographical information and pictures from all sampling sites can be found in Appendixes 1 and 2.

Site 1 – Pine valley, Mbabane

The first sampling point is situated in Pine Valley about 15 km north of Mbabane in the Swazi highveld. It was chosen to represent the water quality in the upper reaches of the River. The water samples were taken just after the small bridge about a kilometer upstream the flow station GS 4. At this point, the River is surrounded by mountains sparsely covered with vegetation. The vegetation cover is occasionally interrupted by rock outcrops. The steepness of the mountains, the sparse vegetation cover and the high erodability of geologic material makes erosion a very important factor for the water quality in this section of the River. Nearby the sampling point are a few small-scale plantations and gardens. Otherwise, potential sources of pollution are rare. No flow measurements were available for this sampling point. No regular monitoring takes place at this location.

Site 2 – Before the Mnjoli Dam

Sampling point number two is by the flow station GS3 just upstream the Mnjoli dam in the Swazi middleveld. Measured along the river, this site is located approximately 60 km downstream site 1. This is one of the two stations referred to in the present water sharing agreement between Mozambique and Swaziland (The Mbuluzi Agreement of 1976).[76] Reasons for choosing this sampling point were to determine the possible impact of the upstream areas as well as to establish the water quality of the water that enters the Reservoir. At this location, the altitude has decreased and the steep hills have made way for rounded hills. The population is spread out and most of them are practicing small scale farming, sugarcane and maize being common crops. Also livestock keeping (mainly cows and goats) is usual. Water samples were taken right at the weir where the water velocity is high. This site is included in the monitoring programme of the Water Resources Branch (WRB).

Site 3 – After the Mnjoli Dam

The third sampling point is situated approximately 8 km downstream the Mnjoli Dam. The site was chosen to establish the water quality of the water leaving the Reservoir and also to determine the quality before the River enters the main sugar growing area. Between the Dam and the sampling point, the anthropogenic influence is insignificant. The samples were taken from the bridge (on the downstream side) as the road crosses the Mbuluzi. Upstream the bridge the River is overgrown with

[75] SWECO & associates 2005
[76] Ibid

large aquatic plants. On the downstream side large rocks create conditions similar to a small waterfall. The WRB measures the water quality at the Mnjoli outflow which can be assumed to be similar to the quality this site.

Site 4 – Simunye
The fourth and last sampling point in Swaziland is situated in the lowveld in the midst of the RSSC sugar growing area, surrounded by sugar cane fields. The reason for sampling this site was to see impacts from the intense agriculture as the Mbuluzi enters Mozambique. The sampling point is situated close to the GS20 flow station, approximately 40 km upstream the border (along the course of the River) and 25 km upstream the place where the River leaves the RSSC property. Samples were taken from the bridge as the road crosses the River, just downstream the weir. Worth to mention is that the River in this section is lined with large aquatic weeds. The RSSC measures the water quality at nearby locations as the River runs through the estate.

Site 5 – Goba
As the River enters Mozambique, the first sampling point was chosen to be by the flow stations E10 and E11 a few kilometers downstream the Swazi border. Here, the River runs through a gorge in the Grandes Libombos mountain range, and the site was chosen to establish the water quality as the River crosses the border. The samples were taken just below the weir of the flow station E10. About five km downstream the sampling site the village of Goba is situated, otherwise, the area is not very densely populated. This sampling site is included in the current monitoring programme of ARA-Sul and has previously been monitored by DNA and Lifab.

Site 6 – Before the Pequenos Libombos Dam
The sixth sampling point is situated just upstream the place where the River enters the Pequenos Libombos Dam. In this section, the River is quite wide and shallow. Measuring the water quality here was considered to be important to determine the quality of the water entering the Dam and hence the influence of the Dam on the water quality. The population in this area is scattered along the River and small scale farming and livestock keeping (mainly cattle and goats) are common on the River banks. The animals graze freely around the River which, during dry periods, is their only source of drinking water. Water pollution from livestock is thus likely even though the whereabouts of the herds (and hence the geographic location of the pollution source) vary. The samples from this location were taken close to the pumping station of *Bananalandia*. No regular monitoring takes place at this location.

Site 7 – After the Pequenos Libombos Dam
After the Pequenos Libombos Dam, a site was chosen to determine the water quality of the water that leaves the Dam. The site was located by the flow station E395 about a kilometer downstream the Dam and a few hundred meter downstream the small bridge. Samples were taken form the shore (close to the scales), from the center of the River. Close to the sampling site, the southern banks of the River are occupied by fruit plantations owned by the *Citrum* Company. This site has previously been sampled by DNA. Further, ARA-Sul continuously measures the water quality within the Dam.

Site 8 – Boane
The last sampling point was chosen in the outskirts of Boane town on the Mbuluzi floodplain. The site lies about a hundred meters downstream the road bridge and 2-300 m downstream the flow station E8 and the railway bridge. Around the bridges, anthropogenic activity is frequent. There are vegetable fields just a few meters from the River, clothes and cars are washed in the River, people swim and wash themselves etc. However, due to the economic situations, few people use chemicals such as laundry detergents, soap and commercial fertilisers. The purpose of this sampling point was to investigate the influence of these local pollution sources as well as to determine how the water quality changes from the outflow of the Dam as the population intensity increases as the river approaches the capital. This sampling site is included in the current monitoring programme of ARA-Sul and has previously been monitored by DNA and Lifab. ARA-Sul used to take their samples from the gauging station (below the railway bridge), but since a few years, the samples are collected from the same site used in this study.

4.3 Analysis of samples

9 parameters were analysed in this study; pH, conductivity, TDS, turbidity, temperature, NO_3^- (including NO_2^-), N-tot, P-tot and flow. For the Mozambiquean sampling locations PO_4^{3-} was also analysed once.

pH, conductivity, TDS, turbidity, temperature and NO_3^- were measured in field. The first three parameters (pH, conductivity and TDS) were analysed with electrode equipment from Wagtech, while turbidity was measured with a 2100P turbidimeter from Hach and temperature was measured with a mercury thermometer. For analysis of NO_3^- a portable photometer from Wagtech (photometer 5000) was used.

With the Wagtech Nitratest method, nitrate is first reduced to nitrite by adding a zink based powder. By adding sulphanilic acid to the solution in the presence of N-(1-naphthyl)-ethylene diamine a reddish dye is produced. The intensity of the colour is measured with the photometer and translated into a concentration of nitrate. Since this method is based on reduction of nitrate to nitrite, the initial amount of nitrite in the water will be included in the result, i.e. the measured concentration is the total amount of nitrate AND nitrite. The nitrite concentration in natural waters, i.e. when aerobic conditions prevail, is normally quite low compared to the nitrate concentration, since nitrite is rapidly converted into nitrate in the presence of oxygen.[77] The measured concentration is thus a good estimation of the amount of nitrate in the water. When analysing nitrate, readings was taken three times (i.e. the same sample was put into the photometer 3 times in rapid succession) and an average was calculated.

Total nitrogen and phosphorus was also measured with a photometer, but these analyses were made at the laboratory of the Ministry of Health (MISAU) in Maputo. The photometer used was a LASA 100, manufactured by Dr. Lange. Contrary to the other equipment, which was borrowed from Eduardo Mondlane University, this photometer was brought from Sweden.

In the Dr. Lange cuvette test LCK138 all inorganic and organic nitrogen is oxidised to nitrate by digestion with peroxidsulphate. Nitrate is then further reacted with 2,6-dimethylphenol in sulphuric and phosphoric acidic solution, resulting in nitrophenol, which is the compound giving the sampling solution its colour.

The test used for analysing total phosphorus was the Dr. Lange cuvette test LCK349. The principle of this test is to create phosphormolbdenum blue, which can be measured with the photometer. Phosphormolbdenum blue is produced by reacting phosphate ions with molybdate and antimony ions in an acidic solution. This results in the formation of an antimonyl phosphomolybdate complex, which is reduced by ascorbic acid to phosphormolbdenum blue. The same principle is used for both orthophosphate and total phosphorus. The only difference is the preparation of the sample. If total phosphorus is the desired parameter, the sample has to be heated in a thermostat to convert all phosphorus to orthophosphate, since it is the phosphate ions that are reacted with the molybdate and antimony. If only the initially solved orthophosphate is desired, heating is eliminated.

Both for nitrogen and phosphorus the concentrations in the River were below the detection limits of the analysis methods (the intervals for the tests being 1-16 mgN/l and 0,05-1,50 mgP/l). To be able to analyse the samples, concentrated solutions with phosphorus and nitrogen therefore had to be added. Since no standard solutions with known concentrations of phosphorus and nitrogen were available at the laboratory, solutions had to be prepared by dissolution of salts. For the nitrogen solution KNO_3 was used and for the phosphorus solution KH_2PO_4 was used. Very small amounts of concentrating solutions were needed, implying that the amount of salt needed was very small. By adding a known amount of salts to a certain amount of distilled water, the resulting concentration can be calculated. The preparation of the solutions thus comprised a mean to check the accuracy of the Dr. Lange equipment. However, no scale for measuring the small amounts of phosphorus needed was available, meaning that the accuracy test could only be done for the nitrogen solution. Calculation for the

[77] Tonderski et al. 2002

nitrogen solution showed that the resulting concentration ought to be 3,74 mgN/l. The spectrophotometer showed 3,36; 3,47 and 3,40 mgN/l. The difference between the theoretical concentration and the measured concentration is probably due to difficulties when transferring the salt from the scale to the solution. A dilution series test was also conducted to check the equipment. When analysing the river samples, the volume used for nitrogen analyses were concentrated according to the ratio 1:1 and the volume used for phosphorus analyses were concentrated according to 1:3. Analyses of the solutions used for concentrating were done at every analysing occasion to get an accurate concentration for the solution (see Appendix 3).

When analysing concentrations for nitrogen and phosphorus, readings were taken five times in rapid succession (see Appendix 3) from the spectrophotometer and an average was calculated. The average was then used to calculate the actual concentration in the River (i.e. disregarding the concentrating solution that was added). Calculations of the actual river water concentration were done according to the following:

Nitrogen: Conc = (reading – concentration of concentrating solution·0,5)/0,5

Phosphorus: Conc = (reading – concentration of concentrating solution·0,75)/0,25

When calculating the river concentration of nitrogen, the average for the concentrating solution, as measured the same day, was used. For phosphorus, the median of the averages calculated at *all* occasions were used for the concentrating phosphorus solution. Reasons for using the daily value for the nitrogen solution and not for the phosphorus was that nitrogen was assumed to be more affected by the time between the analysis occasion (e.g. by vaporization and dissolution of nitrogen gas between the liquid and the gaseous phase in the test tube). Phosphorus has no gaseous phase and thus this is not a problem. On the other hand phosphorus easily precipitates, leading to lower concentrations. This was counteracted by vigorously shaking before the solution was used. The reason for using the median of the averages and not the average of the averages for the phosphorus solution was that one of the averages for phosphorus showed much higher concentration than the others (see Appendix 3).

To validate the analyses made in this field study and also to check the coherence between the laboratories at AdM and MISAU, the sample collected at site 5 on September 21st was analysed both by us and by the two laboratories, i.e. the same sample was analysed three times. MISAU and AdM both strive towards using standard methods for analyses. For results of the cross-analysis, see chapter 6.2.6.

4.4 Information from stakeholders

Previous water quality data was collected during study visits to WRB, SWSC, RSSC, ARA-Sul, AdM and ETA in Boane. Interviews were also made with staff at the different water laboratories, to find out how/where the samples are taken, how they are handled and which methods are used for analyses.

The major farming activities in the River basin are at present Bananalandia (banana plantation), Macadamia (nut plantation), Citrum (citrus plantation) and Royal Swaziland Sugar Corporation. These farms were visited (except Macadamia, were we only interviewed the owner) and information regarding use of fertilisers, future plans and previous management was gathered.

4.5 Statistical analyses of data

For statistical analyses data from WRB, RSSC, ARA-Sul, AdM, DNA, Lifab and this field study were used. Data from Lifab and DNA were made available from SWECO. The Lifab data derive from Prof. Lennart Strömquist’s research in Mozambique.

4.5.1 Data from this field study

Since data from this field study were taken at almost the same time at nearby locations, a paired Wilcoxon signed rank test can be used for analyzing spatial trends and see if there are any differences that can be statistically proved at a chosen significance level (the level chosen in this study was 95%). The command signrank in Matlab was used to perform the tests. The fact that the test is paired means that it is based on the *differences* between nearby locations calculated for every sampling trip. The reason for choosing the signrank test was that the test is non-parametric and thus appropriate for populations with few values, where the distribution is unknown but continuous. The signrank test tests the hypothesis that the differences between the matched samples come from a distribution whose median is zero (the distribution is assumed to be symmetric about its median and not its average). Outcome from the test is h and p. If h = 0 the hypothesis can be rejected (i.e. the median is not zero and thus there is a significant difference between the locations). If h, on the other hand, is equal to 1, the hypothesis can not be rejected. The p value is defined as the probability of observing the given result by chance if the null hypothesis is true, i.e the level at which the hypothesis can be rejected.

Due to the low concentrations in the River water, small changes and errors during analysis had big influence on the measured concentrations. Since actual concentrations had to be calculated from solutions that had been concentrated, one of the calculated nitrogen and four of the calculated phosphorus concentrations became negative. Because of the uncertainties during analysis, all negative concentrations and the concentrations very close to zero were regarded as unreliable and were thus edited before used in statistical analyses. All negative values for nitrogen and also all values below 0,3 mgN/l were set to 0,15 mgN/l (i.e half of the 0,3 limit). For phosphorus all negative values and all values below 0,01 mgP/l were set 0,005 mgP/l. The reason for choosing these limits was that the values below the limits were few and scattered whereas most of the measured values were gathered around and above the concentrations that were chosen to be the limits for “realiable values”.

4.5.2 Data from previous monitoring

In contrary to when using data from this field study, paired tests can not be used when analyzing spatial differences from old data. The reason for this being that the locations were not sampled at the same time. For old data the Matlab tests ranksum and ttest2 were used. Ranksum is similar to signrank, but tests if the medians of two independent samples come from distributions with equal medians (i.e. the test is not based on differences as is the signrank test). For phosphorus and phosphate, where more values were available ttest2 was used. If many values are available or if data are known to be normal distributed, ttest2 is better than ranksum. Since both ranksum and ttest2 assumes that the variance is equal but unknown for the two data sets, which may not be the case, intervals where the variance were assumed to be unequal and unknown were calculated. However, the intervals are based on normal distribution, which, as discussed above may not be a good approximation for values other than for phosphorus and phosphate. The intervals should be interpreted as the intervals that with 95% certainty cover the true difference. If zero is not included in the interval a significant difference is found. For phosphorus and phosphate the intervals probably constitute the best statistical model. For the other parameters (i.e. the nitrogen fractions), both the tests and the intervals should be considered, bearing in mind that the tests assumes equal variance but not normal distribution, while the intervals assume normal distribution but not equal variance. The differences between the models can sometimes result in discrepancy in that one show significance, while the other one does not. This can be seen for example for ammonium at some locations (see chapter 4.5.2). To avoid the assumption of normal distribution in the intervals, the quantile used could have been changed from t-quantiles to the lambda-quantiles. Due to time restraints, changing quantiles was not possible in this study.

Besides analyzing data for spatial trends, old data was also used to find possible significant differences between rainy and dry seasons. This was done using ranksum and ttest2.

Just as for data from this field study, some of the data from previous monitoring programmes had to be edited before they could be used in statistical tests. The different parties measuring water quality have different practices how to present the results. If 0 for example means “not analysed” instead of “below the detection limit” it can have a pronounced effect on the average and other statistical parameters. After discussions with people presently working with water quality issues in the Mbuluzi Basin, data has been interpreted as follows:

WRB: ND and blanc-not determined
NIL-below detection limit

RSSC: 0 (for nitrate data 1995-2000)- not measured
0 (for data other than nitrate)- below detection limit
blanc-not measured

ARA-Sul: blanc-not measured

AdM: blanc-not measured
0-below detection limit

DNA: -1-not measured
0-below detection limit, see discussion below

Lifab: 0-below the detection limit, see discussion below

Some of the data series (the DNA nitrate series at E8, the DNA nitrite and ammonium series at E395 and the Lifab data series for nitrate at E8) start with a series of zeros, whereby it can be suspected that the parameter has not been measured during this first period of record. In this study however, the zeros are regarded as if the parameter has been measured, but that it has been below the detection limit. Reasons for this assumption are that the series of zeros sometimes are cut by a number, and that other nitrogen fractions has been measured at the same time, implying that sampling at least has been done. Thus it is reasonable to suspect that the "zero parameter" also has been measured.

When analyzing data, concentrations below the detection limits have been set to half the detection limit; this in compliance with common practice.[78] The detection limits used are discussed in the section below.

PO_4^{3-}:
For phosphate, all laboratories (see Table 8) claim to use the "Standard Methods for the Examination of Water and Wastewater". Which of the different methods used for analyzing phosphate at the different laboratories are however not known. The only laboratory for which the specific method (and hence the detection limit) used was found, was AdM. The method used at AdM has a detection limit of 0,25 mgPO_4^{3-}/l (noticeable is that all values measured by AdM themselves are below this limit!). Since DNA sent their samples to Águas de Maputo, which later became Águas de Moçambique, it is reasonable to believe that the same method (and limit) as AdM now uses was used also for the DNA analyses. The phosphate values from WRB are much higher than the other values, implying that it does not matter which detection limit that is used for editing; most values are above the limit anyway. The same goes for the values from RSSC. Thus 0,25 mgPO_4^{3-}/l has been used as the detection limit when editing all phosphate values.

Total phosphorus:
Values for total phosphorus were obtained from AdM and RSSC. For RSSC, the method and detection limit is not known. AdM has a detection limit for P-tot of 0,5 mgPO_4^{3-}/l = 0,0815 mgP/l (since P-tot is converted and measured as phosphate). This limit is used for data from RSSC as well.

Nitrogen fractions:
The detection limits for the methods used by AdM are 0,1 mgNO_3^-/l for nitrate, 0,03 mgNO_2^-/l for nitrite and 0,04 mgNH_4^+/l for ammonium. Methods and detection limits for data from DNA are not known, but assumed to be the same as for AdM (according to the reasoning above). Data from Lifab has also been edited regarding to the limits from AdM. The methods used by MISAU (i.e. for the

[78] Norman 2005

ARA-Sul samples) are reported to have the same detection limits as AdM except for nitrate, for which the detection limit was 0,5 mgNO_3^-/l. Due to the fact that the nitrate limit is higher for MISAU than for AdM, data from WRB (with unknown limits) are edited according to the AdM limits. Out of the nitrogen fractions RSSC has only measured nitrate. The method used has a detection limit of 0,01 mgNO_2^-/l.

4.6 Sources of errors

When evaluating the analyses performed in this field study, several sources of errors should be considered. These are listed below;

- *Difficulties in taking representative samples*; e.g. at site 8 it was difficult to get a sample from the middle of the River, meaning that water had to be taken closer to the shore. Temperature and pH may thus differ from water taken from the middle of the River. Further, the influence of local and temporary pollution sources, e.g. a herd of cows that have crossed the River can cause considerable but temporary changes in water quality.
- *Poorly washed bottles*; the distilled water may not be completely free of ions
- *Poorly calibrated field equipment*

The analyses made with the Dr Lange spectrophotometer are considered to be the least reliable analyses since:

- *analyses were made in laboratory* and hence the samples had to be brought from field and stored before analyses. The samples were stored in a cool box with ice. Due to melting ice, etiquettes occasionally detached from bottles, implying that a few samples might have been mixed up.
- *detection limits were to low to detect concentrations* without concentrating the sample, meaning that small differences when reading the spectrophotometer have a great impact on the resulting concentration.
- *the volumes used for analyses were very small* (since the samples had to be concentrated, the volumes of River water were only 0,5 ml for phosphorus analysis and 0,65 ml for nitrogen analysis), implying that small inaccuracies when measuring volumes with pipettes and also accidental pollution from equipment (e.g. the tips for the pipette had to be used several times) can cause large deviations. Further if particles occasionally were included in the small sample volume, it is likely that the concentrations increased considerably.
- *the spectrophotometer were not calibrated* after bringing it from Sweden, i.e. possibly carelessness during the flight may have affected the accuracy of the analyses.
- *the optimal temperature* for storage/usage of the chemical kits is 15-25°C. Temperature in the laboratory exceeded this range on most occasions. Further, it was not possible to check the temperature in the samples after heating them in the thermostat. The temperature after cooling was supposed to be 18-20°C, but since the air temperature was much higher, it is likely that this temperature range was exceeded.
- *the possibility of interference* with other ions were not checked
- *shaking of samples were sometimes forgotten*

To check the reproducability of the analysis methods used for nitrogen and phosphorus, the sample from Goba on October 18th was divided into four volumes that were prepared and analyzed separately. As can be seen in Table 2, the spread is considerable.

Table 2 Results from four separate anlyses of the sample collected in Goba Oct 18th.

Nitrogen mgN/l	Phosphorus mgP/l
-0,338	0,0112
1,238	0,1488
1,15	0,1128
1,402	-0,0048
Standard deviation (std) = 0,807	*Standard deviation (std) = 0,0754*

The spread when comparing averages from the different analysis occasions for the concentrating nitrogen and phosphorus solutions is not as high as the spread for the nitrogen and phosphorus analyses. This indicates that the method with concentrating the samples is not very good.

5 Theory

5.1 Water quality in rivers

5.1.1 Factors affecting water quality

Physical, chemical and biological water quality in rivers is affected by several interconnected factors. These can be divided into natural and human factors. Natural factors, including geology, soils, hydrology, climate and biology are responsible for the background quality and the self-purification capacity of a river. Human factors are for example usage of chemicals, land usage and land management practices. Areas with the same "human settings" can have different water quality due to differences in natural factors.[79]

The pollution load a river can stand without too serious degradation depends on its ability to purify itself. According to Smith and Smith:

> "Streams can purify themselves by natural, bacterial breakdown of organic matter. The time required depends on the degree of pollution and the character of the stream. A fast-flowing stream constantly saturated with oxygen can purify itself much faster than a slow stream, which does not have the luxury of rapid oxygenation".[80]

The term self-purification was originally adopted to describe the degradation of organic matter, but is often used in a wider sense to include any process removing undesired substances.[81] For example, uptake of nutrients by plants can be regarded as self-purification, even though this is rather a temporal purification than a constant elimination of nutrient. The nutrients will eventually be released to the water again when the plants are decomposed. Also sedimentation can be regarded as temporal purification.

To predict water quality in a river, the hydrological cycling of water in ground, on land and in atmosphere needs to be taken into account. The cycle governs the occurrence and movement of water and pollutants. If, for example, a river gets most of its water from groundwater (as is the case during baseflow) it is important to look at the quality of the groundwater to be able to predict the quality of the river water. Rivers gaining water from groundwater are called effluent rivers and rivers losing water to groundwater are called influent rivers.[82] The exchange between groundwater and surface water can change over time, i.e. an effluent river can become influent during rainy seasons.

[79] Hamilton et al.2004
[80] Smith et al 2000
[81] Chorus 1999
[82] Gordon et al. 1992

Anthropogenic activity can also affect the balance between surface- and groundwater. Intense pumping can lower the groundwater level thereby changing a river from effluent to influent. The lowering of groundwater tables affects the water chemistry by creating oxidizing conditions in the soil layer, which in turn can cause formerly reduced chemical elements to oxidize and dissolve in water. An example of this is the arsenic pollution of wells in Bangladesh. If polluted groundwater is discharged into rivers the rivers will also be polluted. Groundwater often has higher concentrations of metals than do surface waters.[83] This is because of weathering and ion exchange in soil (see chapter 5.1.1.1).

In the temperate regions, for example in Sweden, most rivers are perennial (flows all year round). However, in other climates, rivers are often intermittent (flows only parts of the year) or ephemeral (flows only a short time following precipitation events; shorter periods than intermittent rivers).[84] The flow regime of the river and its seasonal variations influences the water chemistry.

5.1.1.1 Natural factors

Geology and soils

The geology in a river basin influences the drainage patterns, bed material and water chemistry of the river.[85]

The faster the runoff (both surface and subsurface) reaches the river the more polluted it usually is, since shorter transportation time leaves less time for self-purification. In areas with low permeability water will not infiltrate to groundwater but will runoff directly to the river, i.e. the retention time will be shorter. Rivers in basins with high clay content (implying low permeability) and underlain by non-permeable bedrock are thus more prone to be polluted than rivers in basins with permeable soils underlain by sand, gravel or highly fractured bedrock (for example karst).[86] Topography, vegetation and drainage will also affect the transport time to the river. Steep slopes, spared vegetation and a high density of tiles and drainage ditches will decrease transportation time.

The presence of different soil types in a basin influences the infiltration rate as well as the flora and fauna. This will in turn affect the water chemistry. Material from eroded soils that are flushed into rivers will end up as suspended solids, reducing light penetration and rate of photosynthesis. High sediment load makes the water darker, leading to an increased absorption of heat and a raising water temperature.

Soils are composed of the following components:

- Weathered rock
- Organic matter
- Living organisms
- Spaces with air and water

Weathering of rocks is the process by which geological substrates becomes soil. The minerals released by weathering have an important effect on nutrients and the water retention capacity in the resulting soil.[87] Slow weathering can limit the nutrient availability. The rate of weathering depends on the weathering potential of the rock specie as well as the climatic conditions such as temperature, precipitation and wind. High precipitation and temperature also enhances leakage of nutrients from soil to surface- and groundwater. This implies that weathering takes place to a greater extent in

[83] Bydén et al. 1996
[84] Gordon et al. 1992
[85] Ibid
[86] Hamilton et al. 2004
[87] Smith et al. 2000

wet/warm climates than in dry/cold. Regardless climate, rivers cutting through easily weathered bedrocks have high salinity.[88]

Bedrock can be classified as:

Igneous rocks:	Created by cooling of volcanic flows. Usually not easily weathered. Properties depend on rate and temperature at which they are formed.
Sedimentary rocks:	Composed of deposited mineral particles. Easily weathered. Properties depend on which type of sediment the rock are formed from (e.g. biological sediment). Permeability is usually high
Metamorphic rocks:	Created by either igneous or sedimentary rocks that has been altered by heat and pressure by overlying rocks. Not easily weathered.

Depending on the amounts in which the components are present, soils can be classified as either organic or mineral soils.

Organic rich soils have a capacity to convert nitrate to nitrogen gas (see chapter 5.1.5) which will be released to the atmosphere.[89] Since nitrate is easily dissolved and transported in soilwater, high amounts of nitrate can be introduced to the river via groundwater. If the river sediment then is rich in organic material much of the nitrate can be denitrified and taken up by the biota before it enters the river.[90]

Acidic soils tend to act as ion exchangers, replacing cations (e.g. Ca^{2+}, K^+, Mg^{2+}) on soil particles with H^+. The cations will then be released to the soil water and transported to rivers. If, on the other hand, there are many cations from easily weathered bedrocks, H^+ on soil particles can be exchanged and released to the river, leading to acidification of the water.[91]

Following are some examples on how geology and soil affect background water quality:

- Nutrient rich bedrock can leak nutrients. For example, basins with phosphatic limestone tend to have a high natural concentration of phosphorus.
- Sedimentary rocks rich in organic material can release high amounts of ammonium if in contact with high-temperate geothermal water that flow into rivers.[92]
- Easily weathered rocks together with hot springs results in high concentrations of dissolved solids.[93]
- Shales high in selenium raise the selenium concentration in rivers.[94]

The examples above show how certain geological formations can increase concentrations of different substances in a river. However, geology can also improve water quality in rivers polluted by humans. In rivers with high calcite concentrations (from carbonate rich bedrocks) phosphorus can coprecipitate with calcite.[95]

Concentrations of bicarbonates and calcium are often lower in tropical inland waters than in temperate inland waters. This is partly compensated for by higher levels of Na and Cl.[96]

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[88] Apodaca et al. 1996
[89] Hamilton et al. 2004
[90] Ibid
[91] Smith et al. 2000
[92] Hamilton et al. 2004
[93] Apodaca et al. 1996
[94] Ibid
[95] House et al. 1998
[96] Sundström 1992

Hydrology
Water chemistry changes from headwater to mouth of a river in compliance with factors such as width, depth, channel patterns, temperature, velocity, sedimentation load and biota.[97] In the headwaters of a river, the flow is generally swift and shaded by trees (this is however not the case for the Mbuluzi) resulting in high levels of dissolved oxygen and suspended solids. The closer to the mouth, the slower the water velocity and the more the river behaves like a lake.

Due to a shorter transportation time and a smaller dilution potential in small streams, a quicker and more concentrated response to rain/irrigation and associated pollutants will arise in small streams than in larger rivers. On the other hand, concentration in larger rivers can remain moderate for a longer time.

The presence of tributaries can have high influence on the water quality in a river, if the tributary is cleaner than the main river, the pollution in the latter will be diluted and vice versa. Isolated rivers have few tributaries and will thus get higher concentrations of pollutants than rivers with many tributaries (if those tributaries are not more polluted).[98]

River flow is affected by climate, topography and hydrology in the basin. The velocity of the river molds the morphology of the river by transporting silt, sand, stones etc. Flow is also connected to water chemistry, for example by oxygenation and nutrient transportation. High flow transports high sediment loads to which phosphorus, heavy metals and toxic substances are adsorbed.[99]

Climate
Frequency and intensity of rainstorms affects the amount of suspended solids (and pollutants attached to it) and salts in the river. Thunderstorms in arid areas contribute with high loads of sediments and salts. The high evaporation rate in arid areas also contributes to an accumulation of salts on soils. During periods of high runoff the accumulated salt will be transported to the river.[100]

Vertical water temperature differences can cause stratification in manmade and natural lakes/reservoirs. This induces changes in water chemistry in rivers flowing through the lake/reservoir. Stratification can be quite pronounced in temperate regions due to high seasonal variability in temperature and winds. Even though the temperature differences in the tropics are smaller, waters can still be stratified. Lakes/reservoirs can have thermal stratification on a day/night basis. The major difference between stratification in temperate regions and tropical regions is the mechanism of circulation and the length of the stagnant period. In temperate regions circulation often occur during autumn- and spring storms. In the tropics circulation is more random due to the presence of heavy rainfall and high flows.[101] High temperatures in rivers affect the biological life (for example by influencing sensibility to toxics, solubility of oxygen and rate of photosynthesis and metabolism) and hence the self-purification capacity. Higher purification capacity during warmer periods is one of the factors leading to seasonal patterns of water quality in rivers. This is especially noticeable in temperate climates where temperature differences throughout the year are bigger. Further, the solubility of minerals increases with increasing temperatures. High temperatures increase the mobility of ions, resulting in higher conductivity.[102]
Seasonal differences (foremost temperature and precipitation) can also have an influence on the groundwater level, which, as mentioned above, can affect water chemistry by influencing processes such as soil chemical reactions and transportation of water in the ground.[103]

[97] Gordon et al. 1992
[98] Hamilton et al. 2004
[99] Gordon et al. 1992
[100] Apodaca et al. 1996
[101] Sundström 1992
[102] Bydén et al. 1996
[103] Ibid

Physiography and biology

A natural river is composed of riffles, pools and hyporheic zone. Riffles are the fast flowing, rough parts of the river where oxygenation takes part and where photosynthesis is greatest. Due to oxygenation in riffles rivers rarely suffer oxygen depletion. Pools are slow flowing reaches where organic material is decomposed. During decomposition carbon dioxide is produced. The production of carbon dioxide is important to ensure that there is enough carbon dioxide for photosynthesis to continue in the downstream riffles. The hyporheic zone is the transition zone between the river and the groundwater and contains water from both subsurface and stream channel origin.[104] The importance of the hyporheic zone is in that it exchanges nutrients and organic matter with the stream flow. Nutrients are stored in the hyporheic zone for example as gases.[105]

Vegetation on floodplains and riparian zones along the river decreases and slows down surface runoff leading to lower concentrations of suspended solids, phosphorus, nitrogen, pesticides etc in the river water. The decreased runoff of pollutants is due to precipitation, flocculation, adsorption and biological conversion and consumption of dissolved and particulate nutrients. Trees in the riparian zone prevent erosion by binding the soil with their roots. Trees also provide shade, which, due to the temperature reduction, means that the amount of dissolved oxygen is increased. The type of trees in the riparian zone influences the water quality in different ways, for example by different abilities to decrease the nitrogen influx to the river. If the riparian zone has been destroyed and re-plantation is planned, the tree specie should be carefully chosen so as to avoid trees that can contribute with nitrogen (i.e. nitrogen fixers) to already nutrient rich waters.[106] Plantation of coniferous forest will contribute with acidic and humic rich water to rivers.[107]

Besides the ability to decrease the amount of runoff (and thereby attenuating flows, control floods and enhance aquifer recharge[108]), vegetation along rivers can act as natural firebreaks.[109]

During floods, elements in the water, for example nutrients and sediments are deposited on the floodplains. Floodplains decrease the energy available for erosion by letting the water spread out, thus decreasing water velocity. Where floodplain is lacking and the slopes of the river are steep the major sources of sediment and phosphorus is small-scale land failures.[110]

Rivers not altered by anthropogenic activities tend to follow a meandering pattern. Meanders make the flow path of the water longer, increasing the retention time in the river and consequently the possibility of self-purification. The environment sustained by meanders can hold a higher diversity of flora and fauna than a straight river channel. Since flora and fauna are essential parts of the self-purification capacity (by biological uptake, decomposition and photosynthesis) the water quality will improve with increased diversity.[111] Photosynthesis and respiration changes for example pH, dissolved oxygen and carbon dioxide.[112]

The amount of wetlands in a river basin will greatly influence the water quality. Wetlands act as sinks of phosphorus, nitrogen and sediments. The main sink for nitrogen in wetlands is uptake by vegetation. Denitrification, due to stagnant and oxygen poor water, can also play a major role.[113]

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[104] The School of Aquatic and Fishery Science (undated)
[105] Gordon et al. 1992
[106] Boon et al. 2000
[107] Bydén et al. 2000
[108] Hirji et al. 2002
[109] Moosa (undated)
[110] Boon et al. 2000
[111] Ibid
[112] House et al. 1998
[113] Boon et al. 2000

5.1.1.2 Human factors

An increasing population and industry density increases the pressures on rivers. The arising problems can be related to chemical use, land use and land management practices.[114] Due to the rapid development in Southern Africa, the pressure on the rivers in the region has increased dramatically during the last 50 years.

Degradation of rivers due to anthropogenic activities has negative impact on economy, aesthetic values, safety and health. The economical loss consists of damage to vegetation, crops and subsequent livestock farming.[115]

Manmade constructions

Manmade constructions, such as dams/reservoirs and interbasin transfers are considered to be the biggest threats to water resource management in Southern Africa.[116] Dams interrupt the natural flood pulse concept (periods of natural flooding), reduce the load of suspended sediment, change the temperature, reduce nutrients, change the morphology of the downstream river reaches and the estuarine deltas and smoothens out the hydrograph. Low flows downstream dams in lowland areas can lead to water quality degradation due to saltwater intrusion from the sea.[117] Dams with different purposes (e.g. flood mitigation, hydropower, and drinking water) influence the hydrological regime in different ways, due to difference in capacity, variability in releases etc. Dams with long retention time have a high potential for improving water quality. Apart from retention time, another factor affecting water quality downstream a dam is the depth from where the water is released. Water released from the surface layer of the reservoir has warm, nutrient rich and well oxygenated water. Water released further down is cold, oxygen poor, rich in minerals and have much soluble organic material.[118] If water is released close to the bottom and anaerobic conditions exist, phosphorus and other substances can be released from the sediment to the downstream reaches of the river. During the initial filling, dams often suffer heavy blooms of phytoplankton and, in tropical regions floating plants.[119] Reasons for the blooms are nutrients originating from flooded land and from decomposition of flooded vegetation.

Regarding interbasin transfers, these can both improve and degrade water quality of rivers depending on the quality of the transferring river. If the transferring river is cleaner than the receiving watercourse, it will improve water quality in the receiving river by dilution and vice versa. The transferring river can, as a result of the transfer, degrade due to decreasing dilution capacity. Transferring rivers can also suffer from increased temperature when water is extracted.

Point sources

Pollutants entering a river can be divided into different groups regarding their origin. A common division is into point- and non-point sources.

Point sources are sources that are distinct and identifiable.[120] Some pollution sources are hard to classify as either point- or non-point sources. An urban centre can, for example, be regarded both as a point- and a non-point source depending on the level of investigation (globally/regional or very local). Storm runoff in urban areas (not collected and treated) can be classified as a nonpoint pollution source, which carries a high concentration of TDS and a high temperature. Due to urbanisation the transportation time to rivers decrease, leading to high peakflows that can carry large amounts of sediment and destroy vulnerable habitats in the river.[121] Pollution from urban areas includes nutrients,

[114] Hamilton et al. 2004
[115] Jonnalagadda 2001
[116] Boon et al. 2000
[117] Hirji et al. 2002
[118] Smith 1995
[119] Ibid
[120] Hirji et al. 2002
[121] Hamilton et al. 2004

pesticides, various chemicals, hydrocarbons, trace elements and salts. Examples of point sources (and pollutants connected to them) in urban and rural areas are:

- Discharge of municipal sewage (organic matter, nutrients etc)
- Industry (e.g. slaughter houses, pulp and paper plants, fertiliser factories, thermal electric power stations, tanneries, chemical plants, textile mills – all kinds of pollutants)
- Waste heaps (organic matter, nutrients, metals, toxic substances)
- Mining (leakage of for example arsenic, cadmium, salts and acidic runoff)
- Leachate from septic systems (organic matter, nutrients, chloride)
- Leachate from underground storage tanks (e.g. hydrocarbons from petrol stations)
- Parking lots draining to stormwater pipes (heavy metals)

Rapid economic and population growth in southern Africa cause increasing amounts of industrial and domestic waste, leading to higher pressures from point-sources.[122]

Non-point sources

"Non-point sources are diffuse in nature and pollutants are discharged over a wide area or from a number of small inputs rather than from distinct identifiable sources."[123]

The most important non-point sources are agriculture, livestock (can sometimes be regarded as a point source), forestry, atmospheric deposition and land degradation.

In areas with defined dry and wet seasons, like Southern Africa, most non-point pollutants come with rains during rainy seasons.[124] The pollution loads are especially high in rains following long drought periods.

Agriculture

The usage of chemicals (fertilisers and herbi-/pesticides) and variability in land management practices makes agriculture the biggest concern for water resource planners. Surface- and subsurface runoff from agricultural land brings suspended solids, nutrients (dissolved or attached to sediment particles), pesticides etc to rivers. The type of fertiliser and the practices of application are highly influencing water quality in nearby rivers. Phosphorus from manure is for example more mobile than phosphorus from chemical fertilisers.[125] It is important to take the soils own N and P-content into consideration when calculating the amount of fertiliser needed.[126] Agriculture increases the decomposition of deep organic soil material by breaking up and mixing soil. This leads to the release of nitrate and nitrious oxide.[127] Concentration of nutrients and pesticides in rivers often follow a seasonal pattern connected to the amount and timing of fertiliser application. Frequency and magnitude of rainfall, irrigation, soil tillage, ploughing and the use of tile drains all contribute to the amount of nutrients reaching the river. Nutrients applied just before heavy rainfall and irrigation are easily flushed directly to the river. However, studies have shown that nitrate from agriculture mostly reaches rivers via tile flow, implying that direct loss of nitrate via surface runoff is not a major source of stream nitrate. Though some nitrate moves directly into tiles, most is accumulated in the soil and leaked to rivers (via tiles) during heavy rains.[128] A change of irrigation system from furrow irrigation to sprinkler and, especially, drip irrigation, can reduce runoff and therefore sediment load, phosphorus load and nitrate load to the river.[129] When using drip irrigation, nutrients can be applied directly to the plants via the irrigation system instead of being applied on the whole field. Drip irrigation also makes it possible to fertilise

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[122] Hirji et al. 2002
[123] Ibid
[124] Ibid
[125] Litke 1999
[126] Killham 1994
[127] Smith et al. 2000
[128] U.S. Geological Survey 2001
[129] Hamilton et al. 2004

when it otherwise would be impossible. It can for example be difficult to reach sugar fields when growth is dense or when rainy seasons make it difficult to use fertilisation aids.

Besides changing irrigation system, usage of cover crops, ground cover and construction of sedimentation basins can improve water quality in farming areas.[130] Leaving a buffer zone along the river also reduces runoff.

Salinisation of soil and water are negative effects of intense irrigation. Irrigation raises the groundwater table, causing dissolved salts to reach the root zone. Accumulation of salts in the root zone can be counteracted by drainage.[131] Salt is naturally present in irrigation water, but added to this is the salinisation caused by increased weathering due to constant presence of water in the irrigated soil (this is especially a problem where the soil is easily weathered). While much of the irrigation water is evaporated, the salt will remain (and accumulate) in the soil and on the surface. During heavy rains or excessive irrigation the salt will be flushed away as surface runoff or as drainage water to the rivers.[132]

In USA concentration of nitrate has been found to be generally higher in shallow groundwater in agricultural areas than in other areas. Nitrate levels in surface water downstream agricultural areas were usually also elevated, but the levels were lower than in the groundwater. Downstream urban areas nitrate in surface waters was found in the same concentrations as downstream agricultural areas. Both NH_4^+ and phosphorus were higher downstream urban areas than at sites downstream other landuses (even agricultural areas).[133] The study was, as mentioned before, performed in USA, and hence the results can not be expected to be the same in developing countries with completely different settings (i.e. smaller settlements, no wastewater treatmentplants, no big commercial agriculture etc). It can, however, give an indication of a future scenario.

In many areas in Africa the slash and burn technique is used as an agricultural practice. This technique simply means that areas are prepared for cultivation by burning. When burning the organic matter, much of the nutrients will remain in the ashes until flushed to the watercourse with runoff water. Some nitrogen will, however, be (temporarily) lost to the atmosphere.[134]

Regarding pesticides, American studies have estimated that, in contrary to nitrate, most of the pollution comes from surface runoff. While the use of pesticides in the developed world is restricted and regulated, the usage in developing countries is increasing and approaching the same levels (or even higher) as in the developed countries. The reason for the increased usage is the high dependency of the economy on agriculture.[135] One problem with pesticides in developing countries is the high expense to monitor and track the occurrence. Pesticides are hazardous even at low concentrations, which is one of the reasons for the expensive analyses.

Livestock

Grazing areas for livestock suffer land degradation by vegetation loss and treading. The closer to the river the grazing area is the greater is the impact on the water quality. Livestock with direct assess to rivers act as a source of bacterial and nutrient pollution by directly depositing in the river. Improved waste handling in livestock farming can improve water quality. P-content in the waste can also be reduced in various ways to improve water quality.

[130] Hamilton et al. 2004
[131] Gowing 2003
[132] Instutitionen för Mark- och Vattenteknik KTH 2004
[133] U.S. Geological Survey 2001
[134] Sundström 1992
[135] Brönmark et al. 2002

Atmospheric deposition
Pollutants in the atmosphere derived from the combustion of organic material (fossil fuels as well as firewood) will eventually return to land and rivers by dry and wet deposition. The most common air pollutions affecting African rivers are sulphur compounds, carbon monoxide, hydrocarbons, nitrogen compounds and volatile organic compounds.[136] Particulate pollutants carrying toxic metals are also a problem. In Lake Victoria indications show that the most important contributor of nutrients to the lake is air born particulates originating from bushfires and dust. [137]

Land degradation
Degradation of land, vegetation loss, rainfall stochasticity and dry land characteristics leads to soil erosion and channel degradation. These processes, that influence water chemistry, progress with a rate far greater in developing countries than in developed countries.[138] Land degradation follows population pressures, fuel requirements, livestock grazing, forestry, invasion of alien vegetation etc. In forested areas the canopies of trees intercept rainfall, reducing erosion during heavy rains. Root systems of trees also aid infiltration implying less surface runoff and erosion. Overgrazing, non-contour ploughing and removal of riparian vegetation are factors that are known to increase the rate of soil erosion in Southern Africa.

5.1.2 General parameters

5.1.2.1 Motives for water monitoring

Reasons for monitoring water quality is to develop regulations and standards, identify pollution sources, prioritise areas more vulnerable to pollutions (areas where improved management have the greatest benefits), improve water monitoring schedules and check compliance with already set standards. To be able to distinguish trends from short time fluctuations it is important to have long series of systematic and consistent measurements. By relating longterm measurements to human activities and environmental settings water quality in unsampled areas with similar settings can be predicted.[139]

5.1.2.2 Measuring and analysis practices

When monitoring water quality it is important to collect, handle and analyse the samples in a consistent way to facilitate comparisons between data sets. The water quality in a river can vary very locally which means that it is important to collect samples where similar conditions prevail, i.e. at similar depths and water velocities. Likewise can storage of samples and inappropriate washed sampling equipment influence concentrations, giving misleading results. Hence, the methods used should always be described. The U.S Environmental Agency (U.S EPA) gives out a publication called "Standard Methods for the Examination of Water and Wastewater". The "Standard Methods" is a compilation of analytical methods approved by the Environmental Agency and used in many countries all over the world to aid compliance in water quality measurements. The analytical methods generally include information on how to collect, transport, store, concentrate, separate, identify and quantify samples.[140] For some parameters there are several different approved methods. Which one to chose depends on assets, range of concentration etc. Another important issue is to keep records of the methods and procedures used and to store data in a consequent and clear manner.

5.1.2.3 Water quality parameters

Water quality parameters can be divided into physical, chemical and biological parameters. The division can be somewhat ambiguous. See Table 3 for a list of some commonly measured parameters and comments to them.

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[136] Hirji et al. 2002
[137] Ibid
[138] Boon et al. 2000
[139] Hamilton et al. 2004
[140] U.S. Environmental Protecting Agency 2006

The parameters that should be included in a monitoring programme depend on the aim of the study as well as the expected pressures within the river basin. The frequency of measurements depends on the focus of the study and available economic means. If long term trends are of interest, regular samplings should be made. If, on the other hand, the main focus is how first flushes influence the quality of the river, sampling should be made more frequently during rain events.

Table 3 Some commonly measured parameters

Type of parameter	**Parameter**	**Comment –** *reasons for measuring the parameter and factors affecting it*
Physical parameters	***pH***	pH affects biological processes, solubility and toxicity of many substances. Bedrock material and soil are major factors influencing pH. High pH is further promoted by laminar flow and sunny conditions that, respectively, minimize atmosphere-to-water transport of CO_2 and maximize photosynthetic uptake of CO_2.[141]
	Temperature	Temperature affects solubility and uptake of for example heavy metals. Solubility of oxygen decreases with increasing temperature. Turbulence, turbidity and water depth are factors affecting water temperature
	Dissolved oxygen(DO)	Toxicity of many substances increases with decreasing DO.[142] Low DO is an indication of eutrophication, since oxygen is consumed during decomposition of organic matter. Turbulent conditions and low temperatures increase the oxygen levels in the water.
	Electrical Conductivity (EC)	Conductivity is a measure of the amount of dissolved salts (ions) in the water. The EC is directly proportional to TDS. Conductivity is enhanced by weathering of geologic material. (see TDS further down). High EC affects biological community, by favouring salt persistent species.
	Flow	To be able to see if a higher concentration of a substance is due to increased pollution load and not to decreasing flow it is important to measure flow and calculate the mass flows.[143] Knowing the size of flows is also vital to calculate the river's dilution potential. Flow affects oxygenation and thus biological processes. Flow is affected by rainfall, catchment properties, evaporation and manmade structures (e.g. dams).
	Suspended solids (SS)	Phosphorus, pesticides and bacteria are often attached to suspended solids. SS reduces light penetration and hence biological activity (i.e. photosynthesis). Climate is one factor that influences the amount of SS in rivers; arid areas have much higher SS concentrations than humid areas.
	Alkalinity	Alkalinity is a measure of the buffering capacity in a system, that is the possibility to withstand changes in pH. Geology is the main influence on alkalinity; dissolution of carbonates by carbonic acid results in the buffering ions bicarbonate-, carbonate- and hydroxide-ions.
	Hardness	Hardness is a measure of the amount of calcium and magnesium in the water and is thus highly dependent on soil and bedrock. High hardness leads to lower toxicity of many substances.[144]
	Total dissolved solids/salts (TDS)	TDS (solids) is a measure of all compounds dissolved in the water (usually measured in mg/l). TDS (salts) is the fraction of TDS (solids) that carry an electrical charge. TDS (salts) is usually measured in mS/m or µS/cm. Since most compounds in waters with low organic content carry a charge, TDS (salts) can be used as a measure of TDS (solids). TDS (salts) is in turn proportional to electrical conductivity, wherefore EC can be used to estimate TDS (salts). The

[141] Dodds et al. 2000
[142] Sundström 1992
[143] Bydén et al. 1996
[144] Sundström 1992

		relationship between TDS and EC in South African inland waters has been determined as: TDS (mg/l)=TDS(µS/cm)=0,65·EC(µmS/cm) [145] eq (1) If very accurate estimates of TDS are required, the conversion factor should be experimentally determined for each specific site.[146] In general TDS is 2/3 of EC. High levels of TDS have a negative impact on irrigation water, drinking water and aquatic life.
	Turbidity	Turbidity is a measurement of the suspended solids (SS) in the water (see SS further up in the table).
Chemical parameters	***Heavy metals and toxics***	Heavy metals (e.g. Cd, Pb) are often adsorbed onto sediments. Even at moderate concentrations heavy metals is toxic to biological life. Factors affecting toxicity of heavy metals are pH, dissolved organic carbon, land use and temperature.[147]
	P-fractions	Phosphorus is important for all biological life. See chapter 5.1.6.
	N-fractions	Nitrogen is important for all biological life. See chapter 5.1.5.
	Metals	Metals can be toxic to biological life. Toxicity and availability is affected by pH. The origin of metals is geological material and antrophogenic activity.
	Chloride (Cl^-)	Cl^- in high levels is toxic to vegetation. Cl^- can be found in areas with sedimentary rocks. Anthropogenic sources of Cl^- are septic tanks, animal wastes and fertilisers (KCl).
	Pesticides/ Herbicides and Fungicides	Pesticides/herbicides and fungicides are commercially produced and are thus often foreign elements in nature. They are persistent and prone to accumulate in higher organisms.
Biological parameters	***Biological oxygen demand (BOD)***	BOD measures the amount of oxygen required for biological use, i.e. it is a measurement of the amount of organic matter. High levels of BOD and low levels of DO imply risks for anaerobic conditions. This often occurs in connection to eutrophic condition.
	Bacteria	Bacteria are measured to evaluate the suitability of the water for drinking purposes. Tropical climate and high levels of organic material favours bacteria.
	Chlorophyll	High concentrations of chlorophyll can be related to eutrophication, since high primary production is one of the characteristics of eutrophic water bodies (see chapter 5.2).
	Invertebrates	Biological monitoring of invertebrates (number of species and individuals) are useful for finding longterm trends. A high diversity of invertebrates indicates a healthy water.
	Fish	To determine water quality, fish can be useful both by biomonitoring and by analysing the tissue for toxic elements (heavy metals and pesticides). Since certain chemical compounds can bio-accumulate in fish, analyses tissue can show longterm changes.

[145] Department of Water Affairs and Forestry 1996a
[146] Ibid
[147] Brönmark et al. 2002

5.1.3 Invasive alien species

The definition of invasive alien species is species that are introduced into a new environment in which they thrive and proliferate to the detriment of the environment.[148] Invasion of alien species is thought to be a major environmental issue the next coming 25 years.[149] Both aquatic and terrestrial alien species affect water quality. Up to 60% of the mean annual runoff in South Africa is transpired and evaporated by invasive alien trees.[150] Native tree species have adjusted to water shortage and hence use the available water more efficiently. More evaporation means less water to the rivers resulting in less dilution of pollutants and change in river morphology. Alien vegetation in the watershed can also increased erosion and lead to siltation problems in rivers. Common trees for afforestation in Southern Africa are the fast-growing alien species pine and eucalyptus.[151] In watercourses, problems with siltation and excessive evaporation are triggered by a*quatic* invasive alien species. Aquatic invaders take dominion over rivers and slow down flows leading to increased siltation and evaporation as well as decreased levels of dissolved oxygen. Reduction of light intensity and different preferences for nutrients and ability to cope with toxic substances changes water quality when invasion occurs.[152] Aquatic alien species of special concern in southern Africa are *Eichhornia crassipes* (Water hyacinth), *Salvinia molesta* (Kariba weed), *Pistia stratiotes* (Water lettuce), *Myriophyllum aquaticum* (Parrot´s feather) and *Azolla filiculoides* (Red water fern).[153] The rapid and passive dispersion of alien species in aquatic ecosystems makes these systems more sensitive to invasion of alien species than the corresponding terrestrial ecosystems. Human acitivities also help in dispersion of aquatic aliens, for example by introducing the plants as ornamental plants or by accidential spreading via boats etc.[154]

Economical loss due to invasion of aquatic alien species can be considerable. Costs are related not only to the problems caused by invasion (problems are similar to those caused by eutrophication see chapter 5.2), but also to combating the invaders.[155]

It can be debated whether invasion of aquatic species is a problem only caused by bringing the plant to the new environment or if it is caused or triggered by eutrophication. The concept “human-driven biotic invasion” can be appropriate here. Alien species can prosper in a new environment by several reasons; they are lacking natural enemies and/or they are aided by human-caused disturbances that disrupt the native communities. These disturbances can be provoked by agriculture, livestock farming, grazing, changes in salinity and nutrient levels in the rivers etc.[156] The invasion of an alien plant can accordingly not always be attributed just to the introduction of it to the river.

5.1.4 Guidelines for evaluation of water quality

The aim of monitoring water quality is to improve or preserve good water quality. Defining water quality as “good” or “acceptable” is however not easily done objectively. Combinations of water quality standards, guidelines, criteria and objectives are often used to define what levels of substances can be acceptable for different water uses.

Standards for water quality have been developed in most countries in Southern Africa. The standards concern drinking water, irrigation water, effluent water and recreational water etc. Neither Mozambique nor Swaziland has developed complete water quality guidelines and so the guidelines more or less follow the WHO guidelines.[157] WHO supplies guidelines for drinking water and for recreational water.[158] Both Mozambique and Swaziland have, however, established guidelines for

[148] Mack et al. 2000
[149] Brönmark et al. 2002
[150] Boon et al. 2000
[151] Hirji et al. 2002
[152] Moosa (undated)
[153] Hirji et al. 2002
[154] Brönmark et al. 2002
[155] Mack et al. 2000
[156] Ibid
[157] Hirji et al. 2002
[158] WHO (undated)

drinking water (see Appendix 4) Mozambique has established guidelines both for treated drinking water and untreated drinking (e.g. water from wells). The guidelines are however almost similar.[159]

South Africa has one of the most complete set of guidelines in Southern Africa. They have established criteria and Target Water Quality Ranges (TWQR) for aquatic ecosystems, marine environment, domestic, recreational, industrial and agricultural (irrigation, livestock watering and aquaculture) uses. The TWQR is not a criterion, but a management objective. The Department of Water Affairs and Forestry (DWAF), who is responsible for setting the objectives, strive to keep the water quality within the TWQR. The TWQR has been derived from quantitative and qualitative criteria.

5.1.5 N-cycle

Nitrogen is a constituent in amino acids/proteins as well as in nucleic acids and can thus be found in all living organisms. When organic matter decays (mineralisation) the organically bound nitrogen is transformed into ammonium (NH_4^+) see Figure 6.[160]

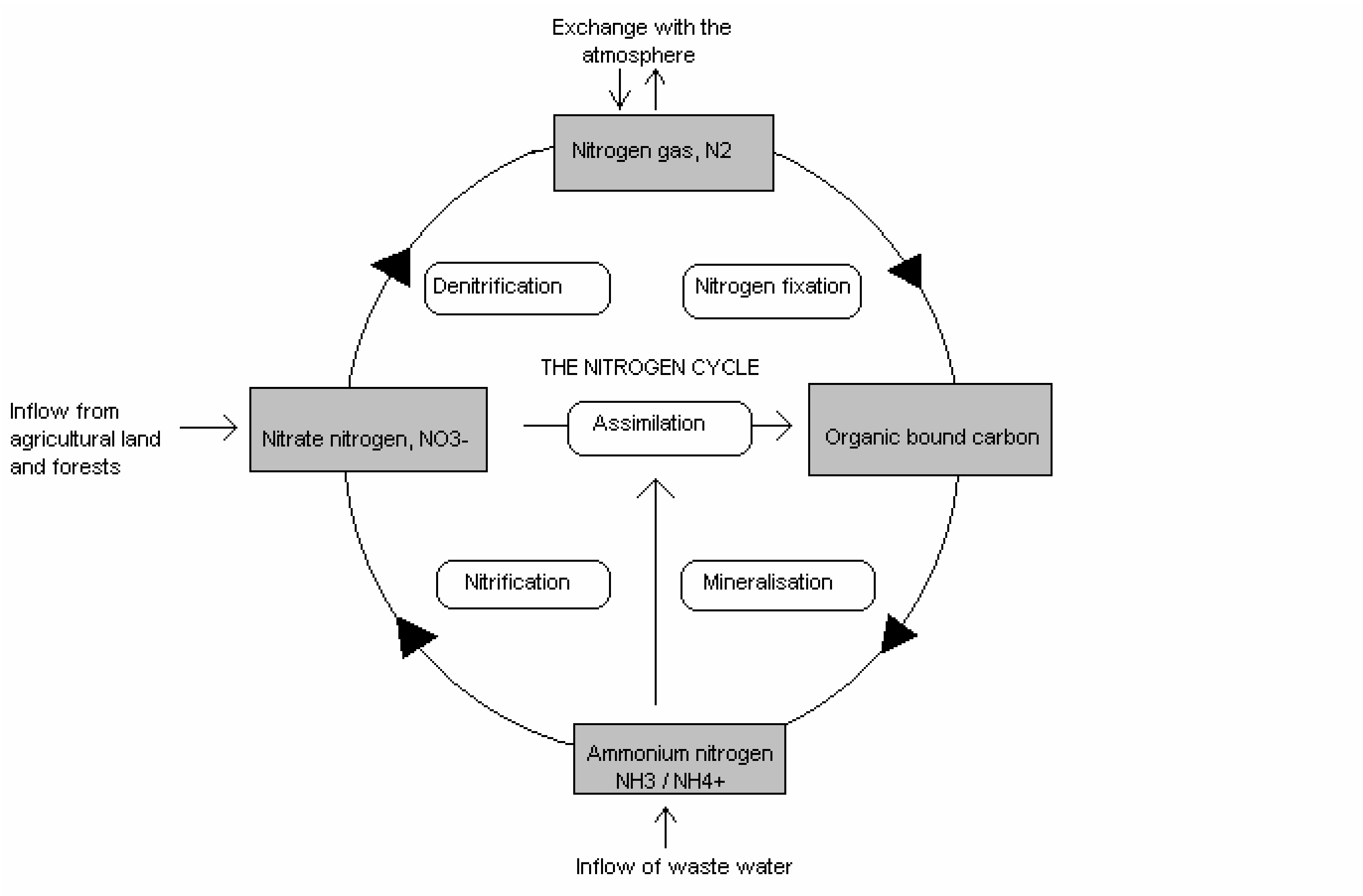

Figure 6 The nitrogen cycle.[161]

Ammonium is soluble in water, but not very stable under natural conditions. If oxygen is present ammonium will oxidise to nitrate (NO_3^+). Oxygen rich water with high levels of ammonium is thus an indication of pollution (for example discharge of sewage). In waters with oxygen deficit, ammonium can accumulate or be converted to nitrogen gas (N_2).

[159] MISAU 2004
[160] Bydén et al. 1996
[161] Freely translated from Tonderski et al. 2002

Oxidation of ammonium to nitrate is called nitrification and takes place in two steps. First ammonium is oxidised to nitrite (NO_2^-) and then nitrite is oxidised to nitrate according to:

$NH_4^+ + 1,5\ O_2 \leftrightarrow NO_2^- + 2H^+ + H_2O$ eq (2)

$NO_2^- + 0,5\ O_2 \leftrightarrow NO_3^-$ eq (3)

NO_2^- is not stable and will readily convert to NO_3^-, implying that nitrate is much more common than nitrite in nature.

As can be seen in eq (2) and (3) nitrification requires oxygen. If not enough oxygen is present nitrite can be the final compound. The reactions can go in both directions meaning that nitrate can be reduced to nitrite in oxygen poor waters. Nitrate is the nitrogen fraction most readily taken up by vegetation.

Under anaerobic conditions denitrification takes place. Denitrification is the process whereby nitrate and nitrite are reduced to nitrogen gas (eq (4)). If small amounts of oxygen exists nitrite and/or nitrious oxide (N_2O) can be the resulting products. As can be seen in eq (4) denitrification requires supply of organic matter.

$2NO_3^- + 2H^+ + \text{organic matter} \rightarrow N_2 + 2HCO_3^-$ eq (4)

The nitrogen gas produced by denitrification is released to the atmosphere and will eventually be brought back to the nitrogen cycle by nitrogen fixation. There are two different kinds of fixation; biological fixation and high energy fixation. Biological fixation (e.g. by cyanobacteria) brings back 100-200 kgN/ha/year to earth. High energy fixation only contribute with 8,9 kg/N/ha/year. Lightening, meteorite trails and cosmic radiation contribute the energy needed for high energy fixation. By high energy fixation nitrogen and water in the air are combined to form ammonium and nitrate. The two compounds are returned to earth via precipitation.

Volcanic activity, ammonia absorption from the atmosphere by plants and soil and windblown aerosols are other input to the nitrogen cycle. Output from the cycle is denitrification, volatilisation, leaching, erosion and windblown aerosols.[162] Sources and sinks of the most common nitrogen fractions are shown in Table 4.

Table 4 Sources and sinks of different nitrogen fractions

	Sources	**Sinks**
Ammonium	• Fertilisers • Livestock farming • Atmospheric deposition via precipitation* • Decomposition of organic material • Sewage	• Uptake by vegetation and microorganisms (immobilisation) • Oxidation to nitrite by nitrosomonas bacteria[163] • Volatilisation
Nitrate	• Agriculture • Atmospheric deposition via precipitation • Sewage	• Uptake by vegetation and microorganisms • Denitrification by pseudomonas bacteria[164] • Volatilisation
Nitrite	• Incomplete nitrification • Decomposition of organic matter in oxygen low waters • Sewage	• Oxidation to nitrate by nitrobacter bacteria • Denitrification

[162] Smith et al. 2000
[163] Ibid
[164] Ibid

Organic nitrogen	• Vegetation • Fauna • Sewage	• Decomposition by bacteria (mineralisation) • Sedimentation
Nitrogen gas	• Assimilation by nitrogen fixing bacteria	• Release to the atmosphere

*The nitrogen in the precipitation comes from burning of forests, burning of fossil fuels (eg cars and industries) and from high energy fixation.

Beside the nitrogen fractions in the table, Kjeldahl nitrogen and total nitrogen (N-tot) are fractions commonly encountered. Kjeldahl nitrogen is the sum of ammonium and organic nitrogen. Total nitrogen is the sum of all fractions.[165]

Nitrate is stable in a wide range of environmental conditions. This, together with its high solubility makes it the most common form of dissolved nitrogen. Due to the high solubility nitrate is readily transported to rivers during storm events. Nitrate transport to rivers increase with increasing runoff.[166]

High levels of NO_3^- rise concerns for human health. Strictly speaking it is not the nitrate that impose a health risk, but nitrite. If nitrate is reduced to nitrite a state called methaemoglobinaemia (or baby blue) can arise. This complaint is especially common in babies since they consume much water in relation to their body weight. The immature digestive system of babies is also more likely to allow reduction of nitrate to nitrite.[167]

5.1.6 P-cycle

Phosphorus is an integral part of the energy transfer mechanism and the nuclear material in living organisms.[168]

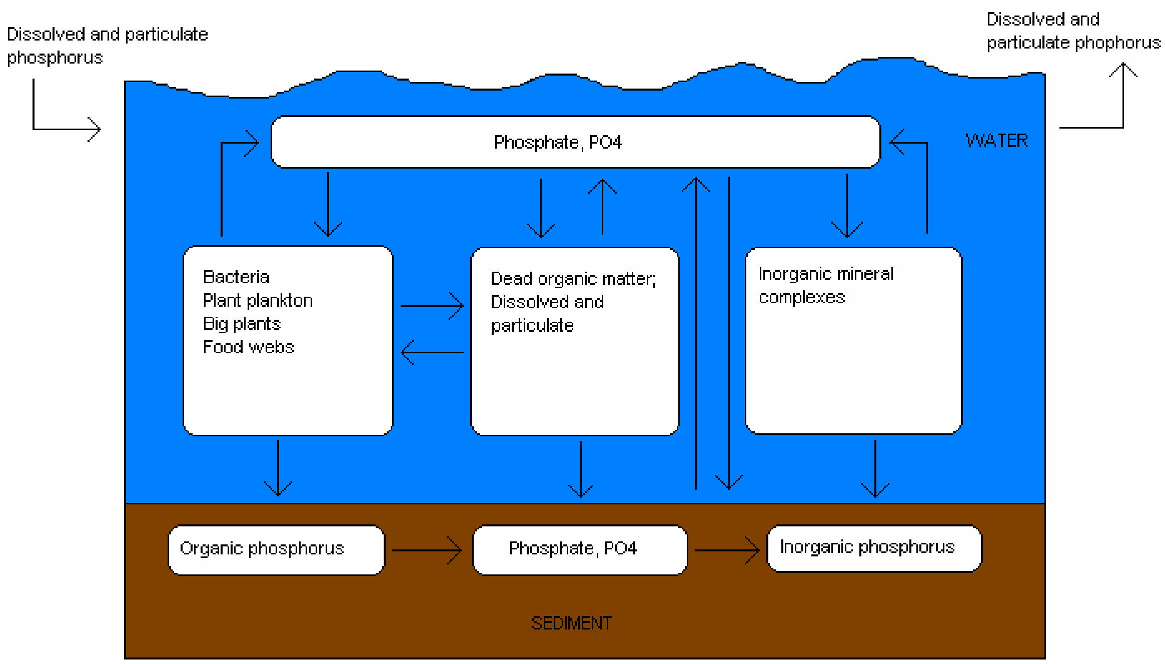

Figure 7 The phosphorus cycle. [169]

[165] Bydén et al. 1996
[166] Fytianos et al. 2002
[167] Lenntech Water treatment & Air Purification Holding B.V 1998
[168] Smith et al. 2000
[169] Freely translated from Tonderski et al. 2002

Contrary to the nitrogen cycle, which is a gaseous biogeochemical cycle, phosphorus has no gaseous state. The phosphorus cycle (Figure 5) can therefore be said to be a sedimentary biogeochemical cycle.[170] Sources and sinks of phosphorus in rivers are shown in Table 5 below.

Table 5 Sources and sinks of phosphorus in rivers

Sources	Sinks
Septic tanks	Settling of suspended matter
Fertilisers	Uptake by vegetation
Livestock farming	Biological transformation
Discharge of sewage	Sorption to clays
Detergents, laundring and other cleaning operations	Coprecipitation
Aquaculture (fishfarms)	
Manure	
Re-suspension of sediments	
Bedrock and soil	
Decomposition and leakage from organic material	

Since phosphorus compounds are very reactive and easily form complexes with minerals, phosphorus often becomes the limiting factor in fresh water systems. Formation of the not easily dissolved aluminiumphosphate in acid waters is just one example of complex formation. Strong interactions with sediments, various precipitation/dissolution reactions and re-suspension by bioturbation are factors influencing phosphorus concentration and the relative importance of different phosphorus fractions.[171] Re-suspension can contribute with more than half of the phosphorus to a stream.[172] Phosphorus bound to minerals and imbedded in sediment can dissolve into the water column again if certain conditions arise. During anaerobic conditions phosphorus bound to for example manganese and iron complexes can dissolve. At low pH phosphorus bound to carbonate complex will dissolve. A high raise of pH results in phosphorus releases from iron-, manganese-, aluminium- and clay complexes.[173]

Phosphate in fertilisers can react with calcium, iron and aluminum in soil and precipitate as insoluble salts, thereby reducing phosphorus transportation to rivers.[174]

Phosphorus in rivers come in the form of dissolved inorganic phosphorus (PO_4-P), dissolved organic phosphorus and particulate phosphorus. [175] PO_4-P is only moderately soluble and is therefore not very mobile in soils and groundwater. However it is readily attached to soil particles. In agricultural areas (and areas with much surface runoff and high potential of bank erosion) particulate phosphorus is thus the most common phosphorus fraction in rivers.[176] PO_4-P in aerated water consists of orthophosphates ($H_2PO_4^-$, HPO_4^{2-} and PO_4^{3-}) and is the only fraction of phosphorus that can be used by plants. The ratio between PO_4-P and total phosphorus varies with season, type of watershed and environmental factors. A ratio of 1:3 or higher is common.[177] The importance of different sources of P can also change with time. For example can P from agricultural runoff contribute with higher loads during rainy seasons than P from sewage systems. During dry periods the sewage system contributes with the higher load.[178] Rainwater in itself is usually low in phosphorus, but can in urban areas show a slight increase.[179]

170 Freely translated from Tonderski et al. 2002
171 House et al. 1998
172 Litke 1999
173 Tonderski et al. 2002
174 Smith et al. 2000
175 Tonderski et al. 2002
176 U.S. Geological Survey 2001
177 Bydén et al. 1996
178 Fytianos et al. 2002
179 Litke 1999

Rivers flowing through a lake/reservoir often have lower concentrations of phosphorus in the downstream reaches than in the upstream reaches. Bydén, Larsson and Olsson (1996) estimate that a lake with a retention time of one year will reduce the phosphorus load with 30-50%. A longer retention time can reduce 70-80% of the load.[180]

5.2 Eutrophication

5.2.1 Eutrophication in freshwater

Eutrophication is the process whereby waterbodies receive excess nutrients leading to excessive plant growth.[181]

Symptoms of eutrophic waters are, amongst others, anaerobic bottom water, proliferation of aquatic plants, algal blooms (can be seen as surface scum) and increased populations of bottom-dwelling fish. Freshwater can be classified according to their nutrient content. Besides eutrophic, waters can be oligotrophic, mesotrophic or hypertrophic. Oligotrophic waters are nutrient poor, clear, pristine waters with minimal plant life. Mesotropich waters have conditions in between eutrophic and oligotrophic conditions. Hypertrophic waters are extremely nutrient-rich waters overrun by aquatic plants and algae.[182]

The characteristics of eutrophic lakes are the same in temperate and tropical regions, even though primary production and photosynthesis is twice as high in the tropics, due to the more favourable climate.[183] Anaerobic bottom water in tropical lakes therefore does not have to be a sign of eutrophication, but can rather be a sign of a naturally high productivity rate.[184]

Much research has been done in the field of eutrophication in temperate regions. Eutrophication in tropical regions is less studied. It seems though as if tropical regions can tolerate higher concentrations of phosphorus for the same amount of algal biomass. A total phosphorus concentration of 50-60 µgP/l has been suggested as the boundary between mesotrophic and eutrophic conditions for tropical African lakes.[185] The corresponding limit in Sweden is 25 µgP/l.[186]

It has been stated that the term eutrophication does not properly apply to flowing waters. Rivers high in nutrients can, however, suffer from accelerated plant growth. An enrichment of phosphorus of as little as 0,01 mgP/l can stimulate abundant algal growth in pristine rivers.[187] Whether this situation can be labelled eutrophication or not, it is a growing, global phenomenon.

Slow flowing rivers (e.g. rivers with extended low flow periods) have characteristics quite similar to lakes and are thus particularly vulnerable to eutrophication.[188]

The U.S EPA characterise eutrophic rivers as rivers with “abnormally luxuriant growth of water weed and filamentous algae”.[189] The term “nutrient impaired rivers” are sometimes used instead of eutrophication. Nutrient impaired rivers are evaluated on the basis whether the river can fully support its designated or historical beneficial use. Hence, if the designated use is not affected, excessive growth of algae does not have to imply nutrient impairment.[190]

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[180] Bydén et al. 1996
[181] U.S. Geological Survey 2005
[182] Litke 1999
[183] Sundström 1992
[184] Ibid
[185] Hirji et al. 2002
[186] Bydén et al. 1996
[187] Litke 1999
[188] Chorus 1999
[189] Clabby 2002
[190] Litke 1999

5.2.2 Limiting factor

In all living material the ratio between carbon (C), nitrogen (N) and phosphorus (P) is 106:16:1 by atoms. This is called the Redfield ratio.[191] For every phosphorus atom used by an organism, 16 atoms of nitrogen are required. The same relationship by weight is 7g nitrogen to 1g phosphorus. By measuring nitrogen and phosphorus concentrations in rivers it is thus possible to get an indication of which nutrient is growth limiting. Apart from the generally accepted 7:1 ratio, the ratios 5-10N:1P and 5-12N:1P can also been found in literature. When the mass weight of N is 5-12 times higher than that of P, the limiting factor can therefore be said to be either nitrogen or phosphorus or both.[192] In tropical systems the N:P ratio is often lower than in temperate systems. This favours nitrogen fixating bacteria, since they can utilise nitrogen in the form of nitrogen gas.[193]

In fresh water systems phosphorus is normally the growth limiting factor. Addition of more phosphorus, either as a result of human activities or by natural causes, therefore means that growth of aquatic plants prospers. Chlorophyll is often used as a measure of biomass, even though the concentration of chlorophyll varies between species and also during the lifecycle of the species.[194] If phosphorus is the growth limiting factor the regression coefficient between total phosphorus and chlorophyll will be high.[195] Studies, for example by Dodds and Welch, oppose the thesis that P is the limiting substance in streams.[196] In the Dodds and Welch study, 158 nutrient bioassays performed by different research teams were investigated. The result showed that of the assays, 13% showed stimulation by N alone, 18% by P alone, 44% by simultaneous N and P additions, and 25% by neither nutrient. The conclusion drawn was that both N and P can be limiting factors in rivers.[197] It is thus reasonable to set criteria for both total phosphorus (P-tot) and total nitrogen (N-tot) in measures to control eutrophication. Setting criteria for both P-tot and N-tot is also supported by the fact that algal cells can store excess phosphorus, so called luxury consumption, during periods when phosphorus concentration is high (for example in first flushes). The stored phosphorus can then be used when phosphorus is the limiting factor in the water.[198]

5.2.3 Eutrophication in developing countries

The industrialisation in the developed countries created the eutrophication problems we suffer today. Eutrophication became a big issue in the developed part of the world during the 1950's and 1960's, when algal blooms and fish kills were experienced in many urban and agricultural rivers. Measures taken have, however, reduced the problems and studies indicate that eutrophication in the developed world will become less of a problem in the future.[199] In developing countries on the other hand, eutrophication is expected to be of major concern the coming 25 years.[200] Studies of rivers and lakes in Southern Africa already show increasing eutrophication.[201] Population increase, urbanisation and industrialisation are factors contributing to increasing eutrophication. Lessons learned from the environmental problems that arose during the industrialisation in the developed countries can hopefully mitigate similar problems in developing countries. Priorities other than environmental conservation might however lead to increasing eutrophication in this part of the world. Increasing research in the field of eutrophication in tropical areas is though promising.[202]

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[191] Brönmark et al. 1998
[192] Sundström 1992
[193] Kitaka et al. 2002
[194] Department of Water Affairs and Forestry 1996b
[195] Kwang-Guk et al. 2003
[196] Dodds et al. 2000
[197] Ibid
[198] Ibid
[199] Brönmark et al. 2002
[200] Ibid
[201] Kitaka et al. 2002
[202] Brönmark et al. 2002

5.2.4 *Effects of river eutrophication*

Excessive growth of algae in lakes can cause taste-and-odor problems due to decomposition of organic material. In rivers, no link between these problems and trophic state has been found.[203] Eutrophication in rivers can, however, cause:

- clogging of filters and water intake pipes (e.g. for drinking water treatment, livestock watering, irrigation and hydropower schemes)
- fish kills (due to oxygen depletion)
- destruction of sensible habitats and change of biota
- impediment of navigation and fishing activities
- water loss due to excessive transpiration by plants and increased evaporation from rivers slowed down by macrophytes
- creation of habitats for disease vectors such as the malaria mosquito
- lowering of recreational values (angling, watersports etc)

Waters with high contents of biological material also tend to form carcinogenic by-products (trihalomethanes) when chlorinated to meet drinking water standards.[204] Further eutrophic rivers can cause eutrophication in estuaries. Property values both in estuarine and riverine areas can decrease as a result of repulsive eutrophic environment. However, oxygen deficit and high pH are perhaps the most severe algal-related problems affecting river water quality.[205] High pH is a result of uptake of dissolved CO_2 by plants in the surface water. The carbonic acid system is thereby shifting towards increasing concentration of CO_2 to counteract the uptake. By this shift hydrogen ions are used and pH rises.

In eutrophic lakes, growth of toxic cyanobacteria constitutes a problem. This is usually not a problem in rivers unless the water velocity is very slow. Rivers high in nutrients flowing into lakes/reservoirs can though trigger blooms of cyanobacteria in the lake/reservoir. The ability of cyanobacteria to fixate nitrogen makes it a common species where nitrogen is in deficit. Due to lack of nitrogen fixing cyanobacteria in rivers, growth can sometime be limited by nitrogen. Since a reduction of nitrogen input from rivers to lakes can cause cyanobacteria to take dominion over the lake and the slow flowing parts of the river, measures to prevent eutrophication by reducing nitrogen instead of phosphorus (or a combination of the both) in these rivers should be taken with precaution.[206] Cyanobacteria produce toxins, which can sometimes give similar symptoms as cholera.[207] The most globally widespread toxins produced by cyanobacteria are the liver damaging microcystins. Tropical climate assists in a shift from more harmless phytoplankton to cyanobacteria; in temperate regions cyanobacteria are common during summer months, but when turbulence and light intensity decreases during autumn/winter other phytoplankton takes over. In tropical region these mechanisms does not exists, thereby implying cyanobacteria to be present all year round.[208]

To sum up, the effects caused by eutrophication constitute an economical loss due to loss of for example crops, fishing and tourism. Other negative effects are health related issues, for example malaria and toxins from cyanobacteria.

5.2.5 *Classification systems and limits for eutrophication*

Eutrophication in lakes has been studied thoroughly and criteria and models have been developed to evaluate trophic states. Eutrophication in rivers is not as well understood. For the same increase in phosphorus, lakes usually accumulate more algal biomass than rivers due to more favourable conditions in lakes. I.e. the chlorophyll yield per unit nutrient is lower in rivers than in lakes. This is

[203] Dodds et al. 2002
[204] Litke 1999
[205] Dodds et al. 2000
[206] Ibid
[207] Personal communication, Serodio 2005
[208] Chorus 1999

substantiated by studies of different river reaches; stable, non-flooding (and thus more lake-like) reaches have higher chlorophyll yield than frequently flooding and unstable reaches.[209]

When discussing chlorophyll origin, the types benthic chlorophyll and phytoplanktonic chlorophyll are distinguished. Benthic algae are the type of algae that grow on substrates, whereas phytoplanktons are free-floating algae. Concentration of benthic algal chlorophyll are more variable in rivers than in lakes due to differences in turbidity, hydrodynamics (flooding etc), grazing, riparian shading and human impact (e.g. discharges of toxic compounds). Measures of the chlorophyll yield caused by a unit increase in nutrients hence differ much from river to river and from time to time. A unit increase in nutrient gives, for example, a higher chlorophyll response in a river with low turbidity than in a river with high turbidity, since light becomes a limiting factor in the turbid river. Benthic algae and macrophytes in shallow water are not affected by turbid water. All factors influencing the correlation between nutrients and chlorophyll (turbidity, grazing, shading etc) can theoretically be altered to mitigate eutrophication. However, since reducing nutrients is the easiest way to control eutrophication, this is the measure usually taken. Due to high variation in the occurrence of benthic algae and the low levels of planktonic algae in rivers, chlorophyll and nutrients are closer inter-related in lakes than in rivers. This since the water column nutrients usually are stronger correlated with phytoplankton than with benthic algae. Different models should thus be used for eutrophication in rivers and eutrophication in lakes. A generally accepted system for classifying eutrophication in rivers based on nutrients (such as the systems used for cassifying lakes) is presently lacking.[210]

One approach to classify trophic state in rivers is to set criteria based on chlorophyll level and not on nutrient level (since the same nutrient level can support very different levels of chlorophlyll). A problem with setting chlorophyll criteria is that the level of chlorophyll that can be regarded as acceptable is subjective. Different kinds of algae also have more or less desirable appearance at the same biomass, making the line drawing even more difficult. Different algae have different nutrient requirements and hence a shift in algae community will occur when the nutrient level changes. Presently too little data exists to relate the levels of nutrient to the type of algae. Criteria based on current data therefore need to be set based only on acceptable chlorophyll levels, regardless how amounts and ratios of nutrients will influence algal communities.[211]

One method proposed for drawing the line between different trophic states in rivers relies upon the cumulative frequency distributions of chlorophyll and nutrients. The lower 1/3 of the distribution is set as oligotrophic rivers, the upper 1/3 as eutrophic rivers and the middle 1/3 as mesotrophic rivers. The 286 rivers used for developing this classification system are situated only in temperate regions, implying that the study has to be extended to include rivers also in other areas to be useful in other types of climate.[212] Each type of river should furthermore be sampled in proportion to its relative occurrence.

Models relating *benthic* chlorophyll in rivers to total nitrogen and phosphorus have been developed, but as discussed earlier these models have a higher uncertainty than corresponding lake models. Models linking riverine *phytoplanktonic* chlorophyll to total phosphorus also exist. Once a phosphorus criterion is set using one of the models the corresponding nitrogen criteria can be calculated using the Redfield ratio.[213] A model by Van Niewenhuvsend Jones based on suspended chlorophyll in rivers shows that lakes are more vulnerable to high nutrient loads than rivers; a river with 8 µg chlorophyll/l (the dividing line between eutrophic and mesotrophic lakes according to OECD) would have a corresponding concentration of P-tot of ~48 µgP/l. The OECD's dividing line for P-tot for lakes is 35

[209] Dodds et al. 2000
[210] Ibid
[211] Ibid
[212] Ibid
[213] Ibid

µgP/l, i.e. for the same amount of chlorophyll (8 µg/l) rivers can withstand 1,4 times more phosphorus than lakes. [214]

As discussed above when using classification models based on chlorophyll related to N-tot and P-tot one should bear in mind that, due to influence of other parameters, the chlorophyll concentration can be lower/higher than expected. If specific data for the local area exists this should be used in the model instead of data from a larger scale. For example, the N-tot and P-tot values that yield a mean benthic chlorophyll concentration of 50 mg/m^2 can be lower for a local data set than for a global data set. Regions with the same settings can however be expected to give the same yields.[215]

A model trying to incorporate both hydrodynamic regime and nutrients to predict benthic chlorophyll has been proposed for New Zealand streams. Using such a model one might be able to set sliding nutrient criteria (i.e. rivers scouring regularly can be allowed to have higher nutrient levels than stable rivers).[216]

For benthic chlorophyll, 200 mg/m^2 has been suggested as a reasonable level for rivers.[217] Higher levels can disturb recreational values and diminish the aesthetical value. Studies have shown that a level of total nitrogen of 3 mgN/l or less should be maintained to keep within this criterion. The corresponding value for total phosphorus is 0,4 mgP/l.[218] Cumulative frequency distributions of nutrients in American rivers gives a limit for rivers impaired by nutrient enrichment of 0,9 mgN/l and 0,4 mgP/l if half of the rivers are said to be affected by eutrophication.[219] Rivers in pristine areas and/or with vulnerable areas downstream should have limits more stringent.

Since macrophytes can assimilate nutrients from both the sediment and the water column it is hard to set water column nutrient criteria for rivers dominated by macrophytes.

Despite the problems with establishing nutrient criteria for eutrophication in rivers the U.S EPA has set guidelines for riverine phosphorus. Rivers draining to natural lakes should have concentrations of total phosphorus below 0,05 mgP/l. Rivers not flowing into lakes should not exceed 0,1 mgP/l. [220] 0,1 mgP/l is also the recommended limit for rivers affected by urbanisation and agriculture. [221] If using these limits for tropical climate one should keep in mind, as discussed earlier, that tropical waters seem to tolerate higher nutrient levels. For phosphate a lower limit of 0,5 mgPO_4^{3-}/l is considered to minimize the risk for eutrophication according to a Greek study.[222] Regarding nitrogen limits, the South African Water Quality Guidelines (SAWQG) states that a concentration of inorganic nitrogen below 0,5 mgN/l should be enough to limit eutrophication in fresh water (i.e. not specific for rivers), unless phosphorus is present in excess and nitrogen fixing bacteria are established.[223] For inorganic phosphorus SAWQG states that 5 µgP/l is a low enough concentration to limit eutrophication.[224]

Different limits for eutrophication in rivers are shown in Table 6.

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[214] Dodds et al. 2000
[215] Ibid
[216] Ibid
[217] Ibid
[218] Ibid
[219] Ibid
[220] U.S. Geological Survey 1998
[221] U.S. Geological Survey 2001
[222] Fytianos et al. 2002
[223] Department of Water Affairs and Forestry 1996a
[224] Ibid

Table 6 Eutrophication limits for rivers.

Phosphorus	
Tot P (rivers draining to lakes- U.S EPA)	0,05 mgP/l
(rivers not draining to lakes –U.S EPA)	0,1 mgP/l
Phosphate (greek study, see text above)	0,5 $mgPO_4^{3-}$/l=0,16 mgP/l
Inorg P (SAWQG)*	0,005 mgP/l
Nitrogen	
Inorg N (SAWQG)*	0,5 mgN/l

* All fresh waters, including lakes

As can be seen in Table 6 nutrient limits for eutrophication in rivers vary significantly depending on the establishing authority and the region. As written before, no generally accepted model for eutrophication in rivers yet exist.

Monitoring risks of eutrophication includes measuring parameters such as phosphorus, nitrogen, secchi depth, dissolved oxygen and benthic and phytoplanktonic chlorophyll.[225]

5.2.6 Salvinia Molesta

Salvinia Molesta (Figure 8) is an alien specie presently causing problems in the lower reaches of the Mbuluzi River. *S. Molesta* (also called Kariba Weed) is a free floating fern originating from South America. The plant was first found in Southern Africa in 1948 in the Zambezi River. The first encounter of *S. Molesta* in Mozambique was in the early 1950's in Lake Cahora Bassa. Today the plant is found at several places in Mozambique (e.g. in the Zambezi River, Incomati River, Mbuluzi River and near Maputo).[226] *Salvinia Molesta* often forms dense floating mats (up to 1m in thickness), in which other plants can grow. The specie is considered an aquatic invasive alien specie and is regarded a big problem due to its very high growth rate and relatively slow decomposition rate.[227] Under favorable conditions the biomass can double in two to three days.[228] The specie reproduces asexually, meaning that it reproduces by fragmentation. Though the plant is well adapted to low nutrient conditions, it thrives in waters with high nitrogen concentrations.[229] Small increases of nutrients greatly increase growth rates of floating aquatic weeds.[230]

[225] Kwang-Guk et al. 2003
[226] Hirji et al. 2002
[227] Julien et al. 2002
[228] Ibid
[229] Couto 2005
[230] Howard et al. 1998

Figure 8 Photo of *Salvinia Molesta* taken in Boane in September 2005.

Photo by A. Gustafsson.

The mats caused by *Salvinia Molesta* impede fishing, navigation, recreation, clog water intakes and completely alter the oxygen, light, carbon dioxide, temperature and pH conditions for organisms living under the mat.[231] *S. Molesta* decreases the nutrient concentration in the water due to assimilation. Harvesting of the plants can thus reduce nutrients in the water column. Due to the risk of spreading, usage of *S. Molesta* for water purification is, however, not recommended by Southern African Regional Commission for the Conservation and Utilisation of Soil.[232] The SADC Aquatic Weeds and Water Quality committee also strongly discourage harvesting and utilisation of *S. Molesta* for other purposes than water purification, since the risk of re-infestation is considered too high.[233]

Temperature and nitrogen are the most important factors determining the growth rate of *Salvinia Molesta*. Temperature affects the rate of extension of existing branches, while nitrogen affects the branching.[234]

Control of *Salvina Molesta* has been successfully implemented in some parts of the world by introducing a host specific weevil called Cyrtobagous Salviniae.

5.3 Earlier water quality studies in the Mbuluzi River

Though water quality, due to the economical and political situation, has not been a prioritized issue in water resources management in the Mbuluzi River, some studies have been conducted. The most important results from these (from the perspective of this study) are summarized below.

Sundström and Mussagy as cited by Sundström (1992)

Sundström conducted a study in the Pequenos Libombos dam in March 1991 and found the following results:

- The average concentration of total nitrogen in the reservoir was of 0,74 mgN/l and the total phosphorus concentration was 0,098 mgP/l.
- Based on phosphorus the reservoir was classified as eutrophic.

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[231] Julien et al. 2002
[232] Hirji et al. 2002
[233] Ibid
[234] Room 1998

- The ratio between N and P was 9N:1P (mass), which indicates that it was not possible to determine weather N or P was the limiting factor at the time. The N to P ratio estimated by Mussagy and based on measurements from 1989-90 was 15N:1P. In this case P was concluded to be the limiting factor.
- Contradictory to the Sundström study, Mussagy found the reservoir oligotrophic regarding nutrients. However, based on chlorophyll-a, secchi depth and phytoplankton composition Mussagy found the reservoir eutrophic.
- Nitrate levels at ETA (the water treatment plant in Boane) were extremely high. This was explained by human activities downstream the Pequenos Libombos Dam. A remarkable decrease in nitrate in the dam since the 70's was also found. This was attributed to less grazing, agriculture and a population decrease due to the political situation.
- Comparing inflowing and downstream concentrations of nitrogen and phosphorus to concentration in the Reservoir, higher concentrations were found both upstream and downstream the Reservoir.
- The concentrations of nitrogen and phosphorus were consistently lower in Mussagy's study than in Sundström's study. However the samples from Sundström was analysed at two different laboratories, one in Sweden and one in Mozambique (INIA), giving considerably higher concentrations in Sweden. The Swedish values were used in the study.
- No signs of salinisation can be seen in the Reservoir since the time of construction.
- Inflowing water contained more suspended solids than the water in the Reservoir.

Chonguiça (1995)
Chonguiça concluded from other studies and some new measurements that:

- No stratification has yet been shown in the Pequenos Libombos Dam.
- Conductivity seems to increase with time in the Reservoir (in Sundström's study no signs of salinisation were however shown).
- Nutrient reduction is indicated to take place in the Reservoir.
- pH in the Pequenos Libombos Dam varies between 7,5 and 8,5.
- Concentration of dissolved solids (during the period 1984-1987) were 3,9 times higher downstream the sugar estates (GS32) than upstream the estates (GS3 sampling point 2 in this study).
- Dissolved solids at E10 (sampling point 6 in this study) and E395 (sampling point 7 in this study) were found at average concentrations of 272 mg/l and 283 mg/l respectively 1§(measurements performed by Chonguiça 1990-94).
- The Mbuluzi carries 2,5 times more suspended material than dissolved material.

Average data from Oliveira (1988) as stated in Chonguiça are shown in Table 7. Units are not presented in the report, but are assumed to be NTU for turbidity, µS/cm for conductivity and mg/l for the nutrients.

Table 7 Data from Oliveira measured 1988

	E10	**E8**
Temperature	24,5	24,3
pH	7,8	7,6
Turbidity	15,2	24,7
Conductivity	425	509
Nitrate	1,2	0,39
Nitrite	0,05	0,09

JTK (2003)

The JTK report considers the Swazi part of the Mbuluzi River basin. In general the water quality on the Swazi part of the Mbuluzi was found to be good. The results from the study include the following:

- Excessive soil erosion is evident in the Mbuluzi River basin. The highest value for Total Suspended Solids (TSS) was 4 352 mg/l.
- Water temperatures tend to increase downstream.
- pH was remarkably constant, both spatially and temporally.
- Benthic algae in the lower Mbuluzi River near Simunye was abundant during a site visit in March 2002, suggesting elevated levels of nutrients.
- A fourfold increase of nitrate was found downstream the sugar estates (0,5 mgNO_3^-/l at GS3 (sampling point 2 in this study) and 2.0 mgNO_3^-/l at Maphiveni).
- Available phosphorus data were exceedingly high, implying possible mix-ups with units and/or different phosphorus fractions. No significant difference in phosphorus concentrations upstream and downstream sugar estates were found.
- Bottom water released from the Mnjoli Dam might be anoxic.
- Turbidity and TSS are among the most significant water quality problems in the area. Median values ranged between 58 and 100 mg/l. The 75-precentile ranged between 82 and 204 mg/l. The highest value, 4 352 mg/l, was recorded at GS3 in May 1993. Concentrations of TSS were significantly higher during December to March than during other months. Values of TSS downstream of Mnjoli Dam were lower than upstream, reflecting sedimentation within the Reservoir.
- Salinity increased after the sugar estates. No increasing trends in time were however noticed at Maphiveni (a station where salinity has been measured for 20 years). The highest salinity measurements have been recorded during drought periods. At most sites salinity remained remarkably constant between seasons, although values were significantly more variable during rainy seasons than during dry seasons.

Mthimkhulu (2004)

A biological assessment according to the South African Scoring System was conducted in the Swazi part of the Mbuluzi by Mthimkhulu in 2004. The monitoring included, besides sampling of invertebrates, some physical and chemical parameters. Sampling was done at 14 locations, once in January, and once in March. The first sampling was done just after the first summer rains. The second sampling was done in the end of the rainy season. Following are some of the conclusions from the study:

- Mountain streams of the highveld of Swaziland have good water quality characterized by a consistent pH of 6,8, a conductivity below 5,0 µS/cm and a total dissolved solid concentration of 3,0 mg/l. The mountain streams had the highest diversity of macro invertebrates.
- The middleveld have relatively good water quality with pH ranging from 7,1 to 7,4, conductivity ranging between 8,8 µs/cm and 22,4 µs/cm and TDS below 15 mg/l. A wide diversity of invertebrates was found.
- Sites within the sugar cane fields in the lowveld of Swaziland showed a declining trend in water quality. pH ranged between 7,8 and 8,0, conductivity values rose to 538 µs/cm and TDS values were the highest found in the River, ranging from 60 mg/l to 344 mg/l. The declining water quality caused a reduced diversity of aquatic invertebrates.
- The Lubombo region located by the eastern border, just as the River flows into Mozambique, showed an improvement of the water quality. After flowing within the Mlawula nature reserve for 15 km, the water quality improves. Although still high, the conductivity values dropped to 200 µs/cm and the TDS fell below 130 mg/l. Diversity of invertebrate communities increased.
- Total dissolved solids were very low in the highveld increasing slightly in the middleveld and then rising considerably in the lowveld and the Lubombo. Total dissolved solids were lower during the second visit after experiencing several rainfall events.

- Turbidity values in the highveld ranged from 5 NTU to 9 NTU. In the middleveld, the site located a kilometer downstream of the Mnjoli Dam recorded the highest turbidity value (80 NTU). The river water was more turbid during the second sampling visit when it had been raining four days before sampling. The reason for high turbidity downstream Mnjoli Dam is that the valves are located at the bottom of the Dam, implying that muddy bottom water is released.
- Nutrient analyses of water samples collected in the lowveld and the Lubombo region revealed that nitrogen concentration was below detectable levels. Total phosphorus was detected at very low quantities. Most of the sites recorded below 1 mgP/l. Total phosphorus concentrations in the Mbuluzi at Nokwane was found to be 0,42 mgP/l. At Siweni, just before the Mbuluzi enters Mozambique, the concentration of total phosphorus was 0,21 mgP/l.
- Overall, invertebrate communities and SASS scores indicate that natural water quality conditions exist in the highveld and middleveld of the Mbuluzi and some deterioration occurs in the lowveld but the conditions improve again once the River leaves the sugarcane fields. The same was supported by the physical analyses of the Mbuluzi River.
- Differences in land use activities were the main causes of the decline in water quality conditions along the course of the River.
- Nutrient enrichment in the lowveld caused slightly eutrophic conditions in the River.
- The water that finally leaves Swaziland for Mozambique is generally within acceptable international water quality standards.

Joint Umbeluzi River Basin Study, JURBS (2005)
The JURBS report compiles water quality data from many different stakeholders. The most important findings in the report are:

- Largely and seriously modified environmental status in the sugar area and in the area downstream the Pequenos Libombos Dam.
- Large seasonal variation in water quality.
- Growth of <u>benthic algae</u> due to excessive nutrients. Problems with *Salvinia Molesta* in the lower reaches of the River.
- Conductivity increases when the River passes the sugar fields. The SAWQG for irrigation water is exceeded on the Mozambique side. It is likely that salts are leached from the sugar area. No trends in time are found for conductivity.
- Nitrate values are higher downstream the sugar fields. Eutrophic conditions exist on the Mozambique side of the River.
- Phosphate is, contradictory to nitrate, not higher downstream the sugar area, implying that phosphate is not leaking from the fields under present fertilizing practices.
- The River is highly turbid, but Pequenos Libombos Dam works as a sediment trap.
- Water quality is generally good and keeps within the targets for domestic, agriculture and industrial use. The most notable problems are problems with benthic and floating algae.

Mhlanga (2005)
Mhlanga performed a study on how irrigation of the RSSC sugar fields affects water quality in the receiving waters. Sampling was done monthly from March 2003 to March 2005. Samples were taken in tributaries to the Mbuluzi as well as in the main River (at the location where the irrigation water is abstracted). The analyses showed that:

- Irrigation affects water quality.
- pH in the River (upstream the sugar estates) varies between 7 and 8 and is always lower in the main River than in the tributaries located in the fields.
- Conductivity is always lower in the main River than in the tributaries
- TDS and conductivity correspond well with each other.

6 Results

6.1 Stakeholder inventory

6.1.1 Study visits to the main actors along the River

During this field study, the major stakeholders along the River were visited. Information was collected regarding current management and fertilising methods, the stakeholders' opinions of the Mbuluzi water quality and the current and previous activities in the vicinity. Common for most stakeholders is that the main concern regards water *quantity* rather than water *quality*. Most stakeholders in Mozambique believe that the upstream sugar plantations in Swaziland have a negative impact on the water quality even though they in most cases do not have any facts supporting these theories. The parties visited were the Royal Swaziland Sugar Corporation in Swaziland as well as Bananalandia, Citrum, Libombos Macadamia and the water treatment plant in Boane. Additionally, some information has been gathered about small-scale farming in the region. All this information can be found in Appendix 5.

6.1.2 Current water quality monitoring programmes

In the following section, information is presented regarding the current water quality management/monitoring in the Mbuluzi River. The information has been gathered by study visits and interviews with the main participants. The results in this section include information about water sampling, preservation of samples, laboratory analysis and the handling of water quality data. The material has been gathered to form a basis for recommendations for future improvements of water quality monitoring in the Basin.

6.1.2.1 <u>Water Resources Branch (WRB)</u>

The information in this subsection derives from meetings with personnel from WRB. The main source of information for this section is Mthimkhulu.

The WRB of Swaziland is the governmental authority responsible for monitoring the water quality in the natural waters of the country. The monitoring programme includes over 40 sites of which ~15 are located in the Mbuluzi basin. The aim is to monitor the sites once per month. Water quality data is available from the mid-80's. Due to logistic problems associated with the standard of roads, the sites are not always accessible (problems occur particularly during rainy season), implying that the set of water quality data is not complete for all locations.

The WRB has a laboratory of their own, which in late 2005 was in the midst of being rebuilt and improved. Due to problems with the laboratory and its equipment, the amount of analysed parameters has decreased since the monitoring programme started. The laboratory is not accredited. Analysis methods used are based on national standard methods from the Swaziland Environmental Authority.

The parameters measured by the WRB at present are turbidity, pH, temperature, conductivity, alkalinity, hardness, chlorides and sulphates. pH and temperature are measured in field. The water sampled for analysis in the laboratory are taken in plastic bottles, transported in a coolbox with ice-packs and kept in a refrigerator over night. Analyses are made within 24 h of the sampling. According to the personnel at the WRB, the water quality data is thereafter stored in paper format (i.e. not in digital format). Data is presently not in good order but is in the process of being digitalised.

According to the WRB, the major threats to the water quality of the Mbuluzi River are high sediment loads (from the areas with easily eroded geologic material) and irrigated agriculture. From local, small-scale farming hardly any pollutants are considered to reach the River since the use of commercial fertilisers (and other products such as laundry detergents etc) is very limited due to the economical situation of the local people.

6.1.2.2 Swaziland Water Services Corporation (SWSC)

The information in this subsection derives from a study visit and a meeting with Fakudze on October 24th.

The SWSC is the company responsible for most water and wastewater treatment plants in Swaziland. The only measurements SWSC make on the Mbuluzi water is at the intake of the water treatment plant that supplies Mbabane with water from Hawane Dam. A 20 km long pipeline transports water from the Dam to the water plant. The water quality is measured as the water enters the treatment plant.

The company has treated water for domestic supply since 1994. The drinking water guidelines used by the SWSC are based on the WHO guidelines.

SWSC has the only accredited laboratory in the country. This means that they strictly follow standard methods. The water quality measuring tasks for the company is to measure incoming water for process parameters and effluent water from water and wastewater treatment plants. In addition to the main laboratory in Mbabane, there are smaller laboratories that on a daily basis measure the process parameters at all treatment facilities. High conductivities in the raw water are reported to be the most significant problem when treating river water in Swaziland.

For non-biological parameters, samples are taken in plastic bottles and stored in a coolbox with ice-packs until analysed. If analyses cannot be made during the same day, the samples are preserved according to standard methods.

The water quality data from SWSC is used for governmental reports every three months.

6.1.2.3 Royal Swaziland Sugar Corporation (RSSC)

The information in this subsection derives from study visits during October 20th and 21st. The main sources are Dr Ndlovu, White, Mnisi and his collegues at the agronomy department.

According to the Swazi water and environmental law, a company such as the RSSC is required only to monitor the water quality in effluent water (for example from sugar mills), whereas the WRB is responsible for monitoring river water. The monitoring programme of the RSSC comprises 26 sampling points in drainage streams and effluent water from mills etc. Most sampling locations are sampled once a month. The purpose of the monitoring programme is to optimize the sugar manufacturing process (from planting of canes to refined sugar) as well as to control the effluents entering the River. Although not required to, the company also monitors the river water quality at a few locations to evaluate their impacts. The water quality sampling has been continuously developed and the company has ambiguous plans and guidelines of how the water quality management is to be conducted. These plans include information on which parameters to analyse (different parameters in river water, ground water etc.), sampling frequencies, sampling methods, which laboratory to use, how data is to be stored/reported etc. To assure good quality of the obtained data, calibration samples should be sent to an external laboratory (SWSC in Mbabane or CSIR in Nelspruit, South Africa) twice a year. The company has also defined objectives for their water monitoring programme. The management plans further includes information about the division of responsibilities between the different departments of the RSSC. However, much of the methodology is still in the process of being implemented.

The focus of the monitoring is put on salts and COD. Parameters presently measured are pH, conductivity, TDS, sodium adsorption ratio (SAR), suspended solids (SS), sodium, calcium, magnesium, potassium and nitrite. Total phosphorus and phosphate have also been monitored occasionally.

The samples are taken by the RSSC agronomy department. Usually they make the analyses themselves, but sometimes samples are sent to the CSIR laboratory in South Africa for verifying analysing methods or to analyse parameters that cannot be reliably analysed in Swaziland. The RSSC laboratory is reported to be good at analysing salts.[235] Analysing costs as well as available equipment have determined which parameters to analyse. COD is considered to be one of the most important parameters to measure since this is the major effluent from the sugar mills and the effluents are controlled by the government. The other major impact from the RSSC is increased levels of salts in the river water, thus making salts (conductivity, sodium adsorption ratio etc) important parameters to mesure.

The collected samples are kept in coolboxes and brought to the laboratory the same day as they are collected. If samples are sent to another laboratory or if the analysis is not performed the same day, the samples are preserved according to standard methods. Samples are taken in glass bottles that have been rinsed three times in distilled water.

6.1.2.4 Administração Regional de Águas do Sul (ARA-Sul)

The information in the following section derives from several meetings with ARA-Sul personnel. The main source of information has been Mateus (several meetings at the Pequenos Libombos Dam) and Dias at the water department at ARA-Sul in Maputo (meeting October 27th).

ARA-Sul is the regional authority responsible for the management of the water resources in the southern part of the country. They have been monitoring water quality since 1998, as required by DNA. Before the de-centralisation of the water management in Mozambique, the water quality sampling was made by DNA themselves. After analysis, ARA-Sul digitilise the values and send the data to DNA.

The sampling programme of ARA-Sul includes ten regular sampling points of which four are located within the Mbuluzi River. Some variations have occurred, but the regular sampling schedule includes the sampling locations E10, PL629, E8 and the intake of Boane water treatment plant. Since 2001, the aim has been to sample every site four times per year (i.e every third month).

The measured parameters are more or less the same as in the monitoring programme that DNA had. They include nitrate, nitrite, ammonium, chloride, pH, hardness, conductivity, turbidity and dissolved oxygen. According to the water quality department at ARA-Sul, they wish to extend the monitoring programme to sample more ions (for example Na^+, Ca^{2+} and K^+) as high salinity is assumed to become a major problem for the expanding irrigated agriculture close to the Pequenos Libombos Dam. Financial matters limit the sampling frequency and the amount of analysed parameters.

Conductivity, pH and dissolved oxygen are measured in field with portable equipment that is not often calibrated. The samples are collected in plastic bottles, in the middle of the River (when possible), a few decimetres under the surface. Samples are stored in a coolbox with ice-packs (no conservation by addition of chemicals) and are brought to the laboratory within 48 hours.

Previously, the laboratory analyses have been performed by MISAU (the laboratory of the health ministry). However, the corporation had ceased and no sampling was made at the time of this field study. As this report is written, no information is available on the future monitoring of the Mbuluzi.

To improve water quality management, the water quality department at ARA-Sul strives towards exchanging data with AdM. Both authorities monitor water at the the intake of the water treatment plant, so by exchanging and comparing data and information improvements of monitoring and analysing procedures can be made.

[235] Personal communication, White 2005

6.1.2.5 Águas de Moçambique (AdM)

The information in this subsection derives from meetings with personnel from AdM. The main source for this section is Gracinda at the laboratory at AdM in Maputo (October 12th) and Gildo at the water treatment plant (October 10th).

Previously, the operator responsible for the water treatment plant in Boane and thus the water supply to Maputo was the governmental Águas de Maputo. In 2000 the company was privatised and is now called Águas de Mozambique. The company is responsible for seven different water treatment plants in different parts of the country.

The quality of the Mbuluzi River is frequently measured at the intake of the water treatment plant (in Portuguese, ETA – Estação de tratemento de Água). When the plant is running, the water quality is measured every 2-3 hours for process parameters to make the purifying process efficient and sufficient. The parameters measured on a daily basis are conductivity, organic matter and turbidity. Once a week several other parameters are measured by the main laboratory of AdM (in Maputo). These parameters include: temperature, turbidity, pH, total hardness, alkalinity, calcium, chloride, carbon dioxide, residual chlorine, organic material, ammonia, nitrite, nitrate, total phosphorus, phosphate etc.

Unfortunately, it is rare that all parameters in the monitoring programme are analysed due to equipment problems. The daily analyses are made at the laboratory at the treatment plant, whereas the weekly analyses (for the complete set of parameters) are made at the AdM laboratory in Maputo. The samples for the non-biologic parameters are taken in plastic bottles. The sampling bottles are cleaned with laboratory detergent, distilled water and then oven-dried at a low temperature. The central AdM in Maputo also measure the water quality at several locations within the pipe network.

The AdM laboratory in Maputo is better equipped than the laboratory at the water treatment plant and also makes analyses for other clients than the company. Neither laboratory is accredited. For reference, AdM in Maputo sometimes send their samples to an accredited laboratory in South Africa. The differences in result are reported to be small. The AdM laboratory follows a set of standard methods compiled by MISAU based on international standard methods.

6.1.2.6 Direcção Nacional de Águas (DNA)

Until 1998, DNA was responsible for the monitoring programme in the Mbuluzi River. Sampling was made on an irregular basis, particularly during the civil war. The analyses of the water samples collected by DNA were made by Águas de Maputo (the predecessor of AdM).

Now, DNA's responsibilities are no longer operational and ARA-Sul has taken over the responsibility for monitoring. DNA is amongst others responsible for national policies regarding water resources management. The results of the sampling from the different operators (such as ARA-Sul) are assembled by DNA and will in the future be stored in a national database including water quality measurements from natural waters in the entire country. DNA is also the authority that is responsible for international relations regarding water agreements etc.

6.1.2.7 Ministério de Saúde (MISAU)

The information in this subsection derive from meetings with personnel from MISAU. The main sources of information for this section are Sono (chief of laboratory) and Luís.

MISAU (the water laboraty of the Ministry of Health) is the laboratory that have analysed the water samples for ARA-Sul since they started their water quality monitoring programme in 1998. Presently, no analyses of the samples from ARA-Sul are made due to an economical controversy.

The main responsibility of MISAU is to analyse the treated water within the cities, but since about 75% of the population (according to their own figures) use untreated water for domestic purposes, they also have an interest in the water quality of the rivers. MISAU do not do any monitoring themselves in natural waters, but analyse water from clients. All results from these analyses are stored in a database. When looking in the database, the values for the Mbuluzi River are the ones deriving from the ARA-Sul sampling programme. The information from the database are used in reports on public health, epidemics etc. MISAU is the authority that has set up the domestic guidelines for drinking water. The guidelines are based on the corresponding values from WHO.

As all laboratories in Mozambique, the water laboratory at MISAU is not accredited. When asking the personnel, they state that all samples are analysed within a few days. However, experience show that this is not always the case. The laboratory strives to follow the international standard methods.

6.2 Analyses of water quality data

All measurements from this fieldstudy are enclosed in Appendix 7.

6.2.1 General parameters – measured during this field study

The results in this section derive from five sampling trips carried out in September and October 2005. When interpreting the information, it should be kept in mind that the results are a product of only a few measurements during a limited time. What also should be kept in mind is that the samples were taken just before the beginning of the rainy season. The rainfall during the five previous years had been less than normal, thus drought conditions prevailed and no major surface runoff had taken place for a long time. All graphs are presented together after the texts describing the parameters. To help the reader, a list of all sampling locations from source to mouth are provided in Appendix 6 together with a map of sampling sites for the monitoring programmes. For a map of the sampling sites in this study, see Figure 1, pviii.

6.2.1.1 Temperature

Figure 9a shows the average temperature values from the sampling trips whereas Figure 9b shows the measurements from each sampling occasion. Generally, the temperature increases as the altitude decreases as the river flows towards the ocean. Earlier studies show the same indication.[236] After both Dams (sampling sites 3 and 7), temperatures are lower than in the inflowing water.

6.2.1.2 pH

pH measurements ranged from a minimum of 7,7 (site 1) to a maximum of 8,7 (one occasion at site 1 and three occasions at site 7). As seen in Figure 10 the values are relative constant for all sampling points except for site 1. The pH tends to increase slightly with distance downstream as concluded in earlier studies by JTK and Mthimkhulu, both covering only the River stretch in Swaziland.

6.2.1.3 Salts (Conductivity and TDS)

Conductivity

The results from the conductivity samplings can be seen in Figure 11. Figure 11a shows the average values from the sampling trips whereas Figure 11b shows the measurements from each sampling occasion.

The conductivity increases continuously as the River flows. A particularly large increase takes place around sampling point 4 where the major irrigated agriculture (sugar cane) is located. Figure 11b shows increasing values for every sampling trip, especially in the lower reaches of the River.

TDS

Figure 12 shows the average TDS (total dissolved solids) values together with the average conductivity measurements. The general relationship between the parameters is 2:3 in natural freshwaters.

[236] JTK Associates 2003

6.2.1.4 Turbidity

The measured turbidity is displayed in Figure 13. Figure 13a shows the average values from the sampling trips whereas Figure 13b shows the measurements from each sampling occasion. The measurements show great coherence except for the two last sampling events at site 1 and site 2. On October 13th a rainfall event was observed in the westernmost part of the catchment, which is a possible cause of the high values after this occasion.

6.2.1.5 Flow

The river flow during the field work was obtained from different sources (see chapter 4.1) with different reliability. No flows were available from site 1 and 8. However, information was obtained from a gauging station between site 4 and site 5. This site is labeled "sampling location 4,5" in the figures below. The obtained flow values can be seen in Figure 14.

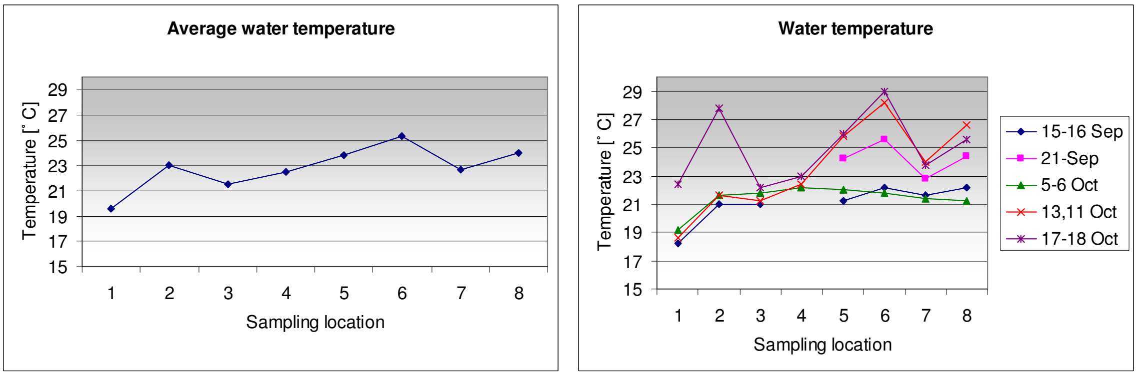


Figure 9 a,b Average water temperature (a) and temperature during individual sampling trips (b) in September-October 2005.

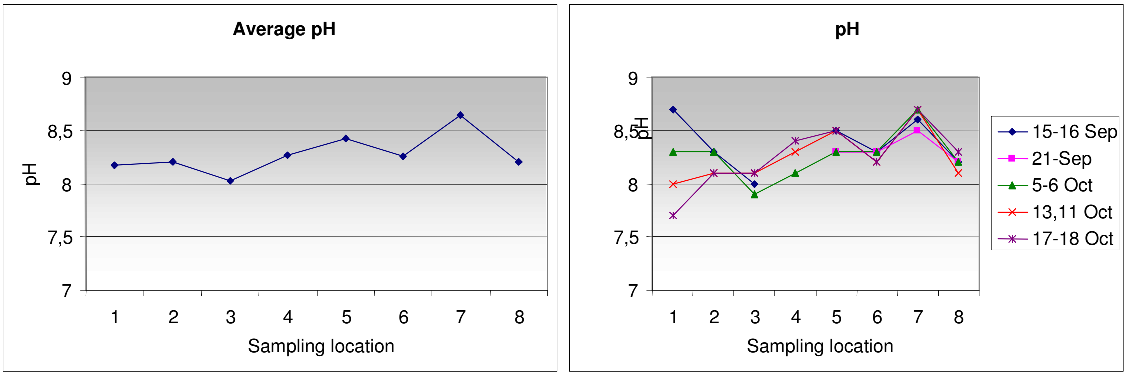


Figure 10 a,b Average pH (a) and pH during individual sampling trips (b) in September-October 2005.

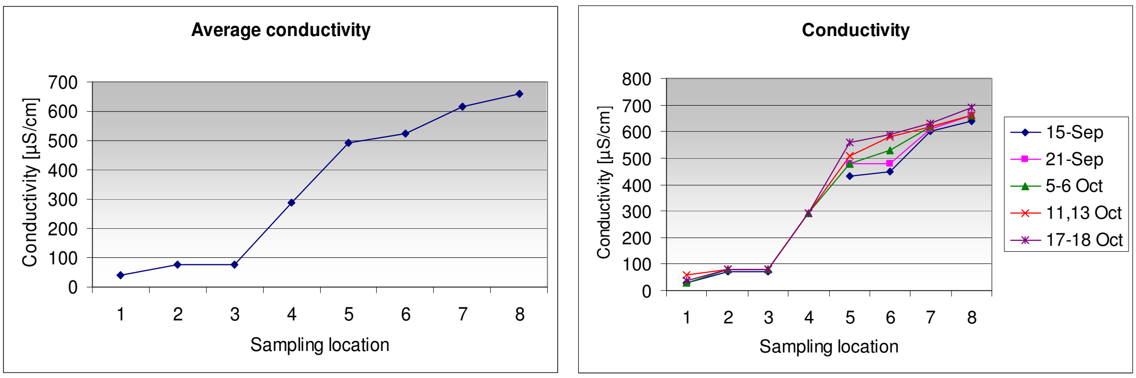


Figure 11 a,b Average conductivity (a) and conductivity during individual sampling trips (b) in September-October 2005.

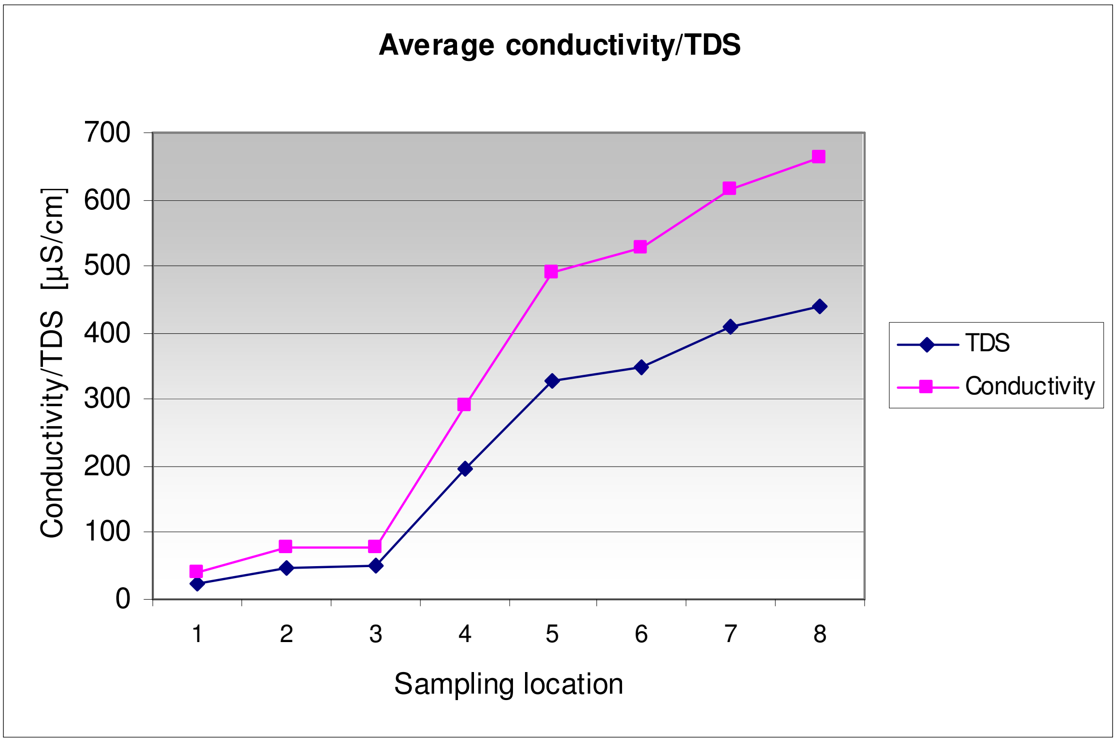
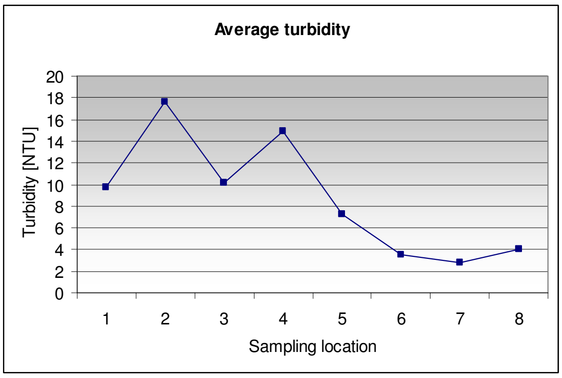


Figure 12 Average concentrations of conductivity and TDS in September and October 2005.



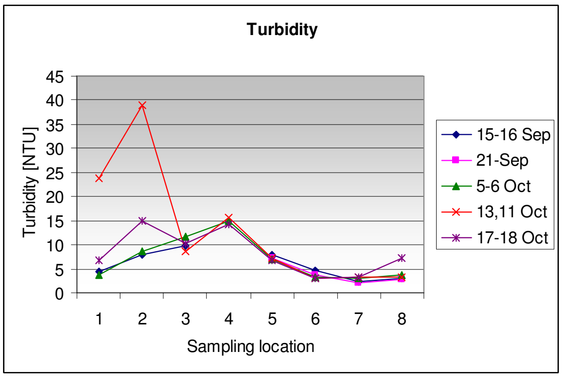
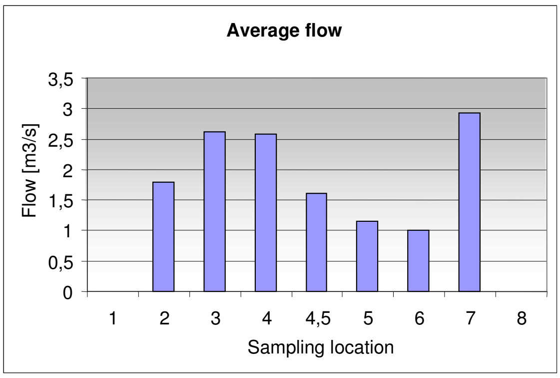


Figure 13 a,b Average turbidity (a) and turbidity during individual sampling trips (b) in September-October 2005.



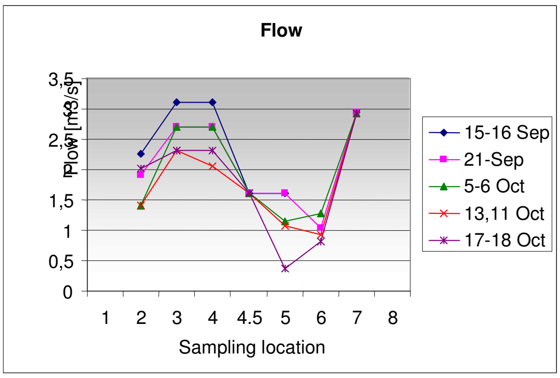


Figure 14 a,b Average flow (a) and flow during individual sampling trips (b) in September-October 2005.

6.2.2 Spatial trends of nutrients along the River

In the following section nutrient data from previous monitoring as well as data from this field study are used to investigate spatial trends along the River. The parameters investigated are phosphate, total phosphorus, nitrate, nitrite, ammonium and total nitrogen. The section is organised after parameter (first phosphorus fractions and then nitrogen fractions). Under each parameter, first old data and then data from this field study is evaluated. Old data have been gathered from different actors along the River and from different time periods. Due to poor coordination, some of the old data are from the same locations and periods. Gaps in the monitoring are frequent. Graphs for all phosphorus fractions can be found after the phosphorus related text; similarly, the graphs of the nitrogen fractions are placed after the nitrogen related text.

6.2.2.1 Phosphate

Phosphate data has been obtained from WRB, RSSC, DNA and AdM (see Table 8). To be able to calculate statistical parameters, all values below detection limits were set to half the detection limit. Unless otherwise stated, calculated statistics are based on data edited in this way.

Table 8 Information regarding phosphate measurements in the River

Sampling location	Responsible authority/ company	Laboratory	Period	No of observations	No of obs. under detection limit	Average- raw data $mgPO_4^{3-}$ /l	Average- edited data* $mgPO_4^{3-}$ /l	Standard deviation- edited data*
Hawane dam outflow	WRB	WRB's lab	Mar 87-Feb 91	18	0	1,76	1,76	0,96
GS3	WRB	WRB's lab	Aug 88-Jul 98	41	1	3,57	3,57	2,83
Mnjoli outflow	WRB	WRB's lab	Dec 86-Jun 94	38	4	3,01	3,01	3,34
Mbuluzi enters sugar area	RSSC	**Agronomy /CSIR	Jul 00-Sep 01	16	3	0,57	0,57	0,40
Nokwane	WRB	WRB's lab	Apr 87-Jun 94	35	2	3,57	3,58	2,65
Maphiveni	WRB	WRB's lab	Aug 85-Sep 98	59	1	3,36	3,36	2,88
Mbuluzi exits sugar area	RSSC	**Agronomy /CSIR	Jul 00-Sep 01	16	1	1,07	1,07	0,87
E8	DNA	Água de Maputo	Feb 84-Mar 84	2	2	0,15	0,15	0,07
E631	AdM	Águas de Mocambique	Aug 02-Aug 05	27	27	0,02	0,13	0,00

* All values under detection limit are set to half the limit.
** The Agronomy Dept. has been responsible for analyses since 2000. Before that, CSIR in South Africa analysed the samples.[237] Prior to 2003 mainly salts were analyzed at the Agronomy laboratory.[238] It is thus unclear if Agronomy dept. or CSIR has performed the phosphate analyses.

Figure 15 shows phosphate concentrations along the River (averages from Table 8). Only the stations sampled by WRB are shown.

Significance tests were used to see if significant differences could be found between nearby locations. The results are shown in Table 9, (if h=1 and/or the interval does not include 0, a significant difference is proved).

[237] Personal communication, Bheka 2005
[238] Personal communication, White 2005

Table 9 Statistical parameters comparing phosphate at different locations. H and p are calculated with ttest2. Data from WRB.

	H	p	Interval	
Hawane-GS3	*1	0,011	-0,402	0,511
GS3-Mnjoli outflow	0	0,420	-0,829	1,954
Mnjoli outflow-Nokwane	0	0,424	-1,972	0,831
Nokwane-Maphiveni	0	0,717	-0,946	1,381

*Contradicted by interval. Reasons for the discrepancy see discussion in chapter 4.5.2

The significance tests above are based on all measurements, regardless seasons. Ttest2 using data only from rainy seasons give similar results, i.e. no significant differences were found.

To check the influence of the sugar farming on the phosphate concentration in the River, data from RSSC can be used. Also data from WRB can be used for the same purpose but then averages of all WRB data upstream and downstream the sugar estates have to be calculated (see Table 10). This can be done using data from Hawane, GS3 and Mnjoli outflow as well as data from Nokwane and Maphiveni.

Table 10 Comparison of phosphate concentrations before and after the sugar plantations

Data source	Concentration before plantations (mgPO_4^{3-}/l)	Concentration after plantations (mgPO_4^{3-}/l)	Significant increase
WRB (1984-1998)	3,01	3,44	No
RSSC (2000-2001)	0,55	1,07	Yes

Figure 16 shows phosphate concentrations (as measured by RSSC) just before and after the sugar estates. As can be seen, the concentration is usually higher after the estates than before.

Significance tests for comparing rainy and dry seasons at the locations measured by WRB show that no significant differences could be found between rainy and dry season anywhere.

Due to limited budget and time frame, phosphate was only analyzed once for the Mozambiquean sites during this field study. No analyses were made of phosphate at the Swazi side of the River. Figure 17 shows the phosphate concentrations found in Mozambique (total phosphorus is included for comparison). Site 6 shows a higher concentration of phosphate-phosphorus than of total phosphorus, indicating problems during analysis (e.g. a particle might have been included in the phosphate sample, but not in the phosphorus sample (see chapter 4.6).

6.2.2.2 Total phosphorus

RSSC have measured P-tot at the two locations where the Mbuluzi enters and leaves the sugar growing area. Both locations were sampled the same days. The resulting averages are shown in Figure 18. During the dry season the average concentration when leaving the estates is lower than when entering, whilst the opposite relationship prevails during the rainy season. Though indications show lower concentrations both in incoming and outgoing water during dry seasons, it is not statistically proved. Neither is it statistically proved that the concentration decrease during dry seasons nor that it increases during rainy seasons.

Except for the data from RSSC, very few data is available for total phosphorus. A few values are however available from the studies by Mthimkhulu (2004) and Sundström (1991).

During this field study total phosphorus was measured at all sampling locations 3 or 4 times (see Table 1). The average concentrations are shown in Figure 19a, whereas Figure 19b shows the individual measurements from the different sampling trips.

Even though no statistically proved variations between sampling locations can be found (using the command signrank in Matlab), indications show that the phosphorus concentration increases from the site within the sugar estates to the site in Goba (i.e from site 4 to 5). Further, the concentration decreases from Goba (site 5) to the location before the Pequenos Libombos Dam (site 6) and then increases again to the sampling point just after the Dam (site 7). Contrary to the decrease in phosphorus found as the River flows through the sugar area during dry seasons using old data (Figure 18), this field study showed an increase of phosphorus between location 3 and 5 (i.e. before and after the sugar estates).

As shown in Figure 19b, phosphorus values vary considerably between the different sampling trips. To determine the concentration at site 5 (considered as one of the most interesting locations since it represents the water quality in the River when it enters Mozambique) and also to see the reliability of the analysis method, four analyses were made of the sample taken from site 5 on October 18th. The average concentration was 0,069 mgP/l (using edited data), but the results varied considerably (see Table 2 chapter 4.6).

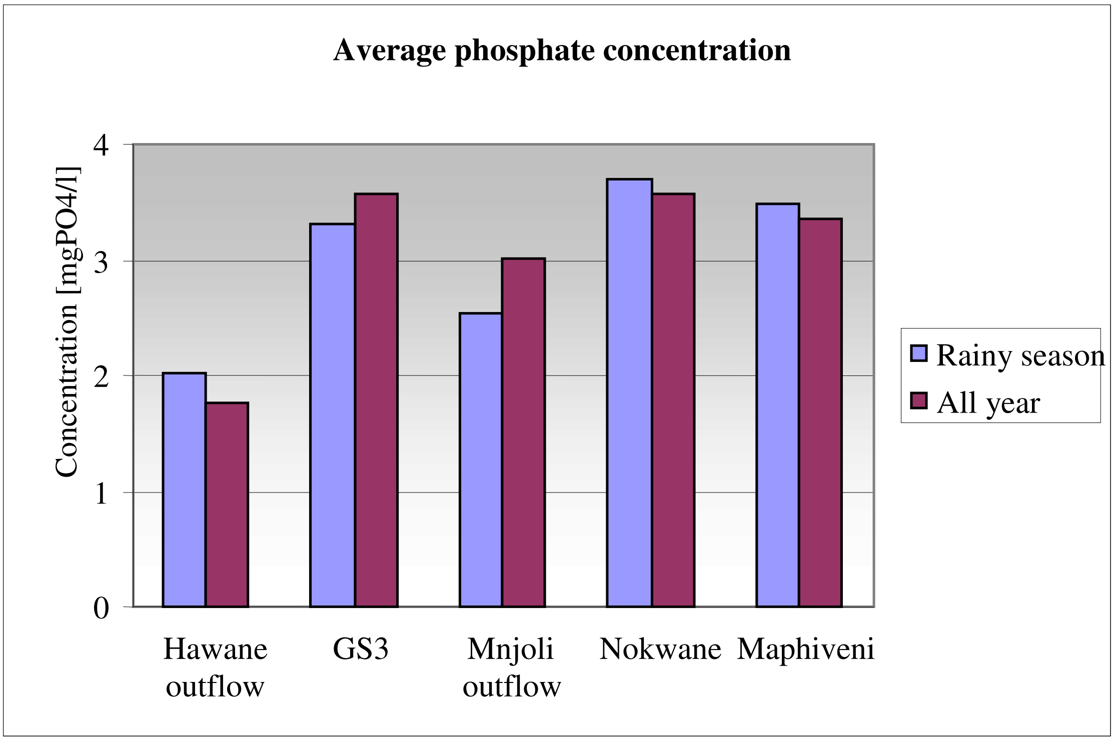


Figure 15 Phosphate concentrations measured by WRB.

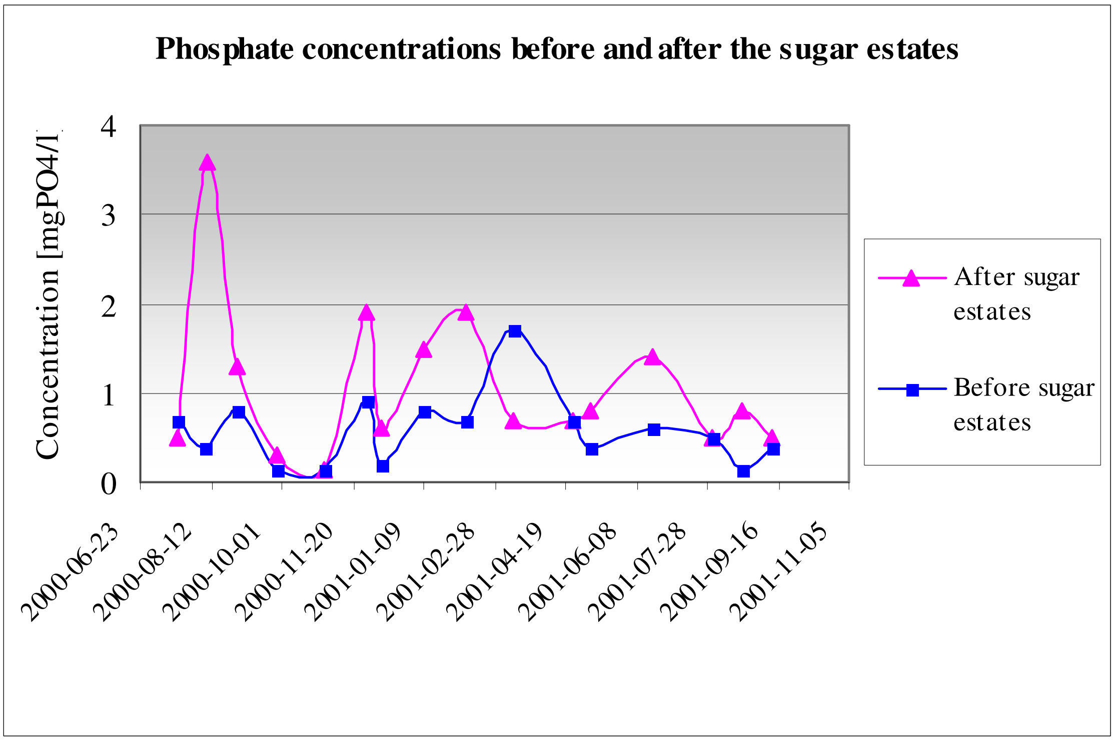


Figure 16 Phosphate concentrations measured by RSSC before and after the River flows through the sugar estates.

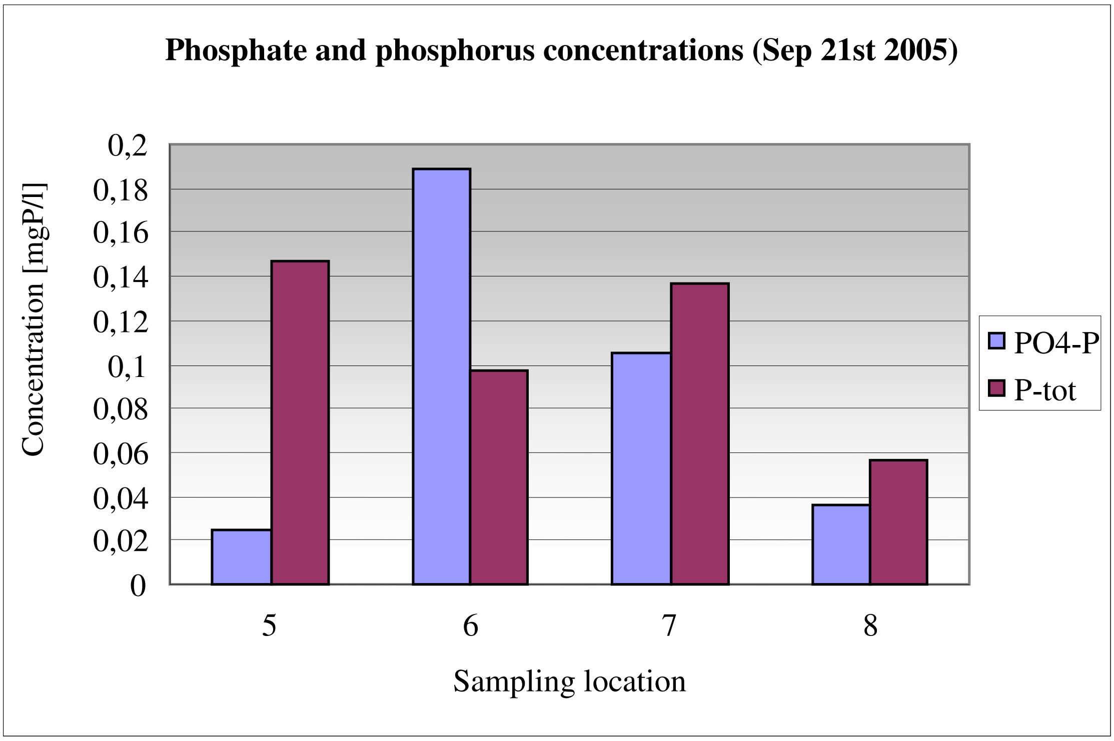


Figure 17 Phosphate concentrations measured during this field study. Total phosphorus is included for comparison.

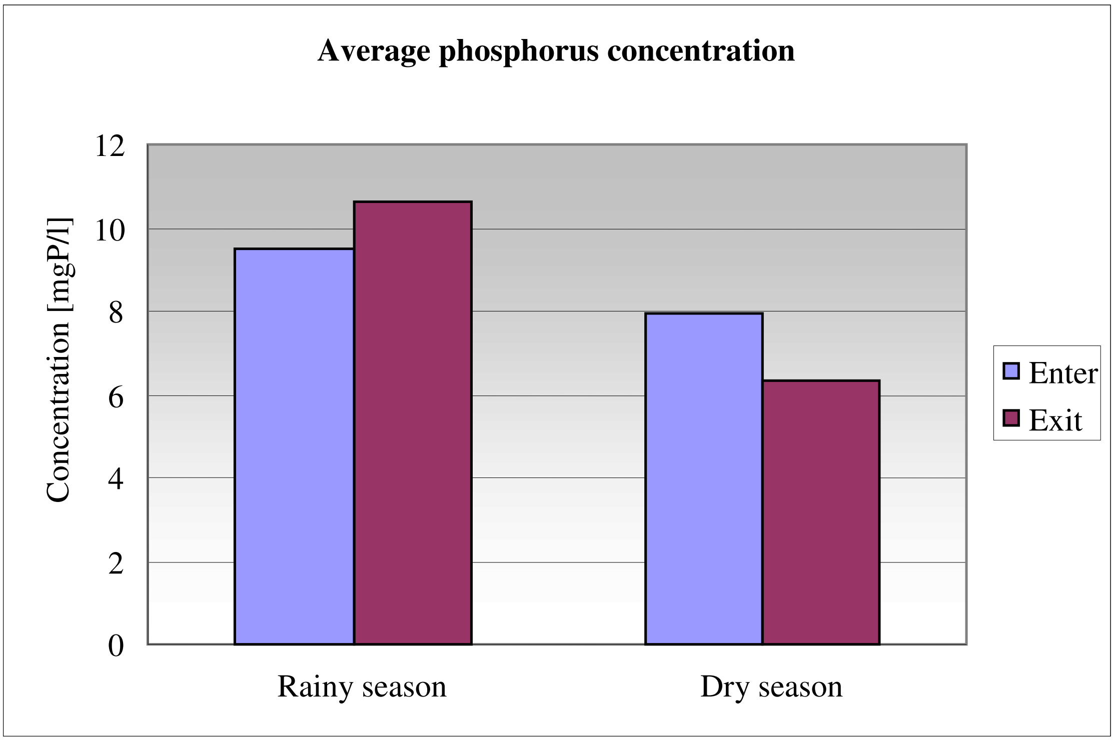


Figure 18 Phosphorus concentration measured by RSSC before and after the River flows through the sugar estates.

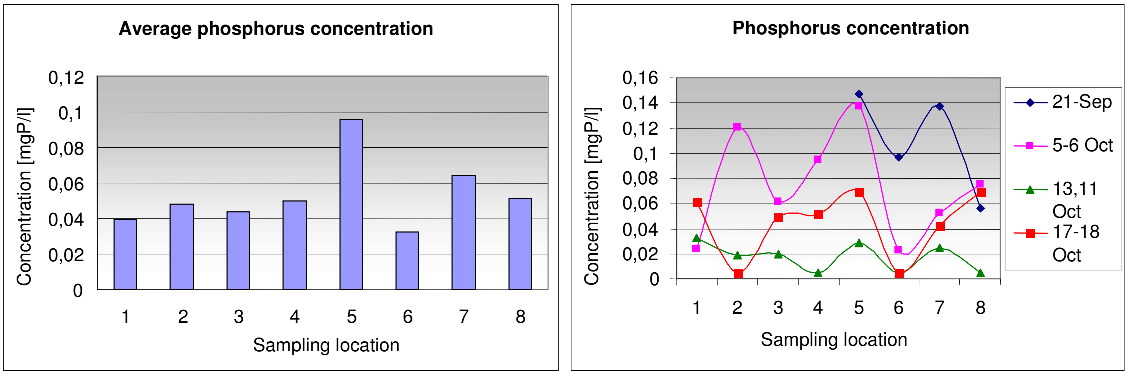


Figure 19 a,b Average concentrations of total phosphorus (a) and total phosphorus during individual sampling trips (b) in September-October 2005.

6.2.2.3 <u>Nitrate</u>

Table 11 Measurements of different nitrogen fractions

Location	Responsible instance	Laboratory	NO_3^-				NO_2^-				NH_4^+			
			Period	**No of obs (no obs. under limit)**	**Average mg NO_3^-/l**	**Std**	**Period**	**No of obs (no obs. under limit)**	**Average mgNO_2^-/l**	**Std**	**Period**	**No of obs (no obs. under limit)**	**Average mg NH_4^+/l**	**Std**
Hawane	WRB	WRB's laboratory	Mar87-Jul91	17 (8)	1,03	1,46					Mar87-Feb91	19 (11)	0,14	0,18
GS3	WRB	WRB's laboratory	Feb91-Nov95	11 (1)	0,67	0,59					Jan89-Jun93	13 (1)	0,30	0,44
Mnjoli outflow	WRB	WRB's laboratory	Oct86-May94	36 (21)	0,96	1,71					Jun87-Aug93	33 (19)	0,17	0,27
Mpumalanga	RSSC	Agronomy dept					Sep04-Apr05	2 (0)	0,080	0,042				
Simunye weir	RSSC	Agronomy dept					Mar03-Apr05	15 (0)	0,170	0,073				
Mhlume	RSSC	Agronomy dept					Feb03-Aug05	20 (0)	0,302	0,310				
Nokwane/ Tambankulu bridge	RSSC	Agronomy dept					Mar04-Sep05	18 (0)	0,143	0,109				
Nokwane	WRB	WRB's laboratory	Feb91-May94	13 (1)	2,03	1,55					Jun87-Aug93	25 (16)	0,21	0,35
Maphiveni	RSSC	Agronomy dept					Mar03-Sep05	22 (0)	0,139	0,111				
	WRB	WRB's laboratory	Feb86-Nov95	17 (0)	3,88	1,53					Feb86-Jun93	16 (0)	3,08	1,48
E10	Lifab		May69-May74	12 (4)	2,65	7,37								
	DNA	Água de Maputo	Jan67-Aug96	46 (23)	0,61	0,03	Jan67-Aug96	49 (36)	0,028	0,033	Jan67-Aug96	49 (24)	0,12	0,18
	ARA-Sul	MISAU	Nov97-Jul04	9 (0)	5,77	4,49	Nov97-Apr04	8 (6)	0,041	0,058	Nov97-Jul04	9 (1)	0,23	0,15
E632	ARA-Sul	MISAU	Nov00-Jul02	4 (0)	9,90	8,26	Nov00-Jul02	4 (2)	0,030	0,021	Nov00-Jul02	4 (1)	0,34	0,43
PL629	ARA-Sul	MISAU	Nov92-Jul04	16 (0)	4,90	3,29	Nov92-Apr04	15 (11)	0,026	0,024	Nov92-Jul04	16 (2)	0,31	0,56
E395	DNA	Água de Maputo	Jul72-Feb85	20 (4)	1,36	1,42	Jul72-Feb85	20 (18)	0,018	0,008	Jul72-Feb85	20 (17)	0,04	0,05
E8	Lifab		Sep77-Oct83	53 (32)	0,86	1,41	Sep77-Oct83	53 (33)	0,033	0,038	Sep77-Oct83	53 (20)	*0,53	2,77
	DNA	Água de Maputo	Sep81-Jul87	46 (29)	0,85	1,49	Sep81-Jul87	50 (32)	0,030	0,035	Sep81-Jul87	50 (21)	0,15	0,21
	ARA-Sul	MISAU	Nov97-Jul04	16 (0)	5,40	2,62	Nov97-Apr04	15 (12)	0,020	0,011	Nov97-Jul04	15 (2)	0,21	0,15
E631	AdM	Água de Mocambique	Jan01-Aug05	45 (11)	0,43	0,37	Jan01-Aug05	47 (37)	0,021	0,014	Jan01-Aug05	46 (5)	0,17	0,10
	ARA-Sul	MISAU	Jan03-Jul04	5 (0)	4,93	3,87	Jul01-Aug05	4 (4)	0,015	0	Jan03-Jul04	5 (2)	0,61	0,56

*mgN/l Std = standard deviation

As for phosphate and total phosphorus, data for nitrogen fractions were edited if under detection limits. Table 11 shows the different parties and laboratories involved in nitrogen monitoring.

Figure 21 shows average annual and average rainy season concentrations for nitrate as measured by WRB and ARA-Sul.

Since the nitrate values originate from several different sources and from very different time periods, it is difficult to compare the values. In this report the main focus is put on the nitrate data from WRB and ARA-Sul. Reasons for this being that these values are relatively new and that measurements have been made at several locations on each side of the border. The nitrate values from ARA-Sul (analysed by MISAU) are suspiciously high (see ch 7.2.3), implying that comparison between ARA-Sul data and other data should be done with precaution.

Results from significance test comparing nitrate concentration between nearby locations are shown in Table 12. The test used was ranksum (equivalent to ttest2, but used when only few measurements are available). As discussed in chapter 4.5.2, the intervals calculated for the nitrogen fractions are, due to the few numbers of measurements and hence the poor assumption of normal distribution, less reliable than the intervals for phosphorus fractions. Table 12 shows that significance was found between Mnjoli outflow and Nokwane and between Maphiveni and E10.

Table 12 Statistical parameters comparing nitrate at different locations. H and p are calculated with ranksum.

	H	p	Interval	
Hawane(WRB)-GS3(WRB)	0	0,582	-0,459	1,181
GS3(WRB)-Mnjoli outflow(WRB)	0	0,254	-0,965	0,387
Mnjoli outflow(WRB)-Nokwane(WRB)	1	0,002	-2,138	-0,017
Nokwane(WRB)-Maphiveni(WRB)	0	0,900	-1,051	1,273
Maphiveni(WRB)-E10 (ARA-Sul)	1	0,001	-7,273	-0,420
E10 (ARA-Sul)-E632 (ARA-Sul)	0	0,330	-15,370	7,115
E632 (ARA-Sul)-PL629 (ARA-Sul)	0	0,143	-6,359	16,362
PL629 (ARA-Sul)-E8 (ARA-Sul)	0	0,283	-2,648	1,643
E8 (ARA-Sul)-E631 (ARA-Sul)	0	0,483	-3,976	4,914

To evaluate the influence of the sugar estates on nitrate levels, the average of all WRB data from upstream the estates (Hawane, GS3 and Mnjoli outflow) was compared to the average of the WRB data from the downstream reaches (Nokwane and Maphiveni). The reason for not only comparing Mnjoli outflow and Maphiveni (the locations closest to the borders of the plantation), was to get more values and thus a more reliable result. The average nitrate concentration before the estates was 0,9266 $mgNO_3^-/l$ and the average after the estates was 1,9717 $mgNO_3^-/l$. The increase was significant ($p = 0,0022$).

Since only few measurements are available for nitrate, statistical tests based on data divided into seasons have not been made. Even though not statistically proved, the average nitrate concentrations during the rainy seasons generally tend to be higher than the averages for the entire year (see Figure 21 and Figure 22.

Figure 21 show an approach to investigate seasonal trends when only few values are availible. The figure show average concentrations of data from four sampling locations (E10, PL629, E8 and E631) divided into quarters of the year. Thus, the average of all data, from all four sampling points from Nov to Jan is plotted in the first pile in the figure. The data used derive from ARA-Sul (in total 39 measurements) and the monitoring period is 1997 to 2004. As can be seen the nitrate levels are roughly twice as high during the "wet" half-year compared to the "dry" half-year.

During the sampling trips in this field study nitrate was measured using a portable spectrophotometer. The results from the fieldtrips can be seen in Figure 22. Graph a shows the average nitrate concentrations at the different sites whereas graph b shows all single measurements. Despite large variation in the individual values, some information can be derived from Figure 22b when looking at general increases/decreases. The values always increase between site 3 and 4 as the River runs through the sugar plantations, whereas they usually decrease between site 5 and 6. The very low value at site 2 on October 13th is most likely due to an analysis mistake in the field laboratory process.

By multiplying the measured nitrate concentrations from this field study with the flows obtained during the same period, values of daily mass flows have been calculated. Figure 23a shows the mass flow calculated from the average concentrations and flows whereas Figure 23b shows the values from each individual sampling trip.

6.2.2.4 Nitrite

Assuming that data from RSSC and ARA-Sul are compareable, nitrite reaches its highest concentration within the sugar estates (Figure 24). Very few data are available for nitrite in the Mozambiquean stretch of the River and most of the available data are concentrations not able to detect with the analysis method, implying that almost all data have been edited.

Apart from from DNA (which only have older data), ARA-Sul is the only instance with coordinated measurements of nitrate and nitrite from several locations. Ratios of these data show that the importance of nitrite related to nitrate generally decrease with downstream distance (Figure 25). An increased ratio can however be found between E632 and the Pequenos Libombos Dam (PL629). However, only four measurements are available for E632.

Table 13 shows significance for spatial nitrite variations using data from RSSC and ARA-Sul. The test used is the ranksum test.

Table 13 Statistical parameters comparing nitrite at different locations. H and p are calculated with ranksum.

	H	p	Interval	
Mpumalanga(RSSC)-Simunye weir(RSSC)	0	0,088	-0,190	0,010
Simunye weir(RSSC)-Mhlume(RSSC)	0	0,841	-0,281	0,017
Mhlume(RSSC)-Nokwane/Tambankulu bridge(RSSC)	*0	0,135	0,007	0,311
Nokwane/Tambankulu bridge(RSSC)/Maphiveni(RSSC)	0	0,733	-0,067	0,075
Maphiveni(RSSC)-E10(ARA-Sul)	1	0,002	0,033	0,162
E10(ARA-Sul)-E632(ARA-Sul)	0	0,812	-0,040	0,062
E632(ARA-Sul)-PL629(ARA-Sul)	0	0,625	-0,025	0,033
PL629(ARA-Sul)-E8(ARA-Sul)	0	0,654	-0,009	0,020
E8(ARA-Sul)-E631(ARA-Sul)	0	0,939	-0,011	0,001

* Contradicted by interval. Reasons for the discrepancy see discussion in chapter 4.5.2

Observing h and p from the ranksum test, significant difference (decrease) was only found between Maphiveni and E10 (where also the shift is from RSSC data to ARA-Sul data). The interval shows a significant difference also between Mhlume and Nokwane/Tambankulu Bridge.

Comparing the average annual concentration of nitrite to the average rainy season concentration (Figure 26), it is evident that nitrite concentrations are generally higer during rainy seasons. Only data from RSSC are shown in the figure, since the only newer data series with relatively many values come from this source.

6.2.2.5 Ammonium

Measurements of ammonium can be seen in Figure 27. The major peak at Maphiveni is mainly caused by one extremely high value. If the one high value is discarded, the average is only slightly higher than at the surrounding sites. Generally (except for Maphiveni), ammonium concentrations are slightly higher in Mozambique.

Table 14 shows the results from significance tests.

Table 14 Statistical parameters comparing ammonium at different locations. H and p are calculated with ranksum.

	H	**p**	**Interval**	
Hawane(WRB)-GS3(WRB)	*1	0,042	-0,441	0,107
GS3(WRB)-Mnjoli outflow(WRB)	*1	0,026	-0,148	0,408
Mnjoli outflow(WRB)-Nokwane(WRB)	0	0,915	-0,204	0,135
Nokwane(WRB)-Maphiveni(WRB)	*1	0,001	-1,443	0,149
Maphiveni(WRB)-E10 (ARA-Sul)	0	0,061	-0,161	1,422
E10 (ARA-Sul)-E632 (ARA-Sul)	0	0,979	-0,702	0,483
E632 (ARA-Sul)-PL629 (ARA-Sul)	0	1,000	-0,569	0,626
PL629 (ARA-Sul)-E8 (ARA-Sul)	0	0,766	-0,245	0,405
E8(ARA-Sul)-E631(ARA-Sul)	0	0,861	-0,806	0,469

* Contradicted by interval. Reasons for the discrepancy see discussion in chapter - 21 -

As can be seen in Figure 27, ammonium, in contrary to nitrate and nitrite, tends to be lower during rainy seasons.

Just as for nitrite, the ratio of ammonium to nitrate was calculated (
Figure 28). Except for at the water intake in Boane (E631), the patterns for the two ratios are similar. The NH_4^+/NO_3^- ratios are highest at the water intake, at E10 and at PL629.

6.2.2.6 Total nitrogen

Figure 29a shows average concentrations of total nitrogen during this field study. As can be seen in Figure 29b, concentration patterns along the River changes from trip to trip and no significant spatial differences could be found using the test signrank in Matlab. However, during most sampling trips total nitrogen increases between site 6 and 7 (i.e. before and after the Pequenos Libombos Dam). Medians also show increasing nitrogen levels between site 2 and 3 (before and after the Mnjoli Dam). Further the concentration decreases from the Pequenos Libombos Dam to Boane (site 7-8) in most cases. Disregarding site 7, the highest average is found within the sugar estates (
Figure 29a).

Just as for total phosphorus, the sample taken Oct 18th from Goba was analyzed four times. The resulting average showed a concentration of 0,99 mgN/l.

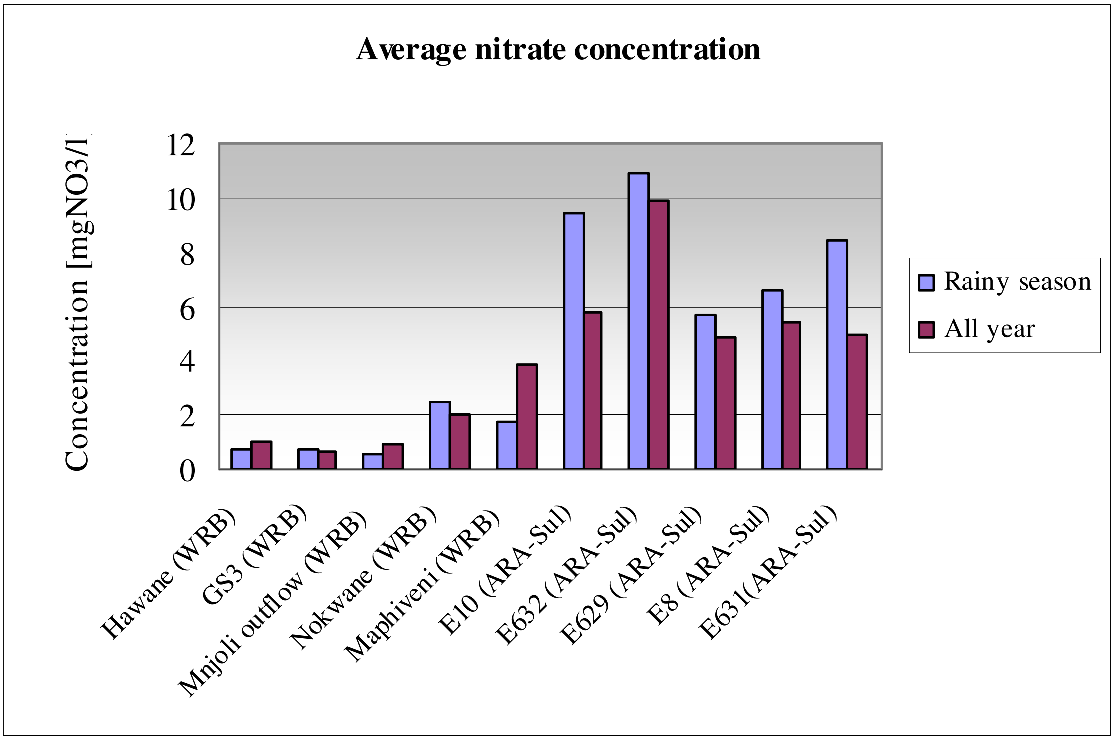


Figure 20 Nitrate concentrations measured by WRB and ARA-Sul (note that higher values on the Mozambiquean side).

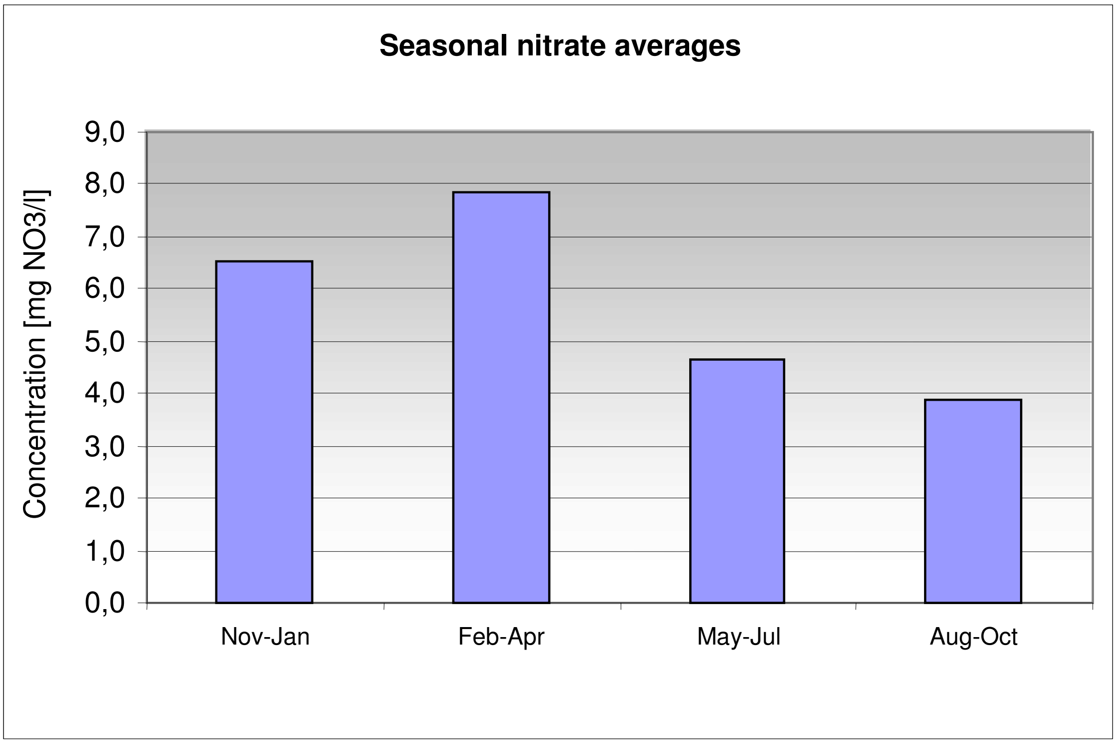


Figure 21 Seasonal nitrate averages. Data from ARA-Sul.

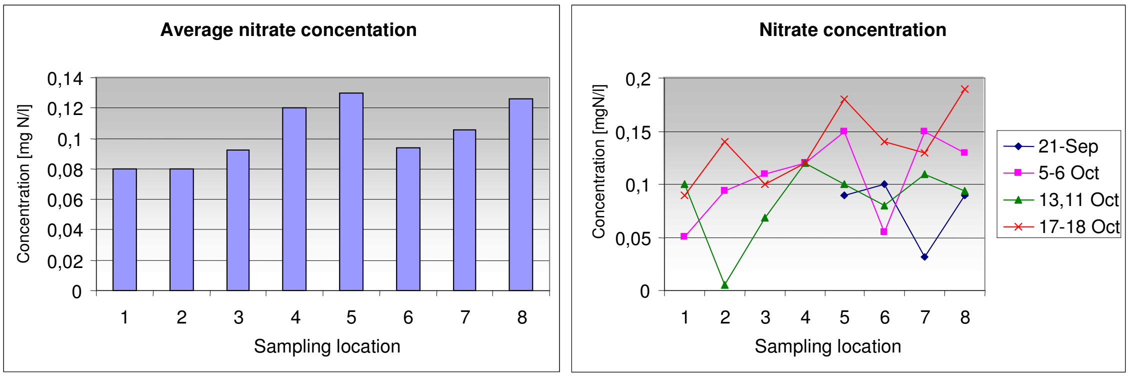


Figure 22 a,b Measured concentrations of nitrate, September-October 2005.

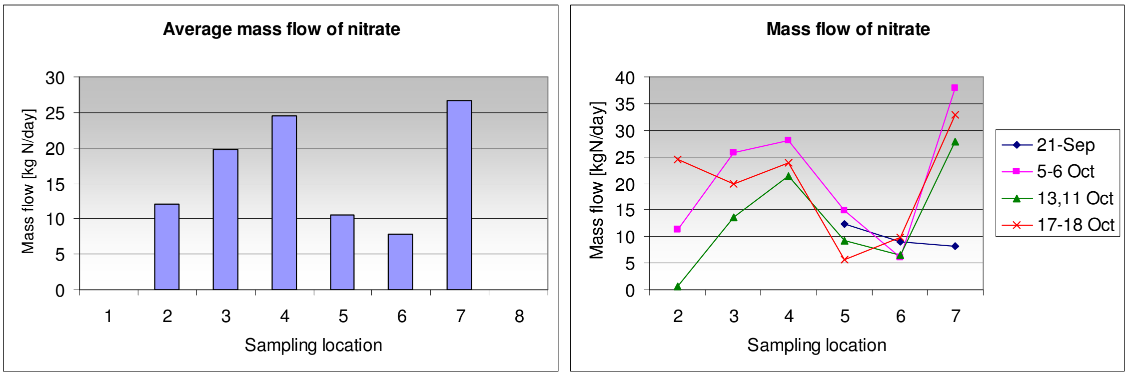


Figure 23 a,b Mass flows of nitrate calculated from measured nitrate concentrations and recorded flows in September-October 2005.

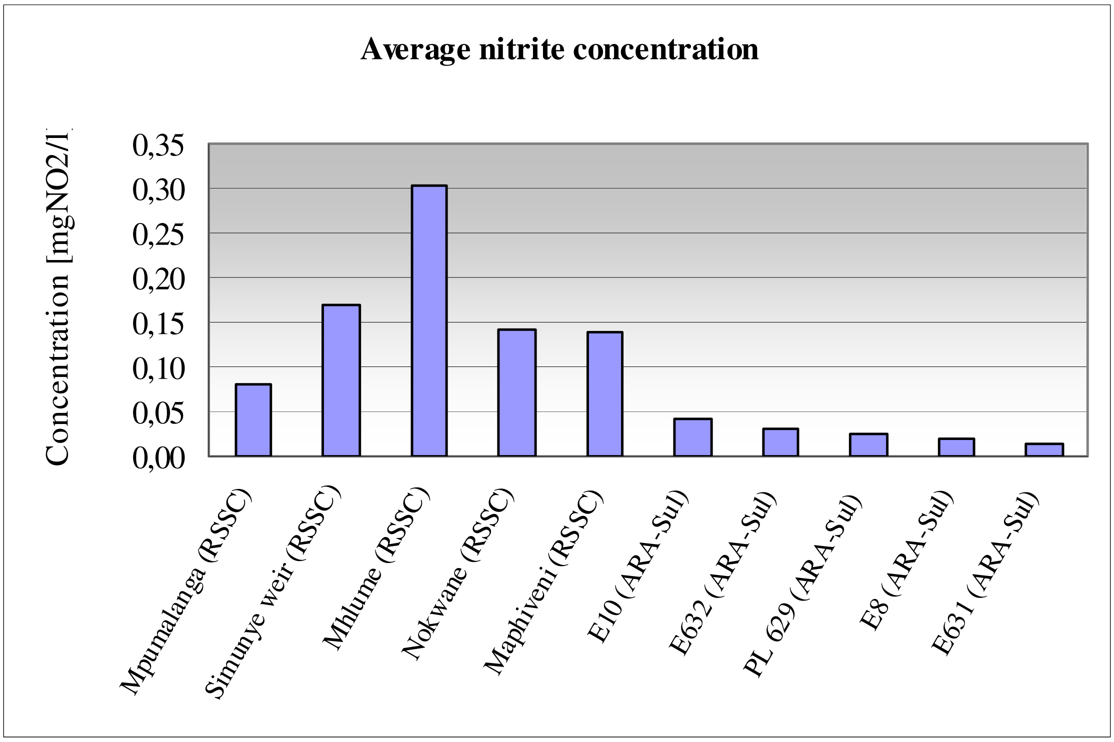


Figure 24 Nitrite concentrations measured by RSSC and ARA-Sul.

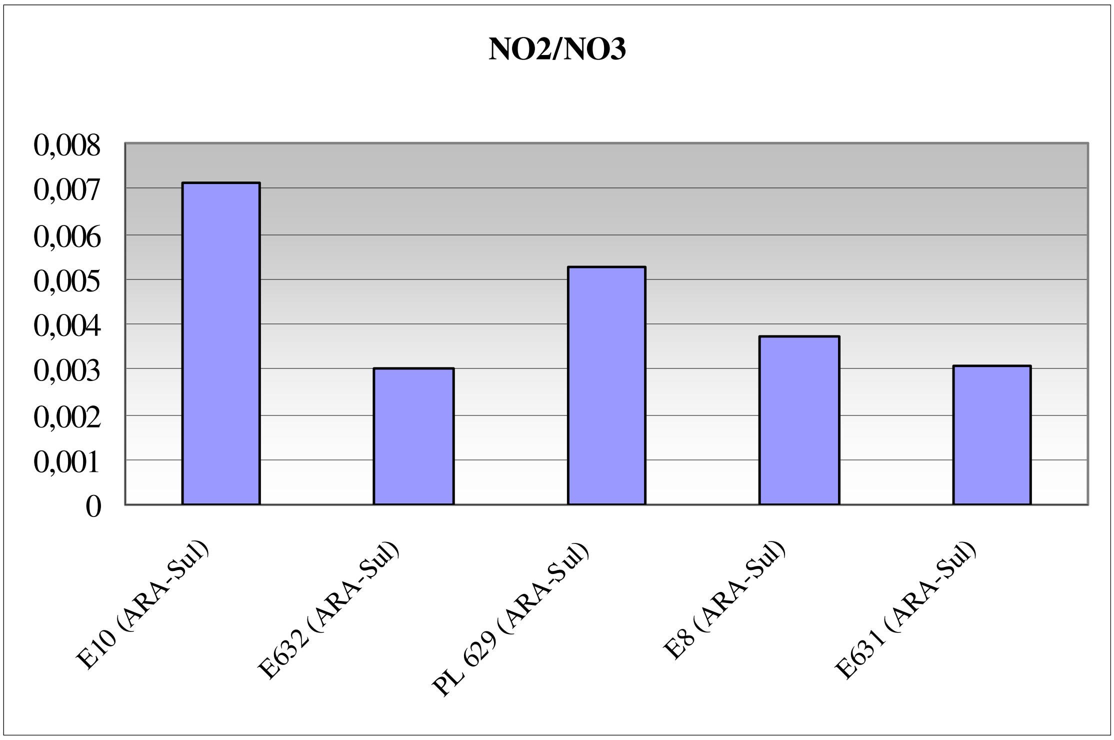


Figure 25 Ratios of NO_2^-/NO_3^- calculated as averages of NO_2^- divided by averages of NO_3^- (i.e. the ratios have NOT been calculated from separate ratios).

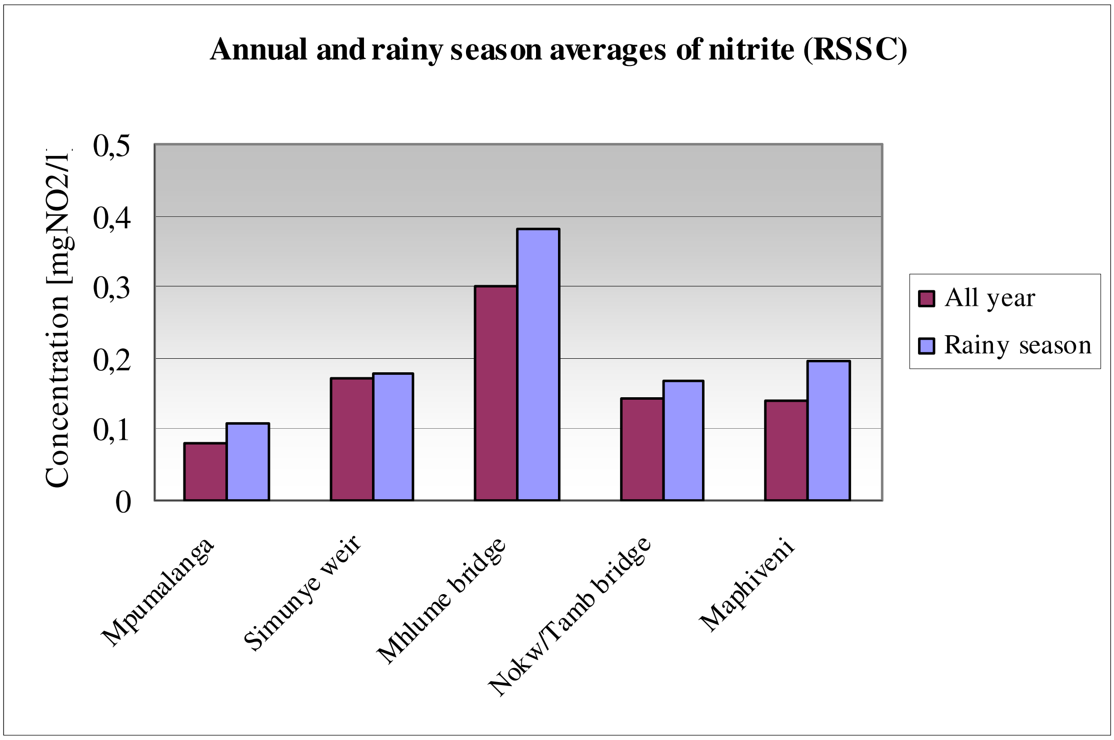


Figure 26 Average nitrite concentrations during all year and during rainy seasons.

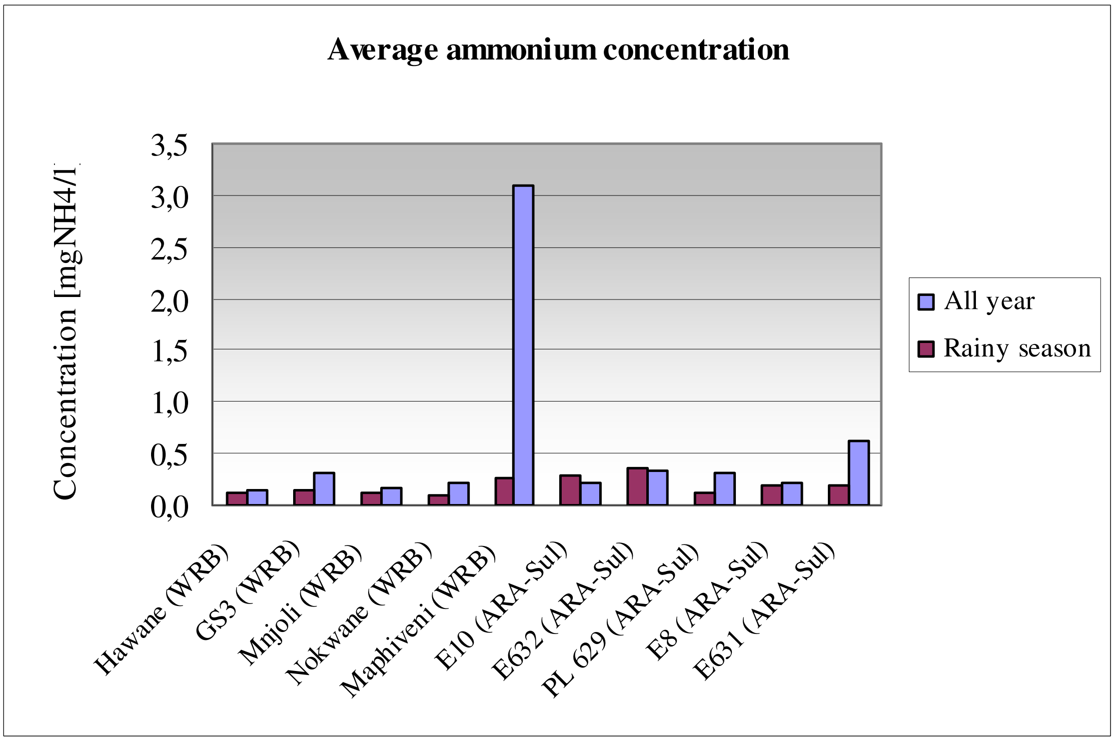


Figure 27 Ammonium concentrations measured by WRB and ARA-Sul.

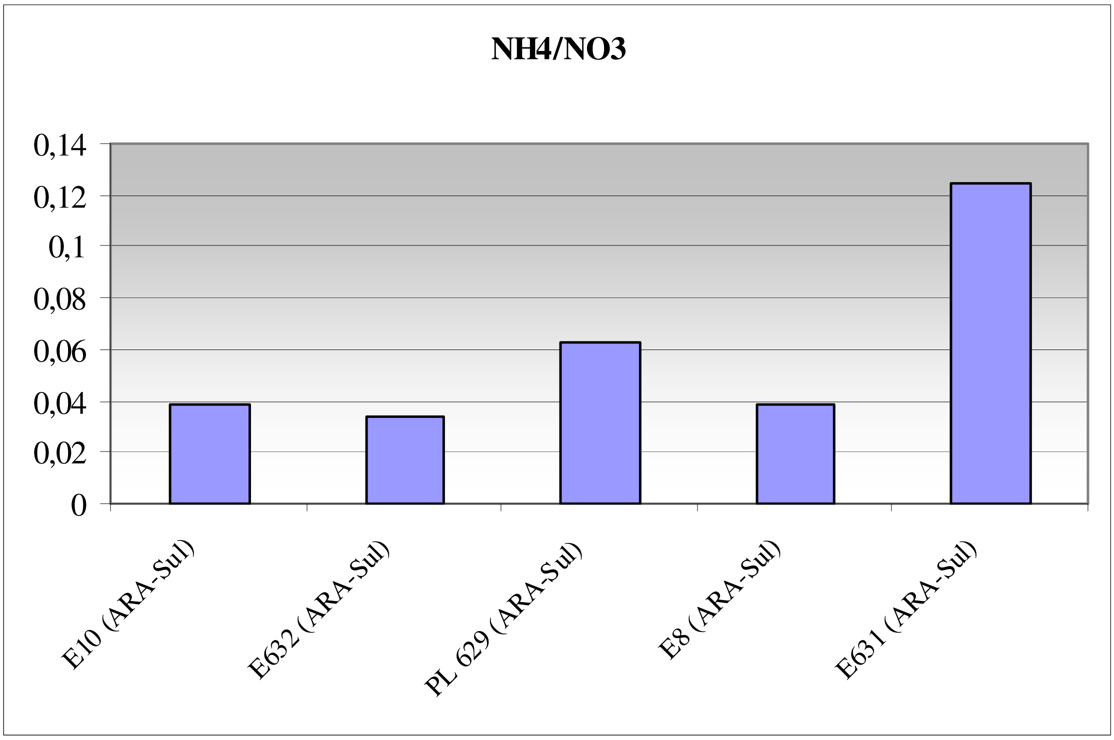
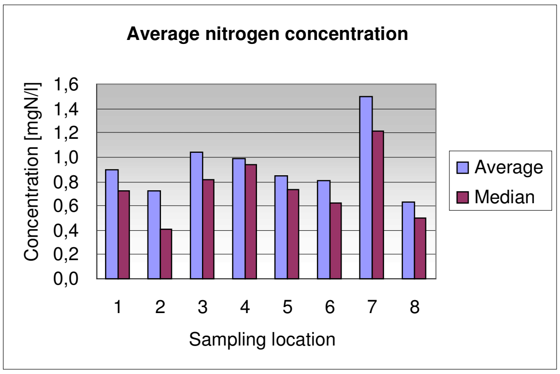


Figure 28 Ratios of NH_4^+/NO_3^- calculated as averages of NH_4^+ divided by averages of NO_3^- (i.e. the ratios have NOT been calculated from separate ratios).



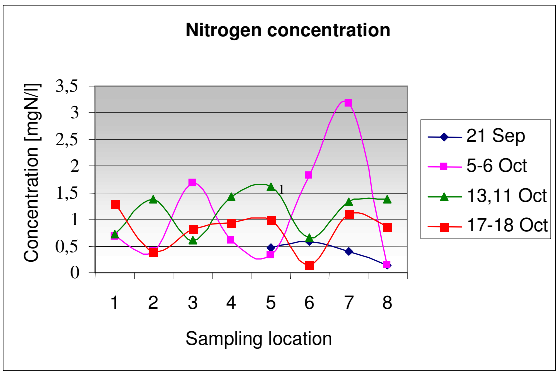


Figure 29 a,b Average and median concentrations of total nitrogen (a) and total nitrogen during individual sampling trips (b) in September-October 2005.

6.2.3 *Table of results from this field study*

Table 15 summarises measurements from this field study. Averages at all sites have been used to show general trends.

Table 15 Summary of measurements from this field study

Parameter	Site 1-2	Site 2-3	Site 3-4	Site 4-5	Site 5-6	Site 6-7	Site 7-8
Temperature	↗	↘	↗	↗	↗	↘	↗
pH	→	↘	↗	↗	↘	↗	↘
Conductivity	↗	→	↗	↗	↗	↗	↗
TDS	↗	→	↗	↗	↗	↗	↗
Turbidity	→	↗	↗	↗	↘	↗	↗
Flow		↗	↘	↘	↘	↗	
Total Phosphorus	↗	↘	↗	↗	↘	↗	↘
Nitrate	→	↗	↗	↗	↘	↗	↗
Nitrate (mass flow)		↗	↗	↘	↘	↗	
Total Nitrogen	↘	↗	→	↘	↘	↗	↘

6.2.4 *Correlation between rainfall and nutrient levels in the River*

Connections were investigated between nutrient concentrations (data from earlier measurements) and rainfall to see if a direct relation could be established. As reported earlier, tendencies show that nutrient concentrations in the River often are higher during the rainy season than during the dry season, despite the "dilution effect" of large flows.

To investigate whether a general correlation could be found or not, nutrient concentrations were plotted against rainfall. The sites and parameters chosen for investigation were the ones that had "many" measurements of nutrients and where daily rainfall measurements were available.

The rainfall stations used were P5 and P425 near Goba (site 5) and Mlawula and Mhlume rainfall stations within the grounds of the RSSC (close to site 4). Rainfall figures were picked out for the dates when water sampling had been made. Correlations were made with the rain the same day of the sampling as well as for the accumulated rain during the 3, 5 and 10 days prior to the sampling. No clear connection was found as the concentration was plotted against the rainfall.

The concentrations that were used were:
Nitrate: "E10 Goba", "Nokwane"
P-tot: "Mbuluzi exit"
Phosphate: "Mbuluzi exit" and Maphiveni

Finally, a correlation between concentration and "larger rains" was attempted for the phosphate at Maphiveni. The accumulated rains for the 10 days prior to the measuring were used and all accumulated rains < 10 mm were discarded. Even though a vague trend could be seen, no clear result could be distinguished. With more data (of higher reliability), a thorough analysis of the relationship between rain and nutrients would be an interesting future project.

6.2.5 *Longterm trends*

To see if concentrations of different nutrients have increased with time, data from previous monitoring were plotted against time. The command "regression" in Matlab was used to see if the found trends were significant. Due to short data series, unevenly spread data and difficulties in comparing data from different laboratories, the discovered trends may often not be due to actual changes in concentrations. For example, if most data during the earlier years are from rainy seasons whereas most data from later years are from dry seasons, the trends found may rather be due to seasonal differences than to actual changes. To avoid this error, data needs to be divided into seasons before trends are investigated. Since only little data was available for this study a division into seasons was not reasonable. If data, contrary to the issue described above, derive only from rainy season, trends found may not be representative for the all year averages and vice versa. Unevenly spread data can further complicate trend analysis; e.g. if there are many measurements from the 70's, none from the 80's and 2 from a cyclone period in the 90's, the values from the 90's will have a very big impact on the trend. The discussion above is also valid for data when analyzing spatial trends. However when analyzing longterm trends, data from several actors usually need to be considered in compilation to get longer records. This implies a problem since data is not always comparable.

Reasons for doing the trend analysis in this study were to see if:

- there have been any changes in water quality due to the establishment and expansion of sugar farming
- there were any changes in water quality during the time of construction of the Pequenos Libombos Dam (e.g due do waterlogging of earlier dry land, increasing sediment load due to digging etc)
- there have been any changes due to the presence of the Pequenos Libombos Dam
- there have been any changes due to the displacement and resettlement of people due to the civil war in Mozambique

Due to the problems discussed above, mainly the discrepancy between data from different actors, the trends found in the trend analysis were considered having low reliability and hence is not presented in this report.

6.2.6 Cross-analysis for comparisons of results

The sample collected at site 5 on Sep 21st was analysed by AdM, MISAU as well as by ourselves. The results are shown in Table 16.

Table 16 Results from cross-analysis

	AdM	**MISAU**	**Analyses from this study**
Nitrate (mgNO_3^-/l)	0,00	2,28	0,39
Nitrite (mgNO_2^-/l)	0,03	0,05	
***Ammonium (mgNH_4^+/l)**	0,00	0,14	
Total nitrogen (mgN/l)		0,154***	0,476
Phosphate (mgPO_4^{3-}/l)		0,165	0,078
Total phosphorus (mgP/l)	0,00	0,12**	0,147

*See discussion below
** re-calculated from 0,38 mgPO_4^{3-}/l
*** re-calculated from 0,20 mgNH_4^+/l

As can be seen from the table, values varied considerably between the two laboratories, implying that nothing could be said about the accuracy of the measurements done in this study. Re-calculating (to the common unit mgN/l) and summarizing of nitrate, nitrite and ammonium from MISAU, gives a nitrogen concentration of 0,64 mgN/l. This exceeds the value of total nitrogen, indicating problems with analysis methods.

Whether it is ammonium or ammonia that is measured at AdM and MISAU is somewhat unclear. The digitilise data from AdM says ammonia, while the paper protocols say ammonium. For MISAU some protocols, mainly older ones, say ammonium, while others say ammonia. However all units (no matter if it says ammonia or ammonium) are NH_4^+/l. When transcribing from paper to computer ARA-Sul has called the concentration analysed by MISAU for ammonium. To further add to the confusion ARA-Sul have have misprinted the units for the nitrogen fractions; in the computorised data it says that the units are mgN/l for all nitrogen fractions. However, looking at the original protocols and talking to personnel at ARA-Sul[239] and MISAU[240] it is clear that the units should be NO_3^-/l, NO_2^-/l and NH_4^+/l. In

[239] Personal communication, Dias 2005
[240] Personal communication, Luís 2005

this study it has been assumed that all data, even data from AdM and ARA-Sul, show ammonium and not ammonia.

6.3 Indications of eutrophication

6.3.1 Visual observations

During study visits and field trips observations regarding signs of eutrophication were gathered. Especially encounters of *Salvinia Molesta* were investigated. In the section below information from stakeholders are presented in the order as they are located as the River flow.

According to Mthimkhulu at WRB in Swaziland, no encounters of *Salvina Molesta* have been reported in the Swazi part of the Mbuluzi River.[241] However increased amounts of small algae have been seen in the Mnjoli Dam during Feb/Mar 2004 and 2005.[242] According to White at RSSC, the sugar cooperation has not experienced any problems associated with algae in the Mnjoli Dam. They have, however, noticed that the spreading of reeds have increased since 2000 (the same year as the cyclone) at the location where the Maphiveni Bridge crosses the River.[243]

Problems with algal blooms and *Salvinia Molesta* seem to be more pronounced in the Mozambiquean part of the River basin than in the Swazi part. Both Serodio and personnel at the Pequenos Libombos Dam (Hanife and Mateus) report problems with blue green algae during rainy seasons (especially during March and April).[244] According to Mateus algal blooms occurred in the Dam 2001, 2002 and 2003. During 2004 and 2005 (during the drought) no algae were found.[245] Scum of algae was also reported during the construction of the Dam.[246] Nutrient levels in the Pequenos Libombos Dam vary considerably. Generally, high nutrient levels (corresponding to algal blooms) have been observed after periods of high runoff/floods.[247]

Substantial problems with *Salvina Molesta* are reported at the intake at the water plant in Boane.[248] The plants clog filters and make their way all the way into the plant, where they disturb the treatment processes to that extent that the processes may have to be altered. Presently, personnel are hired (day and night) to manually remove the plants from the intake (see Figure 30). *Salvina Molesta* was first encountered at the water intake in 2000 (after the flood)[249] and has since then increased. In 2004, attempts were made to remove the plants with boat. Even though the plants disappeared for a while, the problem returned and at present it is not even possible to navigate in the River. In early 2005 a new attempt was made to get rid of the plants. This time a flow of $200m^3/s$ was released from the Pequenos Libombos Dam to flush away the plants. Since the plants were stopped by a bridge about 1 km downstream the water plant, neither this attempt succeeded. The increase in organic material at the treatment plant is reported to have been high the last two years (i.e. since 2003).

[241] Personal communication, Mthimkhulu 2005
[242] Personal communication, Sukati 2005
[243] Personal communication, White 2005
[244] Personal communication, Serodio, Hanife and Mateus 2005
[245] Personal communication, Mateus 2005
[246] Personal communication, Mussagy 2005
[247] Ibid
[248] Personal communication, Gildo, Gracinda and Mateus 2005
[249] Personal communication, Gracinda 2005

Figure 30 Personnel at the water treatment plant in Boane clear the intake for *Salvinia Molesta*. On the downstream (right) side of the weir, the River is overgrown with the weed.

October 2005, photo by A. Gustafsson.

According to observations made by Couto in April 2004, *Salvinia* was encountered at the bridge downstream the treatment plant in Boane, but not at E8 (in Boane town). [250] During this fieldstudy *Salvina,* was however encountered at E8. The specie was also seen at the water intake in Boane and in Movene River (a tributary to Mbuluzi) during this field study.

6.3.2 Indications from data

Nitrogen and phosphorus are two of the most important factors affecting eutrophication. In this field study the average nitrogen concentrations in the River (all sites and trips included) was 0,931 mgN/l (edited data). For phosphorus the corresponding concentration was 0,0542 mgP/l (edited data). For keeping the benthic chlorophyll level in a river below 200 mg/m^2, and hence avoid eutrophication (see chapter 5.2.5), nitrogen levels should not exceed 3 mgN/l and phosphorus levels should not exceed 0,4 mgP/l. All values (except nitrogen at site 7 during the sampling trip 5-6 Oct) kept below these limits. The average phosphorus concentrations at the different sites were however dangerously close to, and in many cases exceeding the guideline for rivers draining into natural lakes (guideline set by the U.S EPA). None of the phosphorus averages exceeded the U.S EPA limit for rivers not draining into natural lakes (0,1 mgP/l). Neither the phosphate limit (0,16 mgP/l) set by U.S EPA was exceeded.

Since lakes and reservoirs are more sensitive to eutrophication than rivers, it is interesting to compare the nutrient levels in the water entering the Dams (i.e. site 2 and 6) with eutrophication limits for lakes. The average phosphorus and nitrogen concentrations in the water entering the Mnjoli Dam were 0,048 mgP/l and 0,73 mgN/l respectively. For the water entering the Pequenos Libombos Dam, the corresponding concentrations were 0,032 mgP/l and 0,81 mgN/l. The OECD's dividing line for eutrophic lakes is 0,035 mgP/l, while the Swedish dividing line is 0,025 mgP/l. Since African lakes are supposed to be able to withstand higher concentrations of phosphorus a total phosphorus concentration of 0,050-0,060 mgP/l has been suggested as the boundary between mesotrophic and eutrophic conditions for tropical African lakes (see chapter 5.2.1). Using the dividing line for African lakes, there is at present no risk for eutrophication in the Dams.

[250] Personal communication Couto 2005

The N/P ratios for the different locations are shown in Table 17. Ratios are calculated as the average N concentration at the site divided by the average P concentration at the site (i.e. the ratios are not calculated as an average of the ratios calculated every single trip).

Table 17 N/P ratios at the different sites sampled during this field study

Site	1	2	3	4	5	6	7	8
N/P	23	15	24	20	9	25	23	12

Except for site 5 (Goba) and site 8 (Boane), phosphorus is the limiting factor affecting the growth rate (ratios above 15:1 are considered to clearly show limitation of phosphorus). For the Pequenos Libombos Dam the ratio is 23:1. This ratio is higher than the ratios found by Sundström and Mussagy.

7 Discussion

7.1 General parameters

7.1.1 Temperature

The reason for the lower temperatures after the Dams is that the water is released from the deeper part of the water column where the water is colder. During most sampling trips, the sites were visited in order from west to east, sites 1-4 during one day and sites 5-8 another day. Hence, sites 1 and 5 were usually visited in the morning when temperatures are likely to be slightly lower. Only during the last sampling trip in Swaziland were the locations visited in reversed order (due to logistical reasons). This can be seen in the graphs - during this trip, the temperatures at sites 1 and 2 were much higher than otherwise. Another reason for the high temperatures at these locations during the last sampling trip might be the high turbidities (caused by a rain event). High turbidity increases the uptake of solar radiation and will thus imply higher temperatures.

When looking at the average temperature, it seems to increase continuously between the Dams (sites 3-6) implying that the daily variations are not as significant as the geographical variations. From the first field trip to the last, the air temperature increased, especially in the lower reaches of the River. This change can be observed when looking at the temperatures in Figure 9. For each sampling trip, the river water temperature increases.

7.1.2 pH

At all sites but the first, the variations in pH between the different sampling trips are relatively small. This can either indicate well buffered water and/or that no pH altering events have occurred. The stability is especially evident in the lower reaches of the River. At the first site, the pH difference between the minimum and maximum value is 1,0, a relatively large difference. Supposedly this can be explained by looking at the low conductivity values. Low conductivity implies that hardly any ions are present and that the surrounding geological materials generally are not easily weathered. The buffering capacity is thus likely to be low. Also, the flow in this section of the River is usually very low which means that the water quality is easily influenced by local incidents.

Compared to previous studies, the pH values in this field study seem to be a little higher. The study by Mhlanga states that pH in the Mbuluzi in the RSSC area varies between 7 and 8, [251] the corresponding figures from this study are 7,9-8,3 (sites 2 and 3). Further, according to Chonguiça, pH in the Pequenos Libombos Dam (~site 7) varies between 7,5 and 8,5. [252] In this study the pH is slightly higher, varying between 8,5 and 8,7. However, it should be stressed that site 7 is situated just after the Dam and thus the water here have properties similar to the bottom water near the dam gates as opposed to the earlier study where samples have been taken in the Dam. The deviation from the earlier studies might be due to a change in the water quality or due to calibration problems of the pH meter

[251] Mhlanga 2005
[252] Chonguiça 1995

used in this field study. However, when calibrating the pH meter for this field study, it seemed to show lower values than the actual value (showing 6,9 in the pH7 buffer). Thus, pH in the River might anyway be higher than during earlier studies. Even though the pH meter used might show values differing slightly from the actual values, the error is expected to be similar for all samples, implying that the trends along the River should be reliable.

The high pH just after the Pequenos Libombos Dam might be an indication of denitrification since hydrogen ions are used in the denitrifying process. For denitrification to take place, anoxic conditions are required, implying that the bottom water in the Pequenos Libombos Dam might be low in oxygen. This in turn can be caused by extensive decomposition of organic matter.

The drinking water standards of Mozambique (by MISAU), as well as the requirement for irrigation water (South African standards) and the guidelines for aquatic environments (set by the Swaziland Environmental Authority and by the Tripartite Permanent Technical Committee) all have an upper pH limit of 8,4-8,5. These values are exceeded a few times, mainly at site 7 just after the outlet of the Pequenos Libombos Dam.

7.1.3 Salts - Conductivity and TDS

It is evident that the conductivity increases as the River runs towards the ocean. This is normal for most rivers, since conductivity largely depends on the leakage of ions from geologic material. As the drained area (i.e. the upstream catchment) increases, the water gets more exposed to materials that can weather, and thus more ions leak to the River. Also, in warm climates, such as in Southern Africa, much water evaporates from rivers (and dams) leaving salts behind. This implies a concentration of salts as the river flows. In the Swazi highveld, conductivity is very low due a combination of short distances to the River (low time of concentration) and a geology composed by minerals that are not easily weathered.

It is clear that a major increase in the conductivity occur in the Swazi lowveld at the intensely irrigated sugar cane plantations. Site 3 is the last sampling point before the plantations, site 4 is located centrally within the plantations and site 5 is located by the border to Mozambique ~15 km downstream the agricultural area. The major increase after site 3 can be explained by the intense irrigation in combination with the easily weathered sodic soils in the area. Earlier studies show similar increases in conductivity.[253] The JTK study shows that the main ions in the river water in this section are ions of calcium, magnesium and sodium.[254] These originate from the geological units basalt and rhyolite which are present in this part of the catchment (especially south of the River before it enters Mozambique in the Mlawula sub-catchment).

Previous measurements made in the small drainage streams within the plantations show extremely high conductivity values (i.e. higher than in the main River and higher than most natural waters). This indicates that salts leak from the plantations but is diluted as the smaller tributaries enters the River.[255] According to the study by Mhlanga, the conductivity is always lower in the main River than in the tributaries. According to White at the RSSC, the conductivity increase is regarded as the most significant influence of the sugar plantations on the Mbuluzi River water quality.

After the RSSC, the conductivity continues to increase but not as much as in the vicinity of the sugar farming areas. The high salinity of the water entering Mozambique is of rising concern since the establishment of irrigated farms by the Pequenos Libombos Dam is increasing. Due to the high conductivity levels, the water quality department at ARA-Sul is considering to extend their monitoring programme to include more ions.[256]

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253 JTK Associates 2003, SWECO & associates 2005
254 JTK Associates 2003
255 Mhlanga 2005, SWECO & associates 2005
256 Personal communication, Dias 2005

According to the figures from this field study, the SAWQG water quality target for irrigation water (400 µS/cm) is exceeded at all sampling points on the Mozambiquean side. The same result was concluded in the JURBS study of 2005. From site 3 to site 5 (total distance about 75km), the conductivity increases almost five times (from ~100 µS/cm to ~500 µS/cm) indicating that the conductivity would probably not exceed the SAWQG in a scenario without the intense irrigation of the RSSC. The drinking water standard value of 700 µS/cm (by SAWQG) is not exceeded. In the report by Chonguiça (measurements from 1990-1994), the concentration of salts are reported to increase almost four times along the same stretch of the Mbuluzi.

Previous studies state that there is no indication of increased conductivity during the last 20 years.[257] Unfortunatly, there are not sufficient measurements from earlier times to determine the extent of the water deterioration due to the intense agriculture.

Apart from irrigation, drought is a factor influencing the conductivity of a watercourse. The absence of rain/runoff diminishes the dilution potential; also, water will evaporate from the river, leaving salts behind, resulting in a concentration of ions and thus a higher conductivity. As mentioned earlier, this field study was conducted during the dry period in late 2005 when previous rainy seasons had contributed with much less rain than normally. Conductivities at this point are therefore likely to be higher than normally. In a previous study from 2001, it is stated that the highest conductivity values have been recorded during drought periods.[258]

High temperatures (and no dilution) will thus lead to increased salinity of water. From the first field trip of this study (September 15th) to the last (October 17th-18th), hardly any rain fell and the temperature rose successively. This would, according to the reasoning above, imply increased conductivity for every sampling trip. This can clearly be seen in Figure 11b. The highest differences can be found in the low lying river stretches in Mozambique, where the temperature (and hence the evaporation) as well as the temperature *increase* was higher during the time of the field study.

The measured TDS values show great coherence with the measurements of conductivity, indicating that most of the total dissolved solids have a conducting ability, i.e. they are salts. The average value for African rivers is 121 mg/l TDS.[259] This value is exceeded from site 4 (within the sugar estates) and downstream.

7.1.4 Turbidity

Turbidity in the Mbuluzi is reported to be higher during the rainy seasons than during the dry seasons, peak values showing great coherence with large flow periods.[260] This is due to the fact that rain events increase erosion and that runoff carries large amounts of sediment into the River. Also, little rainfall corresponds to low flows in the River, implying low water velocities and enhanced sedimentation of particles, resulting in lower turbidity.

At the time of this field study, drought conditions had prevailed for a long time implying relatively low sediment loads (and thus, relatively low turbidity levels) in the River. Compared to rainy season values, all measurements during this field study are relatively low.

The impact of rains is clearly evident in the results from this study. During the Swazi fieldtrip on October 13th, a small rainfall occurred in the westernmost part of the catchment. This rain showed a quick response in elevated turbidity levels at site 1 as well at site 2 (see Figure 13b). No evidence of rain was found at the second sampling point (according to local people), but as the highveld ends not far from this sampling point, the elevated turbidity levels at site 2 probably have its cause in rainfall in the high altitude area. Steep slopes and high erodability in the area upstream site 2 would cause

[257] SWECO & associates 2005
[258] JTK Associates 2003
[259] Ibid
[260] SWECO & associates 2005

considerable sediment transport to the River, thus showing increased levels at site 2 even though this location did not receive any rain. The last sampling trip was made on October 17th (only 4 days later). At this occasion, turbidity levels were still elevated (but not as much), supposedly due to effects of the previous rain event. Due to the topography of the catchment, it may take a few days until all flows originating from a rain reach the main River.

According to earlier studies, the Dams in the catchment are reported to decrease turbidity levels due to the sedimentation that occurs when water velocity decreases as the River enters the Dams.[261] [262] However, according to Nelson Matsinhe the Pequenos Libombos Dam is reported to be a poor sediment trap (only 17% of the sediment is trapped in the Dam).[263] No clear signs of reduced turbidity due to the Dams can be seen in the measurements from this field study, probably because of the prolonged drought situation and the relatively low turbidity in the influent water. Because of the retention time caused by the Dam, the high turbidity levels in the water entering the Mnjoli during the last two sampling events should not really be compared to the effluent water at the same time. Due to the retention time within the Dam, the water that flows into the Dam at a certain time is not the same water that leaves the Dam at the same time. The relatively higher turbidity during the two sampling events in mid-October is not representative for the usual situation this time of the year. To see if turbidity levels decrease in the Dam, measurements have to be made during a longer time period to get long term averages before and after the Dam.

When analysing Figure 13b, the most evident change in turbidity is the increase between site 3 and site 4, that is, from just before the sugar cultivation begins until a sampling point located within the sugar farming area. The increased sediment transport to the River is most likely an effect of the intense irrigation bringing particles to the River via the return flow to the River, mainly through the drainage canals. The same conclusion has been drawn in the JURBS study.

7.1.5 Flow

It should be noted that most of the water required for irrigating the upstream part of the sugar plantations is not taken directly from the River but is transported from the Mnjoli Dam via a canal. As a consequence, the flow do not diminish significantly between sites 3 and 4 but it diminishes noticeably (due to irrigation) between the flow stations at site 4 and 4.5. When studying the figures (Figure 14a and b), it should be kept in mind that all the flows (except for at site 2) are highly anthropogenically altered.

As discussed earlier (for example chapter 7.1.1 and 7.1.3), temperature and thus evaporation increased continuously during the time of the field study. This can also be seen in the figures of the flow, especially on the Mozambiquean side. At the last gauging station in Swaziland (sampling point 4.5 in Figure 14a and b), the recorded flows were constantly 1,2 m^3/s (the flow is regulated by the Mnjoli Dam) to assure water supply to Mozambique. However, at the next gauging station (site 5, Goba), flow values decreased successively during the time of the field study. During the time of the field study, the effluent from the Mnjoli Dam diminished continuously, probably due to water saving schemes connected to the drought situation and the low water level in the Dam. In late October 2005, RSSC had decreased their irrigation to 80% of the normal due to water shortage.[264] At both Dams, the effluent was significantly larger than the influent, implying that the water volume within the Dams diminished during the time of the field study.

At site 2, the flow during the last sampling trip is much larger than during the two earlier sampling trips. This is most likely due to the rain event that occurred in the highveld on October 13th.

[261] JTK Associates 2003
[262] SWECO & associates 2005
[263] Matsinhe (undated)
[264] Personal communication, Ndlovu 2005

7.2 Spatial trends of nitrogen and phosphorous fracions

Spatial trends should be evaluated bearing in mind that the results often are based on few and unevenly scattered data from different sources and with different reliability. Also the time periods and seasons can be different. Further, sampling locations may differ between different monitoring programmes.

7.2.1 Phosphate

Most availible phosphate data from previous monitoring originate from the WRB. Since these data are very high, concerns have been raised weather the units of the data are correct. Comparing data from WRB, where the highest value corresponds to a phosphate concentration of about 1,14 mgPO_4-P/l , to data from this field study (highest value 0,19 mgPO_4-P/l) and also to data from DNA (highest value 0,065 mgPO_4-P/l), it seems that the data from WRB is extremely high. In the JURBS report it is suggested that the unit from WRB should be ppb instead of ppm. This is however rejected by WRB. Regardless the possible "unit problem", data from WRB can be used to compare different sites within Swaziland to each other (the possible error would be similar for all analyses and thus the relationships between the measurements can be used to compare the locations). Comparison of data from WRB to data from other sources should though be done with precaution.

Following the phosphate concentration as measured by WRB (Figure 15) along the stretch of the Mbuluzi River in Swaziland, a decrease is shown between GS3 and Mnjoli Dam. This decrease might either be attributed to the Mnjoli Dam or to the stretch between GS3 and Mnjoli Dam (even though the distance between these locations is not more than a few kilometers). For the Mozambiquean stretch of the River there are no previous measurements of phosphate.

During this study measurements of phosphate were only conducted once (and only at sites 5-8). Similarly to the analyses of the values from WRB, the result shows a decrease as the River flows through a dam. However, the measurements of site 6 are not reliable since the fraction of PO_4-P is more than 100% of the total phosphorus. The confusing result is most likely caused by the presence of a particle in the water sample for phosphate analysis.

It is important to consider that the outflowing water from the Dams is not the same as the water entering the Dams during the same time. Since water is retained within the Dams, the water released from the Dams is older and of other origin. Hence the composition of the outgoing water can differ from the water presently flowing into the Dams (i.e. the water quality is not only affected by the processes within the Dams).

Phosphate often is attached to particles which settle in dams, implying that phosphate levels should be very low at site 7. It is therefore surprising that the phosphate concentrations found in this field study is even lower at Boane than at the outlet from the Dam (Figure 17). Human activity usually increases the amount of phosphate in the water, further adding to the theory that phosphate concentrations ought to be higher at Boane. Reasons for the contradictory result can be that the water is released from the bottom of the Dam and that the anoxic conditions discussed under pH (chapter 7.1.2) makes phosphate bound in the sediment to dissolve. Further the stretch between the outlet from the Dam and Boane is slow-flowing, indicating that sedimentation and thus reduction of phosphate can take place (this theory is strengthen by the fact that also total phosphorus and total nitrogen seem to decrease on the stretch). Uptake by vegetation can be another factor attributing to the decrease. The measured phosphate concentration at Boane during this study was 0,0364 mgP/l. Samples taken by DNA in Boane in Feb-Mar 1984 showed concentrations of 0,0652 mgP/l and 0,0326 mgP/l (re-calculated from the measured values 0,2 mgPO_4^{3-}/l and 0,1 mgPO_4^{3-}/l). Thus the range does not seem to have shifted much since 1984.

Indications from WRB data show that phosphate seems to increase between Mnjoli outflow and the locations in the sugarfield (not significant). This can be due to leakage within the sugar estates. A significant difference between incoming and outgoing water from the sugar estates could be shown comparing data from RSSC. Figure 16 shows that the concentration usually is higher after the estates than before the estates. Except for a few sampling occasions, the pattern for the incoming and the outgoing water is similar, i.e. if concentrations are high in the incoming water it is also high in outgoing water. This seems reasonable since high concentrations in the incoming water probably are caused by rainfall and runoff events in the western part of the catchment. These events also cause runoff from the sugar fields implying increased concentrations of phosphate. The peaks after the sugar area with no corresponding peaks before the area can be explained by excessive irrigation during dry periods, leading to runoff from the sugar fields but not from the area upstream the estates.

Phosphate concentration was measured on the Mozambiquean side of the border to see if the River has a self-purifying capacity regarding phosphate (i.e. an ability to reduce the phosphate increase from the sugar plantations). The results indicate increased concentrations of phosphate between site 5 and 6. Once again, as discussed above, the fraction of PO_4-P was more than 100% of total phosphorus at site 6, implying that the concentration at this site is not reliable. The same stretch (5-6) shows a capacity of self purification regarding nitrate, total phosphorus and total nitrogen suggesting that this might be valid also for phosphate.

Since phosphate is easily attached to particles, an increase of phosphate can be expected during rainy seasons when sediment is flushed to the River. No significant relationship between phosphate and rainy seasons could however be shown using data from WRB. This can be due to disturbance of natural runoff by irrigation (i.e. sediment is transported to the River even under the dry season due to irrigation).

The TPTC standard for phosphate in aquatic systems is 2,0 $mgPO_4^{3-}/l$. This limit is exceeded at almost all locations measured by WRB (which further adds to the suspision of unit errors). Data from RSSC are normally below the limit. The sites in Mozambique measured during this field study keep below the limit.

7.2.2 Total phosphorus

As can be seen in Figure 19b, phosphorus values from this field study vary considerably between the different sampling trips. This can be due to real differences or to problems during analysis (e.g. by accidentally including a particle in the small sample volume - see chapter 4.6). Due to the scattered data one should not only look at averages, but rather consider both averages and data from separate trips. Considering the second and the last sampling trip the big difference in phosphorus concentration at site 2 can be due to the low flow (i.e low dilution capacity) during the second trip and the high flow (i.e high dilution capacity) during the last trip. The flow during the last sampling trip was more than 40% higher than the flow during the second trip.

Looking at the effects of the Dams (Mnjoli and Pequenos Libombos) on the phosphorus concentration, no conclusions can be drawn regarding Mnjoli. The average shows an increase between site 2 and 3, but the patterns varies a lot between the different sampling trips. For the Pequenos Libombos Dam all sampling trips during this field study show an increase of total phosphorus between site 6 and 7, implying an increase in the Dam. Sundström however found a decrease of phosphorus in the Pequenos Libombos Dam. Usually dams work as phosphorus traps, since phosphorus often is in particulate form and thus will settle in the dam. The reason for the increase of phosphorus found in this field study can be that the outlet of the Dam is located at the bottom of the Dam, and that organic matter is accumulated and decomposed there. Turbulence due the outlet can cause re-suspension of organic matter and sediment to which the phosphorus is attached. If the increased concentration of phosphorus is due to re-suspension of sediments, an increase ought to be found also in turbidity. This is not the case in this field study. However, phosphorus can have accumulated in the sediment, meaning that even though the turbidity does not increase, the amount of phosphorus on the sediment can be higher, leading to an increased amount of phosphorus in the outflowing water. Analysing water in the Dam (not at the outlet) can hence show that a decrease of phosphorus is taking place in the water within the Dam, even though this is not the case for the River water. The main reason for the higher concentrations in the outflowing water is however thought to be due to the retention time of the Dam -

the water released from the Dam is not the same water as is presently flowing into the Dam. The decrease Sundström found in her study can further be attributed to the fact that she compared concentrations within the Dam to concentrations in Goba (site 5 in this study). As seen in the results from this field study, the River has a considerable self-purifying capacity on the stretch between Goba and the inlet to the Dam, i.e the reduction might take place partly in the stretch to the Dam and not only within the Dam. One should also bear in mind that Sundström's study was performed during the rainy season (when phosphorus concentrations in the River tends to be high), while this study was conducted during the dry season. Seen during a longer time perspective the Dam is thought to work as a nutrient trap, even though this was not seen during the dry seasons when this field study was conducted.

Using *phosphate* data from RSSC a significant increase can be seen as the River flows through the sugar estatas. Looking at RSSC data for *total phosphorus,* an indication of similar pattern was found during rainy seasons, whilst the opposite (i.e. a decrease) was found during dry seasons. The increase found during rainy seasons can be explained by possible leakage from the sugar estates. The decrease during dry seasons might be explained by uptake by plants. However, this study shows that phosphorus does increase between site 3 and 5, even though the sampling was made during the dry season. However, both this field study and the earlier study are based on few measurements.

The highest increase in phosphorus concentration takes place between site 4 and 5, indicating that most of the phosphorus added as a result of the sugarfarming enters the River in the downstream stretches of the sugar estates. The flow in this section of the River is however lower than by the upstream sampling location, suggesting that the increase in concentration can be due to the smaller dilution capacity.

The average concentration of total phosphorus during the dry seasons as measured by RSSC in 1994-1999 was 6,34 mgP/l when entering the estates and 7,96 mgP/l when leaving the estates. The eutrophication limit for lakes is 0,025 mgP/l implying that the RSSC values are unreasonable high. In this study, the average concentration in the entering water (site 3) was 0,043 mgP/l and 0,096 mgP/l at the sampling location after the estates (site 5). Though more than ten times lower than the RSSC data, the values from Mthimkhulu is still 10 times higher than the values measured in this study. The very wide range of total phosphorus concentrations measured in different studies indicates that further investigations of total phosphorus are needed as well as quality assurance of the methods used for analysis.

Comparing the data from the Pequenos Libombos Dam measured by Sundström 1991 (0,098 mgP/l) to data from site 7 in this study (0, 064 mgP/l), one can see that the present concentration is lower. This might have its cause in the fact that the Dam in the early 1990's suffered from eutrophication problems due to the decomposition of the large amounts of organic material (e.g. trees and bushes) from the land that was flooded during the initial filling of the Dam.[265] Also, the studies were performed during different seasons. The values reported by Mthimkhulu 2004 (0,42 mgP/l at Nokwane and 0,21 mgP/l at Siweni) can be compared to values from this field study from location 4 (0,050 mgP/l) and location 5 (0,096 mgP/l). If not due to real changes, reasons for the big differences (data from Mthimkhulu is 10-20 times higher than data from this field study) can be the use of different laboratories/methodologies. Also the values from Mthimkhulu are from the rainy season, while this study was conducted during dry season.

When looking at average values, all sites sampled in this field study comply with the Mozambiquean standard for domestic water (0,1 mgP/l). However, the sampling trips September 21st and October 5th-6th show that the values at the sites 2, 5 and 7 sometimes exceed the limit. All data from RSSC exceeds the limits (adding to the suspicion that the phosphorus data from RSSC is not reliable). Data from Mthimkhulu also exceeds the limits.

[265] Personal communication, Mussagy 2005

7.2.3 Nitrate

Nitrate values from ARA-Sul (analysed by MISAU) are suspiciously high. Arguments for this are listed below:

- Values from ARA-Sul are much higher than values from AdM, comparing data from the same location (see E631 in Table 11).
- The result from the sample collected during this field study and sent for analysis to both MISAU and AdM showed a much higher concentration in the result from MISAU (2,28 mgNO_3^-/l) than in the result from AdM (no detectable concentration, i.e. <0,1 mgNO_3^-/l) and the result obtained by the field analysis in this study (0,39 mgNO_3^-/l).
- The ratio between (nitrite/nitrate) calculated with the values from DNA and AdM show a ratio of nitrite to nitrate that are about ten times higher than the ratios calculated from ARA-Sul values.
- Comparing old nitrate data from WRB and ARA-Sul (Figure 20) to nitrate data from this field study, (
- Figure 22a) the high shift in nitrate values found between Mozambique and Swaziland during earlier measurements are not found in this study

Due to the reasoning above, comparisons including nitrate concentrations from ARA-Sul should be done with precaution.

Nitrate data from this field study show quite big deviations at the sites in Mozambique (Figure 22b).This can be a consequence of local influences such as carwashing and herds of cows polluting the water. These effects can make a very sudden impact of the water quality on a very local scale. Apart from the outlier from site 2 (October 13th), the values from Swaziland do not show as large deviations, probably because of the lower population density. The nitrate concentrations in this study show two peaks of equal magnitudes, at site 5 (downstream the sugar estates) and at site 8 (the densely populated area in Boane). Thus, local effects from settlements might have an important impact on nitrate concentrations.

From the graph in Figure 22a, the values from sites 1 and 2 suggests that a nitrogen concentration of about 0,08 mg NO_3-N/l can be considered to be somewhat of a natural background concentration since the River in this stretch is not significantly influenced by human activity.

Though not significant, looking at Figure 20, nitrate concentrations (values from WRB and ARA-Sul) appear to be lower after the Dams than at the locations measured upstream the Dams (i.e lower at Mnjoli outflow than at GS3 and lower in the Pequenos Libombos Dam than in Goba). Higher concentrations after the Mnjoli Dam during dry season (an annual average that is lower than the rainy season average implies that the dry season average is lower than the rainy season average) is however an exception. Contrary to the findings from earlier data, this field study shows higher concentration in the effluent water than in the influent water. Since the locations sampled in this study are located just before and just after the Dams - the Dams can thus be said to work as a source of nitrate to the river water. A possible explanation for the increase shown in the measurements in this study might be that the nitrate level in the inflowing water is exceptionally low (due to the prevailing drought conditions). Also, high evaporation from the Dams (and since there has been no dilution caused by rains for a long time) might have concentrated the nitrate levels in the Dams.

The earlier studies, showing that the Pequenos Libombos Dam works as a nitrate trap have compared nitrate levels within the Dam to the levels measured in Goba. In this study, an additional sampling point was sampled just before the River enters the Dam. The results in this study show a clear decrease between Goba (site 5) and the site just before the Dam (site 6), indicating that the River's self-purifying capacity in this stretch is considerable. According to the mass balance made in this study, the daily load of NO_3-N decreases almost 3 kg/d (from 10,5 kg/d to 7,8 kg/d) between site 5 and 6, Due to the placement of sampling locations in the earlier studies, the decline already *before* the Dam shown in this study has not appeared in the previous studies. Also, the previous studies in the Pequenos

Libombos Dam have been conducted during the rainly season when the levels in the influent are likely to be higher than during the time of this field study.

Normally dams are regarded as sinks of nitrate, since denitrification is enhanced and since nutrients are taken up by plants and organisms. The increase of nitrate in this study can possibly be explained by the fact that nitrate concentrations in the River usually are low during dry seasons and that the water released from the Dam originate from other periods, during which the nitrate concentration probably have been higher (in this case the effect of denitrification is less than the effect of the relatively higher concentration in the “old” water). The retention time in the Pequenos Libombos Dam is almost three years, implying that the water in the effluent has been influenced by activities in and around the Dam for several years. Also, the water in the Dam/effluent might originate from one of the other tributaries, that even if they were dried out in late 2005 have been flowing during the last years. The Calichane is the second largest tributary to the Dam (the Mbuluzi is the largest) and this river drains a large sub-catchment north of the Dam substanciating much small-scale agricultural activities. Though not seen in the concentrations in this field study, denitirification is thought to take place in the Dam. The high pH values measured after the Pequenos Libombos Dam is an indication if this, since denitrification increases pH. If no denitrification was taking place the concentrations in the outflowing water would probably have been even higher.

Both investigations of data from previos studies (WRB and ARA-Sul) and this study show an increase of nitrate within the sugar estates. Mthimkhulu found a fourfould increase of nitrate between GS3 and Maphiveni. Also in the JURBS report, increases within the sugar area are reported. Even though the increase partly can be due to natural factors it is likely that the sugarcane farming is responsible for the major part of the nitrate added in the area. According to the field measurements in this study, the average nitrate increase between sites 3 and 5 is 0,037 mg NO_3-N/l (corresponding to an increase of 40%). By multiplying this with the average flow at site 5 during the time of the field study (1,16 m^3/s), this corresponds to a mass flow of 3,7 kg NO_3-N/day. So hypothetically, if the increased concentrations from the Swazi lowveld would not occur, the daily NO_3-N-flow across the border would be 6,8 kg/d instead of 10,5 kg/d.

The peaks of the mass flows are found at site 4 and site 7. At site 4, the peak is caused by high nitrate concentrations (higher than at site 3 where the flow is almost exactly the same), whereas the peak at site 7 is due to the fact the effluent flow from the Dam was roughly three times larger than the influent at the time of the study. The relationship is similar between site 2 and site 3. Another distinguishable trend in the figures is that the mass flow decreases between site 4 and 5 even though the concentration increases. The decline is thus caused by the reduced flow since water is abstracted from the River for irrigation purpose. A smaller decline also occurs between site 5 and 6 due to a concentration decrease as well as evaporation losses from the River (making the flow lower). As seen in
Figure 23b, the mass flow usually increases between site 2 and 3 with an exception during the last field trip (October 17th). The reason for this decrease is that the inflow to Mnjoli Dam was higher than usually (due to a rain event in the highveld a few days earlier) and that the outflow from the Dam was smaller than normally due to water saving efforts due to the drought.

Comparing nitrate data from WRB at Maphiveni to nitrate data from ARA-Sul at E10 to see if the stretch between the sugar estates and the Mozambiquean border is self-purifying, the concentration is increasing rather than decreasing. This implies that that the contribution of nitrate in this section is higher than the self-purification capacity. The data from ARA-Sul is however newer than the data from WRB, which should be taken into consideration. Further, as discussed above, nitrate values from ARA-Sul are consistently suspiciously high. Comparing the WRB data to data from DNA, the nitrate concentration decreases on the stretch between Maphiveni and E10. This indicates an ability of the River to purify itself.

The sampling locations E10 (before Goba village) and E632 (after Goba village) are very near each other implying that the increase in nitrate found in averages from ARA-Sul between the two locations might be due to the village (no wastewater treatment facilities, abstraction of water etc). However, the sites were never sampled during the same time period and there are only 4 measurements from E632, making comparisons unreliable. Further, the measurements from E632 are from the time period just after the cyclone in 2000. If the highest value (the one closest after the cyclone, sampled in November 2000) is disregarded, the difference is hardly noticeable.

Though not statistically proved, nitrate concentrations seem to be higher during rainy seasons than during dry seasons (Figure 20 and Figure 21). Theories that the concentration should be higher during dry seasons, due to less dilution, thus seem to be wrong. The added nutrient input from the rainfall induced runoff thus influence the water quality more than the "dilution effect" of the increased flow.

Comparing nitrate values to the standards and guidelines in Appendix 4, the standard for nitrate set by the TPTC for aquatic environment (50 $mgNO_3^-/l$) is never exceeded. The SEA objectives for river water (10 $mgNO_3^-/l$) are exceeded occasionally. Neither the WHO nor the Mozambiquean guidelines for nitrate in water for domestic use (50 $mgNO_3^-/l$ in both cases) are exceeded.

7.2.4 Nitrite

No data is available to see how nitrite concentrations are affected by Mnjoli Dam. Data from ARA-Sul however show a decrease between Goba and E395 (also nitrate showed a decrease on this stretch). The decrease in nitrite can be due either to self-purification in the River stretch or to a reduction in the Dam (e.g. by denitrification) or a combination of the two. In this field study, nitrite was analysed together with nitrate. This implies that it was impossible to determine whether the decrease found in old nitrite data (between the border and the Dam) depends on the processes in the River or the processes within the Dam. For nitrate, the measurements from this study shows that a major decrease occurs in the River (between site 5 and 6) and that a relatively smaller increase occurs between site 6 and 7. As discussed earlier (see chapter 7.1.2) denitrification seems to take place in the Pequenos Libombos Dam, implying that part of the decrease can be attributed to the Dam.

Within the sugar estates, nitrite increases continuously from Mpumalanga to Mhlume. After Mhlume it starts to decrease, so that when entering Mozambique (E10) the increase due to the estates is no longer detectable (assuming that nitrite values from RSSC and ARA-Sul are comparable). Self-purification thus seems to take place in the downstream parts of the estates and in the remaining reaches between the sugar fields and down to Mozambique. The only significant difference found in old data for nitrite is between Maphiveni and E10. If this is due to the different laboratory used or if it is due to self-purification is not possible to say until the laboratories and the analysis methods used have been further investigated.

The general pattern of a decreasing ratio of nitrite to nitrate downstream E10 is disrupted by an increase after the Pequenos Libombos Dam. This increase strengthens the theory that the bottom water in the Pequenos Libombos Dam is low in oxygen. However it should be kept in mind that only few data were available from E632. The nitrite/nitrate ratios shown in Figure 25 are calculated from averages of the both parameters. To improve the analyses, the ratio for every sampling occasion should have been calculated and then an average of the ratios should have been used. Consideration should also be taken to differences due to seasons (e.g. nitrate might be of higher relative importance during rainy seasons due to its high mobility). Again, the few available data makes a thorough analysis impossible.

All nitrite values on the Mozambiquean side keep well below the limit (3 $mgNO_2^-/l$) set for water for domestic use by MISAU. They generally also keep below the guideline for longterm domestic use (0,2 $mgNO_2^-/l$) set by WHO. Values at Mhlume, however, occasionally exceed the value set by WHO and the aquatic guideline (0,2-3 $mgNO_2^-/l$) set by the Swaziland Environmental Agency.

7.2.5 Ammonium

Data from WRB show peaks in ammonium concentrations at GS3 and Maphiveni. The peak at GS3 is probably due the few numbers of measurements and hence the great impact of one single high value (in June 1989) is considerable. The peak at Maphiveni can be traced to one extremely high concentration measured in July 1986. Possible explanations for the high concentration can be accidental discharge of sewage, mishandling of fertilisers or just improper timing of sampling (for example there might have been cattle excreting in the River just before the sample was taken). It is also possible that the high value is due mistakes during laboratory analysis and/or misprinting when transcribing data from paper to computer. The high impact that single high values have on the spatial concentration pattern along the River shows that it is important to continue measuring to get longer time series and thereby reducing uncertainties caused by outliers.

As for nitrate and nitrite (using old data), ammonium shows a decrease between the sites measured after the Dams compared to the sites measured upstreams the Dams. Similarly it is not possible to say weather the reduction is due to self-purification in the river reaches between the upstream sites and the inlets to the Dams or if it is due to reductions in the Dams.

Disregarding the single high value causing the peak in Maphiveni (data from WRB) and assuming that ammonium data from WRB and ARA-Sul are comparable, Figure 27 shows that the sugar estates do not seem to have any pronounced effect on ammonium concentrations.

Calculations of the NH_4^+/NO_3^- ratios show a pattern similar to that of NO_2^-/NO_3^-. The highest ratio of NH_4^+/NO_3^- is found at E631 (Boane water treatment plant). This indicates that the amount of decomposing organic material is high, the amount of dissolved oxygen is low and that nitrifying bacteria are not able to nitrify all ammonium at this location. According to staff at the treatment plant the amount of organic material, mainly in the form of the aquatic plant *Salvinia Molesta,* has increased at the intake during this period. The high ratio of NH_4^+/NO_3^- during the same period might thus be due to extensive growth of *S. Molesta.*

The finding that ammonium, contrary to nitrate and nitrite, showed higher concentrations in the all year average than during rainy seasons can possibly be explained by less turbulence and thus less oxygenation during dry periods, leading to a lower nitrification rate. This ought however also to appear in the nitrite concentrations, which it does not. Less dilution during dry seasons and the limited number of available data can be other explanations for the difference. Further, it is possible that the ammonium flushed to the River during heavy rain events is converted to nitrate already before it reaches the River.

7.2.6 Total nitrogen

As shown in Figure 29b, patterns of total nitrogen varied considerably from trip to trip during this field study. This can be due to a combination of water quality variations and problems during analysis. The high peak at site 7 during the second sampling trip is most probably due to incorrect sampling and analysis and can thus be considered as an outlier. A possible explanation for the high nitrogen value can thus be that a particle not representative for the sample has been included in the small water volume used for analysis (see chapter 4.6).

All sampling trips during this field study show an increase of total nitrogen between the inlet and the outlet of the Pequenos Libombos Dam (also nitrate values from this study show an increase on the same stretch), implying an increase between the inflow and the outflow of the Dam. The pattern is not as clear for the Mnjoli Dam, but looking at averages an increase can be found also here. Sundström found that concentrations of total nitrogen were higher before and after the Pequenos Libombos Dam, implying a reduction of nitrogen in the Dam. The same reasoning as for total phosphorus is valid here, i.e. reasons for the increase found in this study can be that even though a reduction of total nitrogen takes place in the Dam, water is released from the bottom of the Dam and thus the high content of accumulated organic matter and the re-suspension of sediment (i.e matter containing nitrogen) leads to higher levels of total nitrogen in the released water than in the River and Dam water. Further, part of the increase in total nitrogen is explained by the increase in nitrate. The major reason for the higher values in the effluent is, as for phosphorus and nitrate, thought to be the fact that the water released from the Dam is not the same as the water flowing into the Dam when only looking at a short period of time.

No clear effects of the sugar growing on the concentration of total nitrogen could be found in this field study (patterns varied from trip to trip). Looking at medians (Figure 29a) a peak can however be found at sampling location 4, but concentrations decrease again, so when entering Mozambique the concentrations are lower than before the River entered the sugar area. Looking at the separate sampling trips, two out of the three however show an increase between site 3 and site 5, implying that the effect of the sugar growing on total nitrogen has to be further evaluated.

Average and median values for total nitrogen in this field study show a decrease between Goba and Pequenos Libombos Dam. Looking at the separate sampling trips one can however see that patterns varies from trip to trip. The stretch is though self-purifying regarding nitrate, nitrite and ammonium using values from ARA-Sul (keeping in mind that the reduction in the ARA-Sul data actually can be due partly to the Dam) and regarding nitrate and total phosphorus using data from this field study, indicating that a reduction of nitrogen is probable. The average concentration at location 7, i.e. just after the water is released from the Pequenos Libombos Dam, was 1,50 mgN/l. This is a doubling of the concentration found in the Dam in March 1991.

7.2.7 Estimation of N and P leakages from RSSC fertilising

By using the figures provided by the RSSC, a rough number of a "worst-case"-scenario regarding nutrient leakage can be calculated. According to the RSSC Agronomy department, the nutrient leakage from the sugar fields is not more than 5%.[266] The estate covers 20 000 ha and the average yearly application is 170 kgN/ha and 10 kgP/ha. In total, the leakage from the RSSC would thus be 170 000 kgN/y and 10 000 kgP/y. Assuming that all the excess nutrients reach the River, the additional concentration caused by the sugar estates would be roughly 0,59 mgN/l and 0,035 mgP/l if divided by the average border flow which according to JURBS is 287,8 Mm^3/y. However, it is unlikely that all these nutrients will be transported to the River since they can be consumed by other organisms, accumulated or lost to the atmosphere on their way to the River.

7.3 Eutrophication

The measured concentrations of phosphorus and phosphate in this study show that presently there is no risk for eutrophication in the River, though indications of increased amounts of plants are shown. The only guideline exceeded is the one set by the U.S EPA for rivers draining into natural lakes, but this is mainly set to avoid eutrophication in the lakes. Though there is no risk presently it should be kept in mind that this study was performed during dry season, when the nutrient concentrations seem to be low. During rainy seasons the conditions can change considerable, leading to eutrophication. Discussion with stakeholders also reveals that problems with algal blooms and excessive nutrients have been experienced during rainy seasons.

Regarding possible risks for eutrophication in the Dams, looking at inflowing water to the Dams, this study shows that, using the dividing line for African lakes, there is at present no risk for eutrophication in the Dams unless water from tributaries contributes with high amounts of phosphorus, phosphorus is discharged directly into the Dams or if runoff during rainy seasons change the conditions. The water released from the Pequenos Libombos Dam however has a concentration of phosphorus exceeding the eutrophication limit. This does not have to indicate that the Dam is eutrophic, but rather that the water released from the Dam, due to the bottom release, is not representative for the whole Dam.

The N/P ratios calculated show that phosphorus is the limiting factor in the River (except for at site 5 and 8, where it is not possible to say if phosphorus or nitrogen is limiting). The water released from the Pequenos Libombos Dam has an N/P ratio of 23, implying that phosphorus is the limiting factor also in the Dam. Compared to the ratios found in the Dam by Sundström and Mussagy, 9:1 and 15:1 respectively, the 23:1 ratio is quite high. However, this can be due to the fact that the water monitored in this study is the water released from the Dam and not within the Dam.

[266] Personal communication, Mnisi 2005

According to the results in this study, both nitrogen and phosphorus levels increase between site 4 and 5. The increase also in N/P ratios shows that the increase of phosphorus is relatively larger than the increase of nitrogen. Both the concentrations of total nitrogen and total phosphorus decrease between site 5 and 6. Since the N/P ratio increase between these sites, the explanation must be that the phosphorus levels decrease more (relatively) than the nitrogen levels. Thus, a conclusion can be that the nitrogen impacts of the sugar cane estates are appearent further downstream than the phosphorus impacts.

Although phosphorus is the limiting factor in the River and the Dam, it is important to also keep the nitrogen concentration low. In sea water nitrogen is usually the limiting factor, implying that water high in nitrogen can cause eutrophic conditions in eustaries and oceans. The Mbuluzi estuary is used for shrimp production, making it very vulnerable to possible eutrophication

To make a complete analysis of the eutrophication risk in the Mbuluzi River, monitoring ought to include parameters such as chlorophyll, secchi depth and dissolved oxygen in connection with nutrients. However, due to economical constraints as well as time limitations, this was not possible in this study.

7.4 General recommendations for improved water quality monitoring

Both Mozambique and Swaziland are countries with limited resources regarding economical means as well as skilled personnel. Further, the water availability is low and unevenly distributed. Due to these factors, careful and efficient water management with regards to water quantity as well as water quality is demanded.

Generally, the monitoring programmes are working, but the purpose and extent of the programmes are rarely defined. Recommendations for improved water quality management are divided into sections and listed below.

Efficient water quality monitoring

- Plan the sampling sites so that long series of data can be achieved from the same locations.
- Co-ordinate sampling locations with the other parties so that sampling is done efficiently. For example, at present, both ARA-Sul and AdM sample the Mbuluzi at the intake of the water treatment plant in Boane.
- If however samples are taken from the same location, the results should be used for comparison of equipment and analysing methods. If two samples are taken from the same site almost at the same time, the quality should be similar.
- Facilitate exchange of data between parties/countries.
- Clearly define the purpose of the monitoring programmes and the parameters to be measured.
- Decide how the gathered data should be used and make sure that there are people responsible for handling/using the data.
- Improve continuity in monitoring, so that long-term trends and seasonal variations can be investigated. Samples should be collected at least once during the rainy season and once during the dry season.
- More frequent sampling in case of special events (for example floods or during the first rains after a long drought) is recommended for further understanding of the water quality processes.
- ARA-Sul is recommended to add a monitoring location where the Mbuluzi enters the Pequenos Libombos Dam to be able to properly determine the effect of the Dam on the water quality.
- If possible, ion balances should be used to check the results from the analyses, i.e. the sum of the negative charges should be equal to the sum of the positive charges.
- For analysis of long-term trends the Mann-Kendall test is recommended since this statistical method can handle scattered and few data taking outliers into consideration.

Parameters

- Parameters should be carefully chosen (according to the purpose of the monitoring programme) to monitor the most important processes in the River. For example, RSSC is recommended to measure nitrate instead of nitrite. Since nitrite is a very unstable fraction of nitrogen and thus changes easily, this can result in big temporal variations leading to unreliable conclusions regarding water quality.
- Selection of the parameters sampled should ideally be co-ordinated to facilitate studies of water quality changes.
- It is recommended that pesticides are monitored occasionally. Presently, little is known about the pesticide levels in the Mbuluzi.

Sampling

- Sampling procedures should be clearly defined to facilitate comparison of data.
- Sampling bottles should be rinsed a couple of times with the River water before the sample is taken.
- Sampling bottles should be filled to the top (and if possible be closed under water) to avoid chemical processes involving trapped air.
- Deviations that might cause changes in water quality should be noted (for example, major fires, extreme flows and the presence of bushfires or heards of animals close to the sampling location).
- Sampling information should include details about the sampling utensils (size and materials of bottles, cleaning etc.). Note that samples for analysis of phosphorus should always be taken in glass bottles.
- Sampling information should include where the sample was taken (depth, flowing water, centre of the River etc.)
- During the time from the sampling to the delivery at the laboratory, samples should preferably be stored according to standard methods, usually in coolboxes with ice.

Laboratory analyses

- As far as possible, standard methods should be followed.
- If the samples cannot be analysed quickly, they should be preserved according to standard methods.
- Sampling bottles and laboratory equipment should be cleaned according to standard methods.
- The specific standard methods used should be noted when analysing samples.
- When standard procedures are not possible to follow, notes should be kept of the deviations.
- Equipment and methods should be calibrated/cross-checked continiously, preferably with help of a nearby laboratory.
- Laboratory protocols should be improved. If, for example, total phosphorus is measured it should not be presented under phosphate, even if it is measured in the form of phosphate. In the Mozambiquean protocols, there are presently unclarities regarding measurements of NH_3 (ammonia) and NH_4^+ (ammonium).

Use of chemical kits for analysis

- Chemical kits (such as the Dr Lange cuvette tests used in this study) are not recommended for continuous usage. The kits are very expensive and require very good accuracy in the laboratory.
- When analysing parameters such as total nitrogen/phosphorus, these kits are not recommended since the micro-scale analysis only requires very small volumes of samples which might give non-representative results if large particles are included by accident.

Storage of data

- Experience shows that mistakes sometimes are made when transferring water quality data from paper format to computer file, this pleads for carefulness.
- Important data should be kept nearby the measured values are; units (e.g. mg NO_3^-/l or mg NO_3-N/l), methods used for analysis, laboratory used for analysis, if parameters have been measured in field or in laboratory, how information regarding measurements below detection limits are entered, what term to use if the parameter has not been measured etc.
- Information regarding particular temporary observations that might influence the measurements should be noted.

Agriculture

- Education is recommended for small-scale farmers to optimise their cultivation. This is especially important in the western part of the Basin where the slopes are steep and the soils are easily flushed away.
- For commercial agriculture, it might be advisable of the national authorities to set up guidelines about fertilise usage, banned substances (such as hazardous pesticides) etc.
- For the agriculture on the Mozambique stretch of the River, it is recommended to cultivate salt tolerant crops.

8 Conclusions

The water quality is generally acceptable, but since the water demand is expected to increase, more pressure will be put on this already scarce and vulnerable resource.

General observations of the water quality:

- Conductivity, temperature and pH generally increase from source to mouth of the River, whereas turbidity mainly depends on the presence of rainfall.
- The conductivity values are exceeding irrigational guidelines in the Mozambiquean stretch of the River.
- pH is stable at most sites apart from in the Swazi highveld. After the Pequenos Libombos Dam pH is slightly higher than desired. This may have a connection to denitrification at the bottom of the Dam.
- Average concentrations of total phosphorus along the River are 0,032-0,096 mgP/l. For nitrogen the interval is 0,63-1,50 mgN/l.
- Nitrate+nitrite shows average levels of 0,08-0,13 mgN/l; the lowest values are measured upstream the sugar plantations in Swaziland and the peaks within the plantations and in Boane.
- Extensive growth of the invasive specie *Salvinia Molesta* is a new and problematic issue downstream the Pequenos Libombos Dam.

Effects of the sugar farming in Swaziland:

- Major increase in conductivity due to intense irrigation.
- Significant increase of phosphate.
- Increased levels of total phosphorus (especially during rainy seasons).
- Increased levels of nitrate. According to measurements in this study, nitrate levels increase about 40% between Mnjoli Dam (0,093 mgN/l) and the the Mozambiquean border (0,130 mgN/l).

Self-purification capacity within the River:
Possibilities of temporal self-purification probably exist along the entire River (to different extent). Clear signs of purification has however only been observed where concentrations generally are high (i.e. after the sugar plantations). The self-purification capacity most likely has an upper limit, which if exceeded will result in major water quality problems.

Earlier studies of the Pequenos Libombos Dam show better water quality in the Pequenos Libombos Dam than at the border (Goba), concluding that the Dam has a purifying effect. This study however shows that much of the purification takes place already before the Dam, i.e on the stretch between Goba and the inflow of the Dam, at least during dry conditions when concentrations generally are low. According to values from this study, the decrease on the stretch is valid for total phosphorus, total nitrogen and nitrate+nitrate. Data from ARA-Sul show that nitrate, nitrite and ammonium decrease between Goba and the Dam.

Between the sugar estates and Goba, most concentrations increase making it difficult to evaluate the self-purifying capacity upstream Goba. Tendencies however show that self-purification regarding nitrite and total nitrogen may take place also here. The only parameter that is shown to decrease already before the border is nitrite.

Effects of the Dams:

- Denitrification probably exists in the Dams, leading to a net reduction of nitrogen seen in a longer time perspective (i.e. several years). This is however not apparent at all times/seasons. For example, levels of nitrate and total nitrogen increased between the inflow and the outflow of the Pequenos Libombos Dam during this field study. The explanation for this is thought mainly to be the short time of measurements, meaning that the water measured at the outflow was not the same as the water measured at the inflow, due to the retention time of the Dam. The study was also performed during the dry season during a period of drought, when concentrations in the inflowing water were extremely low. If no denitrification takes place in the Dam, the concentrations measured at the outflow are thought to be even higher.

- pH, values are higher after the Pequenos Libombos Dam than before. This can be connected to the constant denitrification that seems to occur in the Dam. For Mnjoli the lower pH was found after the Dam.
- Levels of total phosphorus, total nitrogen and nitrate are lower before the Pequenos Libombos Dam than after. Most of the earlier studies show a contrary result, but these studies compare water quality in the Pequenos Libombos Dam with water quality in Goba, thus not including the self-purification capacity of the River itself. Further, in this study, inflowing water is compared to outflowing water (and not to water *in* the Dam). Again, the effect of the retention time in the Dam has to be considered when looking only at a short period of time. Though no reduction of nutrients seems to take place in the Dam during the time of this study, the Dam is thought to work as a sediment trap looking at a longer period of time and comparing water *in* the Dam to water just before and after the Dam. The Mnjoli Dam shows similar trends as the Pequenos Libombos Dam, but not as clearly.
- Phosphate concentrations tend to be lower after the Mnjoli Dam than before (no reliable phosphate measurements are available to see the effect of the Pequenos Libombos Dam).

Seasonal variations in the Mbuluzi water quality:

- Nitrate and nitrite levels increase during the rainy season.
- Total phosphorus shows tendencies of increased levels during rainy seasons.
- Turbidity is higher during the rainy season.
- Ammonium and conductivity levels tend to be lower during rainy season.

Present risk of eutrophication:
Measurements of phosphorus and phosphate show that at present (September/October 2005) there is no risk of eutrophication neither in the Dams, nor in the River. This may however change during rainy seasons. *Salvinia Molesta* is spreading in the Mozambiquean part of the River and increased amounts of algal blooms have been reported in the Dams, indicating that eutrophic conditions sometimes arise. The growth limiting factor in both the River and the Dams is phosphorus.

Water quality monitoring suggestions:
The efficiency of the present monitoring programmes can be improved if the objectives and purposes of the monitoring are clearly defined. Ideally, increased co-operation between the authorities would be desirable to improve methodologies, co-ordinate sampling locations and times, facilitate exchange of data etc. Also, the elaboration of water quality objectives for natural waters would facilitate future management. For future management it is advised to sample the sites twice a year, once every season (rainy and dry). Also, since the self-purifying capacity of the River seems to be considerable between Goba and the Pequenos Libombos Dam, it is advisable to add a sampling location where the Mbuluzi enters the Dam to be able to separate the self-purification in the River from the purification in the Dam.

Since all nitrate data from ARA-Sul are unrealistically high, the methods used for analyses should be checked.

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Appendix

Appendix 1 – Pictures from the sampling sites

All photos taken by the authors.

Site 1 – Samples were taken just downstream the bridge.

Site 2 – Samples were taken at the centre of the weir.

Site 3 – Samples were taken just downstream the bridge.

Site 4 – Samples were taken from the bridge.

Site 5 – Sampling was made just downstream the centre of the weir.

Site 6 – Samples were taken from the location of the photographer.

Site 7 – Samples were taken a few hundred meters downstream the small bridge, just below the position of the photographer.

Site 8 – View from Boane Bridge. Samples were taken 50-100 meters downstream.

Appendix 2 – Geographical information fot the sampling sites

Geographical information for the sampling sites. Different sources for sites 1,3,6 [267] and sites 2,4,5,7,8 [268].

Sampling site	Latitude	Longitude	Altitude (m.a.s.l.)	Catchment area (km^2)
1	26° 13' 05''	31° 11' 17''	1004	Not available
2	26° 10' 15''	31° 34' 45''	305	722
3	26° 07' 20''	31° 42' 16''	256	Not available
4	26° 09' 30''	31° 52' 45''	198	2 429
5	26° 11' 48''	32° 06' 59''	63	2 986
6	26° 11' 47''	32° 12' 19''	54	Not available
7	26° 05' 24''	32° 14' 33''	17	3 735
8	26° 03' 00''	32° 19' 30''	3	5 260

[267] Google Earth 2002
[268] SWECO & associates 2005

Appendix 3 – Information from spectrophotometer analyses of N and P
For the calculated concentrations see Appendix 7.

N-tot							
Sampling trip	**Sampling site**	**Readings**					**Average**
2	5	2,61	2,62	2,53	2,53	2,60	2,58
	6	2,67	2,58	2,69	2,69	2,55	2,64
	7	2,60	2,43	2,57	2,45	2,63	2,54
	8	2,34	2,35	2,47	2,33	2,50	2,40
3	1	2,23	2,22	2,14	2,42	2,34	2,27
	2	2,09	2,09	2,17	2,13	2,17	2,13
	3	2,89	2,67	2,65	2,61	3,05	2,77
	4	2,36	2,29	2,17	2,18	2,20	2,24
	5	2,15	2,13	2,10	2,06	2,07	2,10
	6	3,15	2,84	2,84	2,73	2,68	2,85
	7	4,12	3,28	3,43	3,46	3,29	3,52
	8	0,99	1,13	1,10	0,99	0,97	1,04
4	1	2,17	2,11	2,08	2,13	2,17	2,13
	2	2,37	2,34	2,37	2,36	2,41	2,37
	2	2,41	2,63	2,48	2,50	2,71	2,55
	3	2,01	2,00	2,10	2,15	2,11	2,07
	4	2,18	2,25	2,22	2,15	2,25	2,21
	4	2,75	2,68	2,79	2,80	2,70	2,74
	5	3,12	2,92	3,15	3,08	2,95	3,04
	6	2,57	2,63	2,61	2,51	2,53	2,57
	7	3,21	3,33	3,13	3,01	2,99	3,13
	7	2,26	2,27	2,06	2,25	2,24	2,22
	8	2,47	2,51	2,42	2,47	2,42	2,46
5	1	3,11	3,09	3,12	2,93	3,23	3,10
	1	2,21	2,30	2,13	2,14	2,15	2,19
	2	2,18	2,16	2,21	2,21	2,23	2,20
	3	2,49	2,49	2,47	2,27	2,30	2,40
	4	1,99	1,57	1,48	1,38	1,72	1,63
	4	2,59	2,68	2,78	2,53	2,72	2,66
	4	2,66	2,57	2,54	2,89	2,66	2,66
	5	2,06	2,01	1,63	1,64	1,79	1,83
	5	2,56	2,64	2,64	2,76	2,47	2,61
	5	2,53	2,61	2,68	2,50	2,53	2,57
	5	2,49	2,45	2,74	3,00	2,80	2,70
	6	1,81	2,02	2,14	1,69	1,56	1,84
	6	2,13	2,16	2,05	2,32	2,20	2,17
	7	3,14	3,12	2,96	2,70	3,13	3,01
	7	2,15	2,14	2,08	1,97	1,94	2,06
	8	2,83	2,82	2,94	2,82	2,47	2,78
	8	1,82	1,86	1,86	1,91	2,13	1,92

→

Phosphate							
Sampling trip	Sampling site	Readings					Average
2	5	0,627	0,625				0,626
	6	0,615	0,612				0,6135
	7	0,626	0,621				0,6235
	8	0,601	0,603	0,605	0,604		0,60325

P-tot							
Sampling trip	Sampling site	Readings					Average
2	5	0,592	0,586	0,587	0,590	0,588	0,589
	6	0,630	0,628	0,635	0,626	0,629	0,630
	7	0,613	0,610	0,606	0,607	0,607	0,609
	8	0,592	0,592	0,590	0,590	0,593	0,591
3	1	0,593	0,602	0,592	0,592	0,597	0,595
	2	0,619	0,617	0,620	0,621	0,620	0,619
	2	0,656	0,658	0,658	0,649	0,651	0,654
	3	0,603	0,605	0,606	0,604	0,604	0,604
	3	0,640	0,606	0,596	0,594	0,592	0,606
	4	0,622	0,622	0,607	0,608	0,605	0,613
	5	0,627	0,620	0,621	0,626	0,623	0,623
	6	0,597	0,596	0,595	0,594	0,592	0,595
	6	0,597	0,598	0,598	0,599	0,598	0,598
	7	0,607	0,599	0,604	0,599	0,603	0,602
	8	0,620	0,604	0,607	0,599	0,610	0,608
	8	0,595	0,601	0,597	0,593	0,593	0,596
4	1	0,601	0,599	0,594	0,597	0,596	0,597
	2	0,591	0,598	0,593	0,595	0,593	0,594
	3	0,594	0,594	0,594	0,593	0,596	0,594
	4	0,586	0,587	0,586	0,591	0,588	0,588
	5	0,597	0,597	0,598	0,597	0,593	0,596
	6	0,592	0,588	0,586	0,588	0,587	0,588
	7	0,594	0,595	0,596	0,596	0,596	0,595
	8	0,585	0,585	0,584	0,588	0,585	0,585
5	1	0,608	0,607	0,605	0,603	0,600	0,605
	2	0,579	0,580	0,583	0,584	0,582	0,582
	3	0,604	0,601	0,601	0,606	0,596	0,602
	4	0,605	0,606	0,599	0,600	0,600	0,602
	5	0,595	0,593	0,591	0,591	0,590	0,592
	5	0,634	0,647	0,628	0,611	0,612	0,626
	5	0,629	0,617	0,614	0,614	0,613	0,617
	5	0,587	0,590	0,588	0,588	0,587	0,588
	6	0,590	0,588	0,593	0,594	0,591	0,591
	7	0,604	0,607	0,596	0,596	0,596	0,600
	8	0,605	0,616	0,603	0,607	0,601	0,606

→

Measurements of concentrating solutions

Phosphorus

Date		Readings from spectrophotometer					Average
19/20-09-2005		0,811	0,771				0,791
22-09-2005		0,776	0,773	0,775			0,775
07-10-2005		0,805	0,808	0,805	0,804	0,804	0,805
14-10-2005		0,755	0,749	0,754	0,753	0,751	0,752
19-10-2005	*no.1	0,779	0,78	0,782	0,781	0,779	0,780
	*no.2	0,9	0,902	0,894	0,898	0,896	0,898

*The solution was prepared separatly two times to see reproduceability of the spectrophotometer

Average (all readings)	0,803
Standard deviation (all readings)	0,052
Standard deviation/Average	0,064
Median (all readings)	0,781
Median of daily averages**	0,786

**This figure has been used for calculating concentrations in the River

Nitrogen

Date	Readings from spectrophotometer					***Average
19/20-09-2005	3,36	4,00				3,68
22-09-2005	4,70	4,66				4,68
07-10-2005	3,90	3,86	3,86	3,84	3,88	3,87
14-10-2005	3,60	3,59	3,50	3,50	3,49	3,54
14-10-2005	4,67	4,55	4,46	4,40	4,36	4,49
19-10-2005	4,06	4,03	4,03	3,94	3,89	3,99

***These values have been used to calculate the concentrations in the river water

Values from new batch of solution

Average (all readings from original batch)	3,941
Standard deviation (all readings from original batch)	0,511
Standard deviation/Average (original batch)	0,130
Median (all readings from original batch)	3,850
Median of daily averages (original batch)	3,774

Appendix 4 – Water quality guidelines

		Aquatic			Domestic			Irrigation
	unit	SAWQG (TWQR)	**TPTC	***Swaziland (SEA objectives for rivers-draft regulations)	SAWQG (TWQR)	WHO short-term/ long-term	Mozambique (by MISAU)	SAWQG (TWQR)
nitrate+nitrite	mgN/l				6			
nitrate	mg NO_3^-/l		50	10		50	50	
nitrite	mgNO_2^-/l			0,2-3		3/0,2	3	
inorg N (NH3, NH4+, NO2- and NO3-)	mgN/l	*						5
inorg P	mgP/l	*						
total phosphate	mgPO_4^{3-}/l		2,0 enhet					
totP	mgP/l						0,1	
conductivity	µS/cm		1500	1800	700		50-2000	<400
turbidity	NTU		5	5	0-1	5 (not a set guideline)	5	
pH		+/- 0,5 pH units or <0,5% of background condition. Whichever is most conservative.	6,5-8,5	6,5-8,5	6-9	6,5-9,2 (not a set guideline)	6,5-8,5	6,5-8,4
TDS	mg/l, mS/m	<15% of background condition. No disturbance of natural cycles.			0-450mg/l	1000mg/ l (not a set guideline)	1000mg/l	40mS/m=400mg/l
temp		+/- 2°C or <10% of background condition. Whichever is most conservative.						

*No definite criteria established due to dependence of eutrophication on other factors. Max +/- 15% of background condition. No futher eutrophication. No changes of amplitude or frequence of natural cycles. Can be modified if turbid system.

** We are not sure that these guidelines are for river water. Have not been able to find the tripartite documents.

***Seems quite low. We suspect that this is guidelines for domestic use, but since we have not been able to find domestic guidelines for Swaziland we have nothing to compare to.

SAWQG- South Africa Water Quality Guidelines
TWQR-Target Water Quality Range
WHO-World Health Organisation
TPTC-Tripartite Permanent Technical Comitte (Swaziland, South Africa and Mozambique)
MISAU-Ministério da Saúde (Ministry of Health)
SEA- Swaziland Environmental Authority

Appendix 5 – Information from study visits

Royal Swaziland Sugar Corporation (RSSC)

The information in this subsection derives from study visits during October 20th and 21st. The main sources are Dr Ndlovu, White, Mnisi and his collegues at the agronomy department.

The RSSC area in the Swazi lowveld has been used for commercial agriculture since the 1950's. At first, rice was the main crop but the land proved to be more suitable for sugar cane. In the late 70's/early 80's, the plantations that are now RSSC (until 2002 known as Mhlume and Simunye Estates), went through a major expansion. Presently RSSC cover 20 000 ha with no further possibility to expand.

Sugar canes grow in an 11-month-cycle. The fields are planted so that harvest takes place during all months except for January-March. During this period, the fields are inaccessible, and also, the cane grows too fast to acquire the desired quality. Before harvesting, the fields are burned to get rid of leaves (and snakes) and to make the canes accessible. This is yet another reason for not harvesting during rainy seasons, since the wet plants complicate the burning.

The major problem regarding the Mbuluzi for RSSC has so far been water quantity (rather than quality). In late 2005, the irrigation was cut to 80% of the required to prevent the Mnjoli Dam from running dry. To diminish the evaporation losses, irrigation by sprinkler is successively being changed to drip irrigation (presently, 8000 ha is served by drip irrigation).

The change in irrigation system implies lower water and fertiliser consumption since the fertiliser can be added to the water and applied just close to the roots, making losses minimal. Where drip-irrigation is not yet installed, the fertilisers are applied on dry soil surfaces and followed by irrigation. According to the agronomy department < 5% of the fertilisers leak from the fields. The leakage will eventually reach the Mbuluzi River.

Fertiliser is applied to the fields when the canes are small and the fields are easily accessible. At the fields where drip irrigation has been installed, inline fertilising will continue as the canes grow. Fertilisers on non-drip-irrigated fields are applied manually, by tractor or by ground rigs. Usually, the fields are irrigated just after fertilising. To reduce the application of commercial fertilisers, stillage (a potassium rich bi-product from the sugar mills) is applied to the fields. Other fertilisers include UAN, phosphoric acid, KCl and urea. Further, the ash from the burning (during the harvesting) remains on the fields to act as a natural fertiliser for the new canes. In average, the applied fertilisers per ha and year are 170 kg N, 10 kg P and 85 kg K. Herbicides are mainly used in the initial stages of the growth cycle (applied by aircraft, tractor, knapsack or drip irrigation).

According to the environmental manager at the RSSC, the major impact of the RSSC on the River is increased sodium levels. Due to the intense irrigation, the sodic soils leak salt through the sub-surface drainage streams. The drainage streams have been constructed to prevent accumulation of salts in the sugar fields. Previously, high COD levels from the sugar mills have been a problem. The processing of the effluent water is continuously improved to fit Swazi environmental law. Simunye Mill is now within the legal limits whereas the Mhlume Mill is still in the midst of improving the quality of its effluents. According to the "polluter pays" principle, RSSC pays environmental fees on their COD pollution.

Bananalandia

The information in this subsection derives from a study visit on September 29th. The sources are Johannes Wessecs and Deon.

The banana plantation *Bananalandia* on the south shore of the Pequenos Libombos Dam commenced in 1999 by South African investors. In late 2005 the farm covered 250 ha, but the company is still expanding and aims for a plantation of 300 ha.

The cycle from seed to fruit takes roughly 11 months. After harvest, a new sprout continues to grow as the old trunk is cut down. Thus, the same plant can be used for several harvests (a plant carries fruit for about seven years). The bananas are planted during different months implying that harvest takes place all year round.

Bananalandia is irrigated with water abstracted from the Mbuluzi River upstream the Pequenos Libombos Dam (at the location of sampling point 6 in this study). From there the water is pumped to a small storage dam between the Pequenos Libombos Dam and the banana fields. Every field is sprinkler irrigated approximately 3 hours per week. For the used water, the company pays a tariff to ARA-Sul based on the irrigated area.

The plants are fertilised when the bananas are planted (once every 7 years) and thereafter approximately once every month. During the warm and wet season the plants grow very well by themselves, implying that fertiliser may only be applied once every second month. During these months, when rainfall is high, the fertilisers are at great risk of being flushed away from the plants which is yet another reason for decreasing the fertilising during the wettest months of the year. Fertiliser (KCl and KAN) is applied manually in the form of granules (50 g per plant). For best effect and to minimise runoff, the fertiliser is applied on wet soil after irrigation or after a rain event. Inline fertiliser is planned to make fertilising more efficient. To decrease the needed amount of fertiliser, leaves and trunks from old plants are spread out on the fields to act as extra fertiliser. No pesti-, herbi- or funghicides are used on the plantation.

The climate as well as the soils is highly suitable for growing bananas. The low permeability (caused by the high clay content in the ground) decreases the risk of subsurface runoff as well as groundwater recharge. This, in combination with the location of the farm (on flat ground, 500-1000 m from the Pequenos Libombos Dam) diminishes the risk of nutrients leaking to the Dam. The company has not yet experienced any problems connected to the quality of the Mbuluzi water.

Citrum

The information in this subsection derives from a study visit on October 25th. The sources are A. Negrão and P. Negrão.

The Citrum Company was commenced in its present form in 2002 when the regime changed from governmental to private. Since then, the farm has developed noticeably, partly by improving irrigation practices. The farm has existed since the 60's, having most of their crops just a few hundred meters downstream the Pequenos Libombos Dam. The rest of the fields are located just before the Dam, upstream the Bananalandia plantation.

The main crops in the plantation are grapefruit and oranges, flanked by bananas and papaya that have a shorter harvesting cycle and thus act as economic stabilisers. Presently, the plantations cover 700 ha (divided at the two locations) and have 250 ha additionally for future expansion. In total, the Citrum plantations have about 30 000 citrus trees.

The time from the planting of the citrus tree to the first fruit is about 5 years. Thereafter, the trees will stay productive for 20-25 years. Harvesting season lasts from May to August and most of the harvested fruit are exported to Europe. The export is still expanding. During these first three years, the export has doubled every year.

Irrigation of the fruit trees takes place in eight hour periods by micro-jets placed between the trees. The fertilisers used are granules of LAN (limestone-ammonium-nitrate, containing 28% N) and KCl. 30 t/y and 9 t/y respectively are used. The granules are applied manually beneath the trees once a year during the cold and dry season. Immediately after the fertiliser application, the trees are irrigated for about two hours.

Pesticides are used in a limited extent. To minimise the pesticide usage, the trees are checked individually every day to determine how much (if any) of the chemicals that the tree needs. Further measures to reduce the use of chemicals, are by using beetles to eliminate red scales (a disease that destroys the rind of the fruit) and by using a sticky strip of plastic around the foot of the trees to prevent ants to climb the fruit trees. Fungicides are used in the packaging process to protect the fruit during the transport to the customer, i.e. to give the fruit longer shelf life in the shops.

The climate and soils in the area are highly suitable for farming citrus. The water quality is reported to be sufficiently good for the plants even though the fluctuating pH is a problem, since some of the used chemicals require a certain pH to work. To obtain the right pH, pH stabilisers have to be added to the water.

Libombos Macadamia
The information in this subsection derives from a meeting with António Gomes on October 25th.

The plantation of Libombos Macadamia was commenced in 2004. The farm is located about 500 meters from the Pequenos Libombos Dam on the northern side. The same owner also has a 200 ha banana plantation south of Boane.

In October 2005 the macadamia planted area comprised 53 ha, but according to the plan 107 ha were to be planted by the end of the year. The planned extent of the nut plantation is thus 150 ha. It takes five years form planting until the macadamia nuts are ready to harvest. To get an income sooner, banana trees (which give fruit in less than a year) are planted between the rows of nut trees. As the nut trees grow, the bananas between the trees will be phased out.

The fertilisers used are KAN, KCl and superphosphate. These are initially applied in small quantities when the nuts (/bananas) are planted. Thereafter the fertilisers are applied manually as granules about four times a year. Irrigation (by sprinklers) takes place just after fertilising. A significant amount of the chemicals are said to be flushed away during rains. The nuts and the bananas are fertilised and irrigated in the same way.

The river water is well suited for the crops even though the pH and conductivity are somewhat too high (the optimal values are 6,5-8,4 and $\leq$550 µS/cm respectively). The main concerns are related to high levels of Fe and Mg in the water which might cause clogging problems in the micro-irrigation system.

Boane water treatment plant - AdM
The information in this subsection derives from a study visit to the water treatment plant in Boane on October 10th. The souce is Gildo. Further information comes from Naiene at the AdM office in Maputo (September 27th) and from Gracinda at the AdM laboratory (October 12th).

The water treatment plant for Maputo is located in the lower stretch of the Mbuluzi River, close to the estuary. The present capacity of the two co-existing plants is about 8000 m^3/h (2,2 m^3/s). During the time of the visit, a new sand filter was in the midst of being built and a third plant is planned to be built soon.

The major water quality problems experienced by AdM are high levels of organic material and turbidity. During the floods in 2000, maximum turbidity values of up to 800 NTU were measured at the intake. The high turbidity and high concentrations of BOD demands more chemicals in the purifying process. Similar problems are frequently encountered at the other AdM facilities that are supplied by rivers (in Beira and in Nampula).

Variations in water chemistry due to climatic variations are reported from the plant. During dry periods, levels of conductivity and hardness increase, whereas levels of turbidity and nutrients decrease. At the treatment facilities in Beira and Nampula, conductivity levels are reported to be significantly lower than in Boane (about 100-200 µS/cm compared to almost 700µS/cm). This has its cause in different activities and geological conditions in the different basins.

Since a few years, large amounts of the aquatic plant *Salvinia Molesta* (see chapter 5.2.6) getting into the plant has been a major problem. Problems are also reported connected to the intense usage of the River by local people by the bridges in Boane. Here, the River is frequently used for washing of cars, clothes, swimming etc. The personnel at the water treatment plant has influenced Boane municipality to erect a sign banning car washing. The sign is still there, clearly visible, but no improvement has been shown.

Small scale farming
The small scale farming in the catchment can be characterised by farming/animal keeping for domestic purposes. The majority of the population in the catchment has a very low standard of living and their livelihoods are dependent on their farming. Cattle and goats are common livestock, usually wandering about freely with a young boy as their guard.

Usual crops for agriculture are maize/corn, bananas and papaya. According to personal contact with local people, usage of commercial fertilisers is not common. An agricultural technique that is frequently used is to burn of the land that is going to be cultivated. The ash will act as a fertiliser, but the risks are high (especially during the dry season) that the ash will be spread by the wind or flushed away in case of rain.

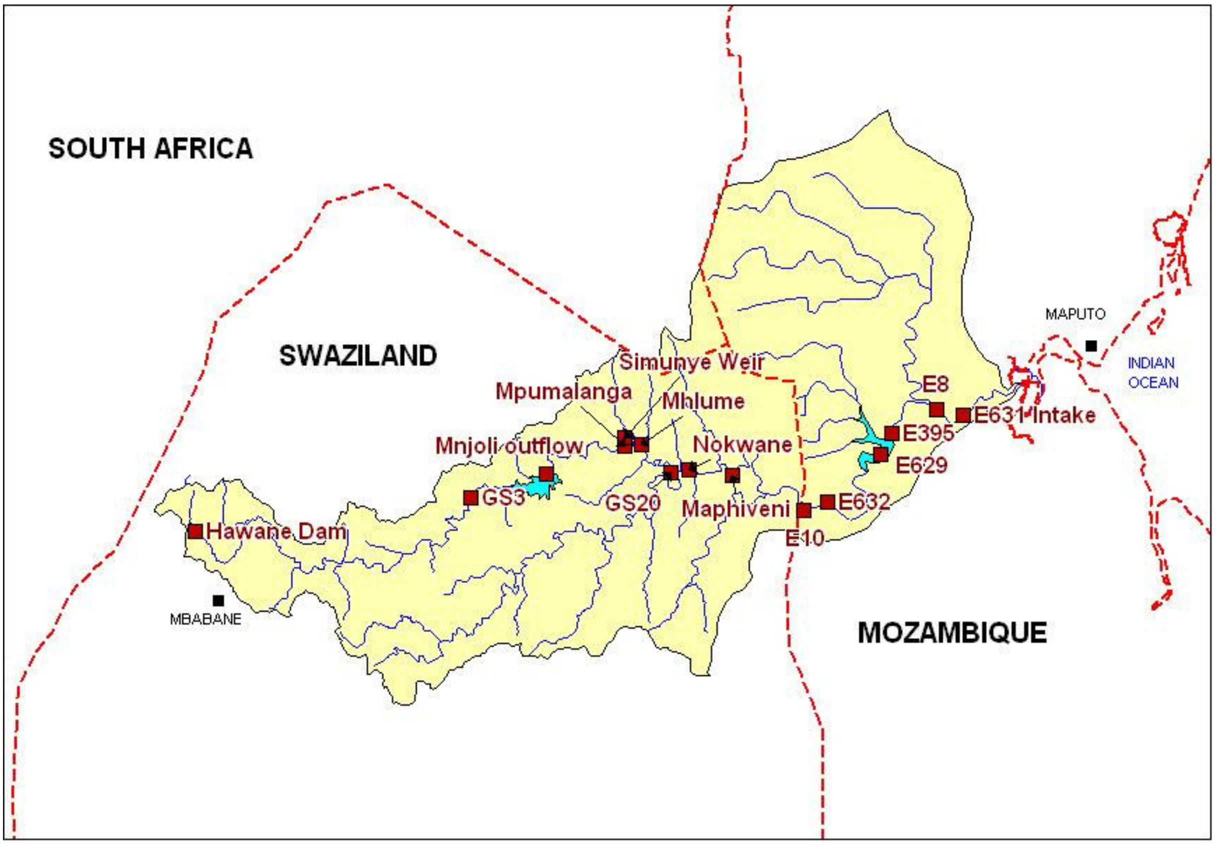
The recurring droughts and floods are major threats to the small scale farmers. By having their fields close to the River, the farmers have access to a secure water source for irrigation, but at the same time they expose their fields to high risks of flooding in case of high river flows.

The civil war in Mozambique has had a big influence on the population situation. During the 80's, the rural areas were de-populated and hardly any agriculture or livestock farming was practised. After the war, people have returned to the rural areas. It has not been possible to determine weather or not there are more or less people living in the areas now compared to the time before the war.

Appendix 6 – Monitoring locations (this study and others)

This list shows all monitoring locations (from this study as well as from other measurements) as they are located from the source and downstream. The map further below shows all sampling locations except the ones used during this study (for a map of the sites used in this field study see Figure 1).

Hawane Dam
Site 1 ~ GS4
Site 2 = GS3
Mnjoli Dam outflow
Site 3
Mpumalanga
Simunye weir
Mhlume
Site 4
Nokwane/Tambankulu Bridge
Maphiveni
Site 5 = E10 Goba
E632 Goba village
Site 6
Pequenos Libombos Dam - PL629
Site 7 = E395
Site 8 = E8 Boane town (the bridge)
E631 = Intake at Boane water treatment plant (ETA, WTP)



Appendix 7 – Measurements recorded in this field study

	Date	Time	Temp	Turbidity	pH	Cond	TDS	Flow	N-tot	Nitrate+nitrite	P-tot	Phosphate
			°C	NTU		μS/cm	μS/cm	m3/s	mg/l	mgN/l	mg/l	mgP/l
Site 1	15-09-2005	17	18,2	4,48	8,7	30	20					
	05-10-2005	11	19,2	3,68	8,3	30	20		0,672	0,051	0,024	
	13-10-2005	11	18,6	23,8	8	60	40		0,728	0,1	0,033	
	17-10-2005	15	22,4	6,84	7,7	40	20		1,292	0,089	0,062	
Site 2	16-09-2005	11	21,0	7,95	8,3	70	40	2,26				
	05-10-2005	14	21,6	8,66	8,3	80	50	1,4	1,68	0,094	0,121	
	13-10-2005	13	21,6	38,9	8,1	80	50	1,4	1,38	0,0051	0,019	
	17-10-2005	13	27,8	15	8,1	80	50	2,02	0,406	0,14	*0,005	
Site 3	16-09-2005	12	21,0	9,77	8	70	50	3,11				
	05-10-2005	15	21,8	11,7	7,9	80	50	2,7	1,68	0,11	0,061	
	13-10-2005	14	21,2	8,65	8,1	80	50	2,31	0,612	0,068	0,02	
	17-10-2005	11	22,2	10,3	8,1	80	50	2,31	0,818	0,1	0,05	
Site 4	16-09-2005							3,11				
	05-10-2005	17	22,2	14,9	8,1	290	190	2,7	0,612	0,12	0,094	
	13-10-2005	15	22,4	15,7	8,3	290	200	2,06	1,418	0,12	0,005	
	17-10-2005	10	23	14,3	8,4	290	200	2,31	0,939	0,12	0,051	
Site 5	16-09-2005	15	21,2	8,02	8,5	430	280	1,61				
	21-09-2005	11	24,2	7,2	8,3	480	320	1,61	0,476	0,089	0,147	0,0252
	06-10-2005	10	22	7,04	8,3	480	320	1,14	0,336	0,15	0,137	
	11-10-2005	11	25,8	7,27	8,5	510	340	1,07	1,6	0,1	0,029	
	18-10-2005	12	26	6,73	8,5	560	380	0,37	0,985	0,18	0,069	
Site 6	16-09-2005	16	22,2	4,58	8,3	450	290					
	21-09-2005	12	25,6	3,67	8,3	480	320	1,04	0,592	0,10	0,097	0,1892
	06-10-2005	11	21,8	3,25	8,3	530	360	1,27	1,828	0,055	0,022	
	11-10-2005	12	28,2	3,01	8,2	580	390	0,93	0,652	0,08	*0,005	
	18-10-2005	13	29	3,1	8,2	590	390	0,81	0,15*	0,14	*0,005	
Site 7	16-09-2005	17	21,6	2,39	8,6	600	410	2,94				
	21-09-2005	13	22,8	2,09	8,5	610	400	2,94	0,392	0,032	0,137	
	06-10-2005	12	21,4	3,14	8,7	620	420	2,93	3,164	0,15	0,053	0,1052
	11-10-2005	13	24	3,22	8,7	620	400	2,93	1,338	0,11	0,025	
	18-10-2005	14	23,8	3,2	8,7	630	420	2,92	1,09	0,13	0,042	
Site 8	16-09-2005	18	22,2	3,14	8,2	640	430					
	21-09-2005	15	24,4	2,81	8,2	660	440		0,15*	0,089	0,056	0,0364
	06-10-2005	14	21,2	3,71	8,2	660	440		0,15*	0,13	0,075	
	11-10-2005	14	26,6	3,23	8,1	660	440		1,38	0,094	*0,005	
	18-10-2005	15	25,6	7,31	8,3	690	450		0,856	0,19	0,069	