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Sustainable Development Indicators for Urban Water Systems

A case study of King William´s Town, South Africa

ERIC ZINN

Water Environment Transport
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2000

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KUNGL TEKNISKA HÖGSKOLAN
Royal Institute of Technology
Centre for International Environmental Studies, CIES

Preface

This study has been carried out within the framework of the Minor Field Studies (MFS) Scholarship Programme, which is funded by the Swedish International Development Cooperation Agency, Sida.

The MFS Scholarship Programme offers Swedish university students an opportunity to carry out two months' field work in a Third World country resulting in a Master's dissertation or a similar in-depth study. These studies are primarily conducted within subject areas that are important for development and in a country supported by the Swedish programme for international development assistance.

The main purpose of the MFS programme is to increase interest in developing countries and to enhance Swedish university students' knowledge and understanding of these countries and their problems. An MFS should provide the student with initial experience of conditions in such a country. A further purpose is to widen the Swedish personnel resources for recruitment into international cooperation.

The Centre for International Environmental Studies, CIES, at the Royal Institute of Technology, KTH, Stockholm, administers the MFS programme for all faculties of engineering and natural sciences in Sweden.

Sigrun Santesson
Programme Officer
MFS Programme

Postal address
KTH, CIES
SE-100 44 Stockholm
Sweden

Visiting address
Drottning Kristinas väg 47C
Stockholm

Telephone switchboard
+46 8 790 60 00
Fax
+46 8 20 37 16

Internet
http://www.ce.kth.se/aom/cies/cies.htm

Abstract

Most sectors of modern society are today reviewing the environmental impacts of their practices in order to achieve a common goal, sustainable development. The urban water system (UWS) sector is no exception, as its further development will increase pressures on the world's limited freshwater resources, and the chemicals and energy used for drinking- and wastewater treatment affect the environment. UWS may also, though, provide options that will improve the situation. By using dried sewage sludge as an agricultural fertilizer, the need to used commercial fertilizer, where mined phosphorus (a limited resource) and fixated atmospheric nitrogen (produced through an extremely energy-demanding process) are constituents, will decrease. The further development and construction of UWS is vital, especially in developing countries, where the lack of proper sanitation stands in the way of a sustainable development.

A transformation from unsustainable practices demands tools, which show how progress is going and can warn of future trends. Sustainable Development Indicators (SDI) have been suggested as such tools for a number of fields, including the UWS sector.

This case study applied 19 SDI to the UWS of King William's Town, a smaller city in the semi-arid, mostly underdeveloped Eastern Cape Province of South Africa. The main aim was two-fold: to evaluate the sustainability of the UWS, and to evaluate the individual indicators according to criteria. The SDI were found useful in assessing the temporal variation of the UWS.

The UWS of King William's Town is currently not moving towards sustainability. The freshwater withdrawal from the Maden and Rooikrans Dams has passed acceptable levels. The future plans of inter-basin transfer are not believed to guarantee this resource past 2025. The treatment performance of the Schornville Sewage Treatment Works is poor, and the removal percentage of phosphorus is even decreasing. Coupled with the increasing concentrations of P, N and COD in the raw wastewater, the Buffalo River, already threatened by eutrophication and salinification, is now receiving increased nutrient loads and oxygen demand. The erratic reuse of sewage sludge as an agricultural fertilizer, and the total lack of sludge quality monitoring, allows for large improvement in this area. Certain aspects have been improving, though. The water use per capita has stabilized around 230 l/cap*d, and the use of ferric chloride at the Schornville STW has become more efficient.

Among the largest difficulties encountered during the case study were the access to certain data (*e.g.* tap quality tests), the quality of the acquired data (*e.g.* chemical content of sewage) and an apparent lack of data (*e.g.* sewage sludge quality). Improvements concerning these factors are necessary in order to increase the quality of future studies into the sustainability of this urban water system.

Of the 19 SDI tested, 13 were chosen for future use through evaluation according to five criteria concerning: the ability to show trends of sustainable development, if the indicator covers an aspect of SD without overlapping other SDI, if goals and objectives exist for the indicator, if data of sufficient quantity and quality was available and easily accessed, and the ease of understanding the SDI's results. Although the indicator topics should be able to be used in studies of other similar UWS, the SDI parameters may need to be reviewed before being applied in another geographic area. Several possible SDI improvements were also identified, which may increase the analytical and communicative properties of the indicators

Keywords: environmental assessment, indicators, sewage, South Africa, sustainable development, water

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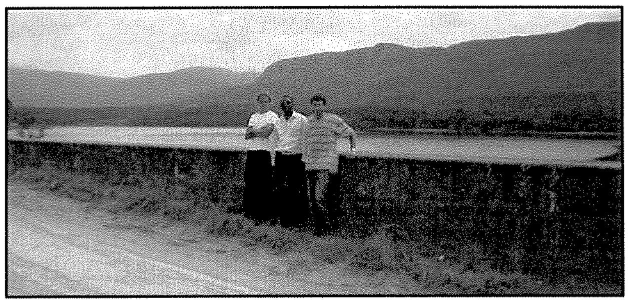
In South Africa, my local supervisor **Prof. O. S. Fatoki** of the Department of Chemistry at the University of Fort Hare, arranged for my arrival and well-being while in country. His comments have been very useful and his help in establishing local contacts was vital. **Mr. D. Katwire** supplied us with up-to-date computer equipment and Internet access, in an area where such technology is not common. His friendliness and hospitality was appreciated, and made me feel very welcome. **Ms. Lilana Ndiki** arranged for my accommodation and made sure that I was given the opportunity to interact with students at the university. The hours she spent looking after me were greatly appreciated. **Ms. D. Dolley** and **Mr. C. Mhambi** at the Schornville Sewage Treatment Works were enormously helpful in supplying me with data from this plant and the Breidbach Sewage Treatment Works, as well as informing me of the plant's functions and operation. **Mr. Braweni** at the King William's Town Water Purification Works introduced me to the plant, and accompanied me to the Rooikrans and Maden Dams. His friendliness was warming. I would also like to thank **Mr. C. Hetem** of the Engineering Section of the TLC for taking time from his busy schedule to answer my questions and review the work and results. **Mr. D. Stratford**, Receipting Accountant at KWT TLC, provided me with energy use data at the plants and aided in my understanding of this rather complicated data. **Dr. Carolyn "Tally" Palmer** at the Institute for Water Research at Rhodes University, Grahamstown, provided me with useful feedback on the work and results and supplied me with a number of reports on previous studies of the Buffalo River. Personnel at **DWAF** supplied me with enormous amounts of data, both while in South Africa and back home in Sweden, via e-mail.



The author, Mr. Braweni and Mr. Jacobsson in front of the Rooikrans Dam, near King William's Town, South Africa

In Sweden, my head supervisor **Prof. Gregory Morrison** at Water Environment Transport has aided me immensely. With his help, this project took form and he introduced the idea of performing the case study in South Africa. His ideas and comments have, most definitely, improved the quality of my work. I have also had invaluable help from **Ms. Margareta Lundin**, lic. eng., at Water Environment Transport who has been my expert on SDI for urban water systems and sacrificed innumerable hours answering my many questions and reviewing my work, and aided in my knowledge of the subject.

Last but certainly not least, I would like to thank my colleague **Mr. David Jacobsson**, with whom I worked with closely in South Africa, and without whose help this work would not have been possible.

Glossary

Carrying capacity: the maximum size of a population that an area can support without reducing it ability to support the population in the future

Critical load: the amount of pollution that an ecosystem can handle, before considerable damage is caused

Eco-efficiency: term used by the World Business Council for Sustainable Development (WBCSD) *viz.* producing more value with less environmental impact

Ecological Footprint: the area that would be required to support a defined human population and material standard

Effectiveness: the extent to which objectives are achieved

Efficiency: the extent to which resources are utilized optimally to produce outputs (goods or services)

Environmental accounting: refers in the context of national resource accounting which can include statistics about a nation's consumption, extent, quality and value of natural resources

Environmental Performance Indicators: (EPI) parameters describing the level of achievement in respect to environmental targets

Framework: conceptual model used to identify and organize indicators

Life Cycle Assessment: (LCA) an approach to identify environmental consequences of a product, process or activity through its entire life cycle

National Resource Accounting: (NRA) satellite accounts to the System of National Accounts include natural resources in physical and monetary units

Performance Indicators: (PI) parameters describing the level of achievement in respect to one or a set of reference values

Socio-Ecological Indicators: (SEI) term used by the Natural Step foundation and others for indicators based on a framework for sustainability and focusing early in the causal chain

Strong sustainability: the existing stock of natural capital must be maintained and enhanced because the functions it performs cannot be duplicated

Sustainable Development Indicators: (SDI) Pieces of information that aim to measure and assess progress towards sustainable development

System of National Accounts: (SNA) an internationally used framework for the systematic and integrated recording of the flows and stocks of an economy

Weak sustainability: manufactured capital of equal value can take the place of natural capital

Abbreviations

BOD, Biochemical Oxygen Demand

COD, Chemical Oxygen Demand

DPSIR, Driving force-Pressure-State-Impact-Response

DWAF, Department of Water Affairs and Forestry

EEA, European Environment Agency

KWT, King William's Town

NV, Naturvårdsverket (Swedish Environmental Protection Agency)

OECD, Organization for Economic Co-operation and Development

PDG, Palmer Development Group

PSR, Pressure-State-Response

SD, Sustainable Development

SDI, Sustainable Development Indicator(s)

SDR, Sustainable Development Records

SEI, Socio-Economical Indicators

STW, Sewage Treatment Works (South African term), equals WWTP

TLC, Transitional Local Council, South African term equaling municipality

UNCSD, United Nations Commission on Sustainable Development

USEPA, Environmental Protection Agency (in the United States)

UWS, Urban Water System(s)

WHO, World Health Organization

WPW, Water Purification Works (South African term), equals WTP

WRC, Water Research Commission (in South Africa)

WTP, Water Treatment Plant

WWTP, Wastewater Treatment Plant

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1. Introduction

Most sectors of modern society are today reviewing the environmental impacts of their practices in order to achieve a common goal, sustainable development. Aspects being studied include the use of non-renewable resources and energy, contributions to environmental concerns (such as eutrophication and global warming) as well as more social factors, such as the environmental awareness of employees and their behavioral patterns. One of society's sectors has concerned itself with environmental issues for several decades, the urban water system (UWS) sector. This sector includes our freshwater sources and reservoirs, drinking- and wastewater treatment plants, and the necessary distribution and transportation pipe networks that connect the sources, treatment plants, consumers and final destinations of treated wastewater and sewage sludge with each other.

In order to measure the environmental progress of a company, region or nation, and then consequently relay this information to its intended audience, whether it be policy-makers, engineers or the general public, tools for these purposes are necessary. Several different methods have been suggested, such as Life Cycle Assessment, Environmental Accounting, Sustainable Development Records, and others. Indicators, the subject of study in this report, have already proven themselves useful in several fields of science: the Gross National Product is an indicator of a nation's economic activity, while the Human Development Index measure more social issues, such as longevity and levels of education. As many of the quantitative parameters measured within an UWS are suitable for indicator usage, these have been suggested as possible future tools for measuring this sector's progress towards a sustainable development.

Lundin *et. al.* (1997) initially proposed a total of 20 Sustainable Development Indicators (SDI) for UWS, which were consequently tested in a case study (1999) in Göteborg, Sweden. Through this case study, the SDI were proven to be useful for assessing the temporal variations of an UWS, and 14 of the original 20 SDI were recommended for future use.

As the Göteborg case study was in an urban environment in a developed country with little stress on its freshwater resources, it inherently had similar systems in mind, such as those found in Western Europe and North America. Developing countries, with moderate or large stress on their freshwater resources and severe economical restraints, are facing additional and different problems. The employees' awareness of environmental problems, the actual relevance of these problems, and the accessibility to and quality of data are other factors that may differ between Sweden and developing nations, which mandates a separate study into the use of indicators in such an area.

2. Aims and Objectives

The overall aim of this Master's Thesis is, through the performed case study, to evaluate the use of 19 SDI in the field of urban water systems. The individual objectives are:

- to collect substantial amounts of data of sufficient quality to make an analysis possible and meaningful,
- to analyze the current situation of the study area, with regard to Sustainable Development (SD), and identify future trends,
- to evaluate the use of the individual indicators and their informative qualities,
- to produce a working list of the SDI found appropriate for future studies.

3. Methodology

Following an extensive literature review of publications concerning SD, indicators, urban water systems and developmental aspects, 17 of the 20 SDI originally proposed by Lundin *et. al.* (1997) were chosen for the case study, with the remaining three rejected on the grounds that they were not believed to be either applicable, suitable or provide useful information. In order to cover the developmental aspects that were not included in the original set, complementary SDI were believed to be necessary. A review of the United Nations Commission on Sustainable Development's (UNCSD) Working List of SDI[1] found that two, of a total of 134 SDI, might prove to cover this aspect, without overlapping any of the other 17 SDI.

Upon arrival to South Africa in October 1999, the UWS of King William's Town was chosen as the subject of study, and its system boundaries were identified as starting at the Maden and Rooikrans Dams and ending with the Buffalo River (see Figure 4). This system was sufficiently developed with functioning drinking- and wastewater treatment plants and a complete pipe network, and data for a majority of the SDI was believed to be present. Also, the UWS's close vicinity to the University of Fort Hare, the base of the study, allowed for multiple and frequent visits.

Data collection started immediately and included personal interviews with staff at different municipal offices, as well as at regional and national authorities. Several private companies that the municipality employs for measurements and research were also contacted and visited.

A pre-evaluation of the SDI values was conducted while still in South Africa, and the results were presented to contacted officials at the municipality, in order to attain feed-back prior departure. Back in Sweden, the result evaluation continued with the help of several researchers at Chalmers University of Technology (Sweden), the University of Pretoria (South Africa), Rhodes University (South Africa) and the University of the Orange Free State (South Africa) and personnel at the Department of Water Affairs and Forestry in South Africa, as well as an evaluation of the SDI concerning their usefulness and informative qualities.

Prior completion, this report has been reviewed by the following persons:

Prof. Gregory Morrison
Water Environment Transport
Chalmers University of Technology
Göteborg, Sweden

Ms. Margareta Lundin, Lic. Eng.
Environmental Systems Analysis
Chalmers University of Technology
Göteborg, Sweden

Ms. Sonja Oetken
Official opponent, M.Sc. student
Applied Environmental
Measurement Techniques
Chalmers University of Technology
Göteborg, Sweden

Prof. O. S. Fatoki
Department of Chemistry
University of Fort Hare
Alice, South Africa

Dr. Carolyn "Tally" Palmer
Centre for Aquatic Toxicology
Institute for Water Research
Rhodes University
Grahamstown, South Africa

Ms. Jay Walmsley, M.Sc.
Centre for Environmental Management
University of the Orange Free State
Bloemfontein, South Africa

[1] The UNCSD's Working List of Indicators can be found on the Internet:
http://www.un.org/esa/sustdev/worklist.htm

4. Sustainable Development and urban water systems

An urban society needs a number of infrastructural installments to function properly. The provision of safe drinking water and the removal and treatment of wastewater and stormwater are prerequisites for a healthy population and functioning city, and it is for these objectives that UWS were initially designed. More recently, global awareness and recognition (*e.g.* Agenda 21) of society's negative influence on the environment has grown, and calls for additional purposes and goals of an urban environment's sub-systems, including its UWS.

In addition to the original objectives, which mainly concerned human health, a modern water and wastewater system must consider energy efficiency, resource use, environmental effects, access to service, service equality and other aspects of SD.

When considering UWS, this breaks down to the following individual objectives:

- Preserving the quality of raw water sources.
- Sustainable use of raw water sources.
- Supplying the general population with safe drinking water in sufficient quantity.
- Supplying the general population with adequate sanitation.
- Reducing the use of limited resources and energy to within levels of sustainability.

In a developed country like Sweden, with previous decades of industrialization and infrastructural improvements, the access to an abundant supply of water at an affordable cost allows a focus on more environmental issues. Many developing countries, like South Africa, face enormous problems in the near future as they lack not only the infrastructure (in certain areas) and investment capital, but often also have very limited amounts of freshwater resources. The rapid urbanization and population increases in these countries add additional stress to the situation. Today, more than one third of the world's population of over 6 billion people do not have safe drinking water and a quarter do not have adequate sanitation. This results in the 50,000 deaths that occur daily, due to waterborne diseases (Fielding, 1999).

The author of this Master's Thesis believes that the importance of a sustainable development of the urban water systems in these countries, as well as in developed countries, is understood. The importance has been internationally emphasized (see *e.g.* Chapter 18 in Agenda 21). In order to understand the current situation and identify its trends, thereby finding ways to achieve a more sustainable development, tools like SDI are hoped to prove to be very useful.

5. Sustainable Development Indicators

5.1. Introduction

Indicators have been used in several fields of science as tools of measuring SD-progress, identifying problems and communicating this information to an intended audience. When studying SD with an economical emphasis, the Gross Domestic Product and Gross National Product have been thought of as convenient indicators, although they are currently being revised by using satellite accounts, so as to "green" these indicators. More recently, the Index of Sustainable Economic Welfare (ISEW) has been suggested as a more appropriate measurement of true welfare. In order to measure development in a social context, the Human Development Index (HDI) is currently being used by the UN Development Program to measure a population's longevity, literacy rate, and level of education.

Indicators, in general, are pieces of information, which have a wider significance than their immediate meaning (Bakkes *et al.*, 1994). An indicator is useful if it is of fundamental interest in decision-making, simplifies or summarizes important properties, visualizes phenomena of interest and quantifies, measures and communicates relevant information (Gallopín, 1997). In addition to its essential quantifying function, further relevant functions include (Gallopín, 1997):

- assessing conditions and trends (sometimes in relation to goals and targets),
- providing information for spatial comparisons,
- providing early warning information,
- anticipating future conditions and trends.

5.2. SDI frameworks and methodologies

The development of SDI has been world-wide and been undertaken by a number of organizations (*e.g.* OECD, UN) and professionals of different faculties, where a framework is first created, which acts as basic conceptual structure of underlying ideas pertaining to SD. A large number of different frameworks and methodologies have been developed, largely depending on the author's interpretation of SD. Those with an economic background tend to favor "weak sustainability", *i.e.* where manufactured capital can take the place of natural capital, whereas those with an environmental background choose "strong sustainability", where spent natural capital cannot be replaced. Another factor that has influenced the frameworks and methodologies has been the intended audience, whether it be politicians, a private company or the general public as a whole. (Lundin, 1999)

5.2.1. Environmental Accounting

Environmental Accounting is intended as a tool to determine the use of natural resources at a national level, but can also be applied at a corporate level, for management purposes. The goal is to develop a system in which it is possible to deal with the use of natural resources and the environment in the same way as financial resources are dealt with. The development of National Environmental Accounting is in progress within the United Nations, the OECD and certain individual countries. The UN's System of Integrated Environmental and Economic Accounting (SEEA) attempts to evaluate changes in the environment in financial terms. (Lundin, 1999)

5.2.2. Sustainable Development Records

Sustainable Development Records (SDR) are also based on economic theory. The authors Nilsson and Bergström (1995) refer to sustainability as a 'non-undermining of the resource base' and 'coping with environmental preconditions while satisfying societal needs.' This model stresses the link between the services produced and the social, material and financial resources used in their production. There are three types of SDR indicators, formed as relationships between the service, the operation that provides the service and the amount of resource throughput needed for the operation:

1. Effectiveness ratio (service/operation),
   which links the service to the size of the operation.
2. Thrift ratio (operation/throughput),
   which links the operation to the use of the resources.
3. Margin ratio (throughput/resource base),
   which links the use of resources to the total resource base.

5.2.3. The PSR model

The Pressure-State-Response (PSR) model relies more on environmental sciences than the previous two. Developed by the OECD and others, the PSR model (see Figure 1) has pressure indicators that represent the environmental pressures of anthropogenic activities (*e.g.* emissions, resource use). State indicators reflect the state of the environment, like the quality or quantity of natural resources, and aid in supplying the intended audience with a picture of the overall environmental situation. Response indicators represent what actions society takes in responding to environmental changes and concerns.

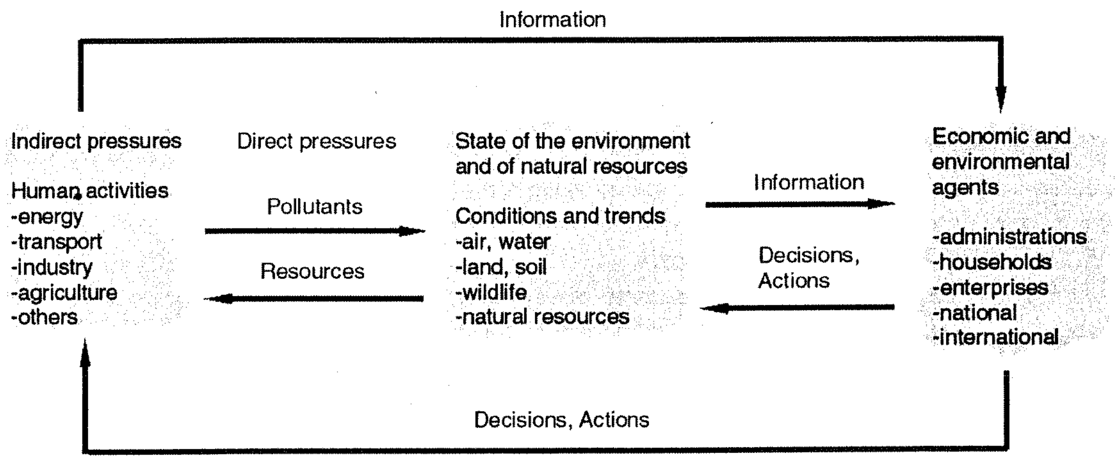


Figure 1. The Pressure-State-Response (PSR) model (OECD, 1998).

The PSR model is generally approved of and a number of other organizations including the UN, the EU and the USEPA have all proposed frameworks based on this one. (Lundin, 1999)

5.2.4. The DPSIR model

The European Environmental Agency (EEA) and the European Statistical Office (Eurostat) have extended the PSR model to include Driving Forces and Impacts (see Figure 2). Driving Forces include economic development, population, education and lifestyle, while Pressures include emissions, physical impacts and the use of natural resources. State indicates the concentrations of pollutants, quality/quantity of natural resources and biodiversity. Impact includes health-related aspects and biological effects. Responses may be changes in energy policy, installments of pollution-reducing technology, or even purely remedial actions (*e.g.* lake liming).

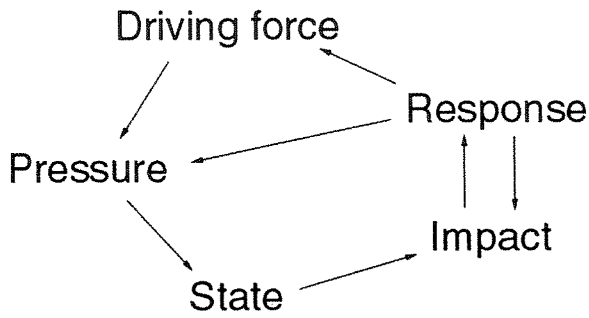


Figure 2. The DPSIR model used by the EEA (Eurostat, 1997).

As the DPSIR model is an extension of the PSR model, it is more complicated, but also more flexible. The Swedish EPA has used this model in order to monitor the 15 national environmental objectives[2].

5.2.5. The Media Approach

The US Office of Water, in an attempt to make water quality information available to the public, has created a tool for water management and established a national baseline, using a media-based framework. Here information concerning water resources, drinking water quality and the state of aquatic ecosystems is provided. The two types of indicators suggested by this method correspond to the Pressure and State of the PSR model, although here they are referred to as the vulnerability and condition of the aquatic ecosystems.

'The Media Approach' is a holistic method, as it emphasizes the well being of the ecosystem and the stresses on the environment caused by different human activities.

5.2.6. Socio-Ecological Indicators

This is a framework that focuses early in the causal chain, i.e. in the chain of causes in society to effects in the environment. These indicators are directed towards the causes within society, rather than their environmental effects, and therefore hoped to provide an earlier warning than environmental quality indicators would. The process of indicator development is based on four principles of sustainability (Azar *et al.*, 1995):

1. Substances extracted from the lithosphere must not systematically accumulate in the ecosphere.
2. Society-produced substances must not systematically accumulate in the ecosphere.
3. The physical conditions for production and diversity within the ecosphere must not become systematically deteriorated.
4. The use of resources must be effective and just with respect to meeting human needs.

[2] For more information, see http://www.environ.se:8084/.

The Socio-Ecological Indicators are usually formulated as a ratio between environmental pressure and a reference value based one of the four principles of sustainability (see Table 1).

Table 1. Examples of Socio-Ecological Indicators (Azar *et al.*, 1995).

	Principle 1	**Principle 2**	**Principle 3**	**Principle 4**
Socio-ecological Indicators	Lithospheric extraction rates	Anthropogenic flow compared to natural flows	Transformation of lands	Share of population that does not get their basic human needs
	Non-renewable energy supply	The long-term implications of present emissions	Nutrient balance in soils	Intergenerational justice

5.2.7. The Ecological Footprint and the Sustainable Process Index

One of the most well known indexes of SD is the Ecological Footprint, developed by Wackernagel and Rees (1996). The idea is that one can assess the environmental impact of a service in terms of land areas. To do this, five major categories are included: food, housing, transportation, consumer goods, and services. Even land and water needed for waste assimilation is to be included.

The Sustainable Process Index is another area-based framework, but is intended for and focused on process technologies (Krotscheck and Narodoslawsky, 1996).

5.3. Current SDI Programs

5.3.1. The UNCSD Indicator Program

The UNCSD has defined a working list of 134 indicators, based on the PSR-framework and the indicators originate in the generally accepted dimensions of SD: social, economic and environmental, as well as other dimensions such as institutional or cultural aspects. These are currently under testing by 22 countries (incl. South Africa) in order to prove the individual indicators' worthiness and make these available to policy-makers by the year 2001. (UNCSD, 1999)

5.3.2. The OECD Indicator Program

The OECD and its member countries currently run an indicator program with the following purposes:

- to keep track of environmental progress
- to ensure integration of environmental concerns into sectoral policies (e.g. transport, energy and agriculture)
- to ensure integration of environmental concerns into economic policies
- to use indicators to measure environmental performance and to help determine whether countries are on track towards sustainable development.

The members have agreed to use the PSR-model as a common harmonized framework and identify sets of indicators based on their policy relevance, analytical soundness and measurability. The indicators are measured on a country-by-country basis. The "OECD core set of environmental indicators" is a commonly agreed upon set of indicators for OECD countries and for international use, and is published every two years. (OECD, 2000)

6. SDI for urban water systems

6.1. Definition, objectives and criteria

Although several definitions of the SD of urban water systems exist, the definition presented by Lundin *et al.* (1997, 1999) has been used in this report and is as follows:

> "A sustainable urban water system should over a long time perspective provide required services while protecting human health and the environment, with a minimum use of scarce resources."

With this definition in mind, the objectives of a modern urban water system can be listed as four points:

- Reliable supply of safe water to all users for drinking, hygiene and household purposes
- Safe transport and treatment of wastewater
- Drainage of urban areas
- Recovery of resources for reuse or recycling

When developing and evaluating SDI for urban water system, this definition and its consequent objectives may not be sufficient. Several other aspects arise that may be important for the assessment of existing systems and future solutions.

Lundin (1999) has compiled a list of criteria from several publications that deal with this subject, which include technical, environmental, economical and social aspects.

Technical performance has two aspects: effectiveness and efficiency. The effectiveness is to which degree pre-defined objectives are achieved (*e.g.* treatment performance), while efficiency deals with the amount of energy and resources that are used in order to achieve the objectives (*e.g.* chemicals and energy used for treatment).

Reliability, flexibility and adaptability. An urban water system is reliable when it can provide its intended service in spite of unexpected events, such as power failures. Although a system may fail, the system's recovery must not demand unnecessary effort or cost. As changes in ecosystems and public demand, as well as technological improvements occur, an urban water system's potential to change (flexibility) and its ability to change (adaptability) will affect the system's future possibilities of achieving SD. Municipal wastewater treatment plants (WWTP) are designed to receive household and industrial sewage of similar type, but not stormwater. The separation of these flows allows different, more adequate treatment options.

Durability refers to the longevity of the technical system. As the life expectancy of the components of a WWTP is long (several decades), a balance between the endurance and the flexibility of the system must be met, so as to not decrease the possibilities of future changes of equipment.

Scale and degree of centralization should depend on the area's specific requirement and possibilities. When the population density is low and the natural conditions are appropriate, a local water supply and/or small-scale wastewater treatment may be advantageous. In large cities, where the economical and geographical conditions are different, the potential for using sophisticated technology is enhanced and contributions to other technical systems, *e.g.* the energy system, are economically and technically possible.

Environmental protection. Only those urban water systems that fulfil the objectives of limited pollution of the environment and promote a cyclic and/or sustainable use of resources can be considered environmentally acceptable. The recycling and reuse of the limited resource phosphorus is especially important, but other plant nutrients, water, organic compounds, energy and chemicals should also be recycled and reused when possible.

Noise, odor and traffic are factors that need to be considered, e.g. for the collection of sewage and the transportation of sludge.

Cost-effectiveness and affordability can be viewed from several aspects: household, organization, and society. The user requires an affordable service, the organization focuses on a cost-effective system, while society as a whole must consider a number of different priorities, *e.g.* stable, but flexible systems, the cost of detrimental effects on human health and the environment, the need and willingness to achieve SD, etc.

Personnel requirements. This applies to the time required for operation and maintenance of the urban water system as well as the level of personnel skills. The need for civil engineers to embrace development in microbiology, chemistry, ecology and information technology (IT) is increasing, and is catalyzed by SD. Diversity in terms of education and gender among the personnel is required to ensure a flexible and adaptable organization.

Demographics, such as population, population growth and density, specific water use and supply coverage of population are traditional indicators that are used to assess the future and existing needs.

Social dimensions. The basic human needs of a safe water supply and adequate sanitation must be met. Hygiene is vital for both the users and those who operate the urban water system or take care of the final product (*e.g.* sludge). It should be convenient as well as socially and culturally acceptable. As some individuals are willing to sacrifice time and effort in reducing the environmental impact, while others are not or cannot, freedom of choice is important. The system should be able to function as intended under both circumstances.

Awareness and promotion of sustainable behavior. Our behavior has a direct effect on the function of urban water systems. Water and chemical use are obvious effects, but our life styles affect resource use and emissions as well. For example, by decreasing the intake of protein-rich foods in our diets, the emissions of nitrogen will decrease. Even the way we travel affects our urban water systems, as cars pollute stormwater, which reaches rivers and lakes, and when combined sewers are present, possibly even our agriculture through sludge fertilization.

6.2. The 19 applied indicators

Lundin *et al.* (1997) initially proposed a list of 20 SDI for urban water systems, by first categorizing the urban water system in terms of four environmental and technical systems: freshwater resources, drinking water, wastewater and sewage sludge. Each system was represented by a limited number of dimensions broken down into indicators, which were selected on the basis of five criteria:

- Move towards or away from sustainability
- Availability of data of sufficient quantity and quality to provide spatial and temporal trends
- Representativity of one or more aspects of the sanitary system
- Applicability to a range of sanitary systems
- Ease of use

The indicators were subsequently tested in a limited case study in Göteborg (Lundin *et al.*, 1999), where 14 were demonstrated as useful in assessing the temporal variations of an urban water system.

In this case study, 17[3] of the originally proposed 20 indicators (see Table 2) have been tested in an attempt to evaluate the sustainability of the urban water system of the study area, and also to consequently evaluate the use of the individual indicators. The 14 indicators selected in the Göteborg case study are marked (GBG).

Table 2. The 17 SDI used in this case study (adapted from Lundin *et al.*, 1997).

Suggested indicator	Type	Suggested reference value	GBG
Withdrawal, %	Pressure	<100	•
Raw water quality	State	All water should be drinkable	•
Protection	Response	All sources should be protected	•
Water Use	Driving Force	Sufficiency	•
Drinking water quality		WHO or National Standards	•
Chemical and energy use for water supply	Efficiency	As efficient as possible	•
Leakage, %	Efficiency	Low	•
Reuse, %	Efficiency	No reference value suggested	
Wastewater production, (liters per capita per day)		Only sewage should be treated	•
Combined sewers, %		0% combined 100% separate	
Treatment performance, % removal of BOD, P and N	Effectiveness	At least according to regulation	•
Loads to receiving waters of BOD, P and N	Pressure	What nature finds acceptable	•
Chemical and energy use for wastewater treatment	Efficiency	As efficient as possible	•
Resource use per removal of nutrients	Efficiency	As efficient as possible	
Recycling of nutrients, %	Effectiveness	100%	•
Quality of sludge		Below standard	•
Energy recovery	Efficiency	As high as possible	•

[3] Three of the original 20 SDI were rejected on the grounds that they were not believed to be either applicable, suitable or provide useful information.

These SDI were primarily developed for studies in developed countries in Western Europe and North America. As this study was to be performed in South Africa, a developing country, additional indicators were believed to be necessary to cover the additional developmental aspects present. The 134 indicators described by the previously mentioned UNCSD Working List of Indicators of Sustainable Development (UNCSD, 1999) were reviewed as to which may have developmental relevance in the field of urban water systems without overlapping the other 17 proposed indicators. Two indicators were chosen from the Working List on the basis of these two criteria (see Table 3).

Table 3. The two additional indicators developed by the UNCSD and used in the case study.

Suggested indicator	Type	Suggested reference value
Access to safe drinking water	State	100%
Access to adequate sanitation	State	100%

The following chapters describe the individual indicators as proposed by Lundin *et al.* (1997) and tested by Lundin *et al.* (1999), except the two indicators concerning development, where descriptions by the UNCSD (1999) have been used.

6.3. Descriptions of the applied indicators

6.3.1. Withdrawal

The withdrawal indicator is calculated by dividing the annual freshwater withdrawal by the annual available amount. It shows whether or not the withdrawal is at an acceptable level, and if future shortages are to be expected. Therefore, it is a sensitive SDI and should indicate an early warning. High quality data is usually easy to attain on withdrawal volumes, as these are measured by a waterworks, but this needs to be complemented with data from other consumers, *e.g.* irrigated agriculture and industries. Only estimations are possible for the available volumes of surface and groundwater. Data between areas varies depending on climate, population, economic development and seasonal variations. The withdrawal indicator also relates to population and population growth, the future demands of agriculture and industry, and ecosystem health.

6.3.2. Raw water quality

This parameter is essential for the sustainable future of freshwater ecosystems, as well as for human health. Treating polluted raw water is not a sustainable activity, when large amounts of chemicals and energy are used. In agricultural areas, pesticides and nitrate may pose a threat, while insufficiently or untreated sewage might affect the concentrations of the biochemical oxygen demand (BOD) and coliforms. For larger suppliers of raw water, the quality is usually measured on a routinely basis, and this information can often be found at other authorities and organizations as well. This indicator also gives information on other activities that might affect the raw water source, *e.g.* point sources of municipal discharges, industrial discharges and waste facilities, non-point sources such as agricultural and urban runoff and landfills. It also indicates the amount of treatment necessary to produce drinking water of a required quality, which costs energy and resources.

6.3.3. Protection

A high degree of protected water sources ensures present and future freshwater quality, assuming the protection is well functioning. The existence of a contingency plan indicates how prepared a community is for accidents and eventualities. Without protection and contingency plans, the risk increases that the raw water quality will be affected by potential hazards such as agricultural runoff containing pesticides and nitrate, landfills, municipal and industrial wastewater discharges containing bacteria and virus, traffic leaving heavy metals, petrol and oil or accidents occurring involving these or other chemicals. As this matter is often up to politicians, it shows the level of concern for the environment and for human health issues on a political and democratic level.

6.3.4. Water use

As the population increases and development progresses, increasing volumes of water are used for domestic and industrial purposes. It is therefore important that water is not unnecessarily wasted. At the same time, sufficient volumes of water must also be supplied to the public for development to proceed. Data on this is available from the local waterworks, and the distribution on different sectors (*e.g.* agriculture, industry, leakage) is also of interest. For households and industries with individual supplies, such as wells, data for this indicator may be difficult to collect, for which estimations may be necessary. As the consumption of drinking water affects the use of energy and resources, it is well linked to the general idea of sustainability.

6.3.5. Drinking water quality

In order to protect human health, the quality of drinking water is of the utmost importance. It should have, at the most, tolerable levels of bacteria or chemicals (*e.g.* nitrate, lead, herbicides). Drinking water quality is measured in larger supply systems at the treatment works, but this may deteriorate before arriving at the consumer due to corrosion or contamination. Therefore, the drinking water quality may be difficult to assess at tap. Also, the quality of water in individual wells may be less well known. Such factors as leakage into the system may cause a difference between measured drinking water quality at treatment plant and actual quality at tap.

6.3.6. Chemical and energy use for drinking water treatment

The sustainable usage of chemicals and energy requires an efficient use of these, but not at the cost of the drinking water quality. Increased efficiency also means decreased cost for the treatment works. Uncontaminated groundwater requires little or no treatment, while surface water and contaminated reserves usually require at least some treatment. On the other hand, groundwater may require more energy due to pumping. The raw water quality and the degree of protection of freshwater resources affect this indicator. It, in turn, affects the quality of drinking water.

6.3.7. Leakage

Leakage occurs in great volumes in decaying pipes, and leads to increased pumping costs, loss of water (and revenue), loss of pressure, and increased risks of contamination by bacteria and corrosion products (*e.g.* copper, iron and zinc). Large amounts also enter the sewage pipes, diluting the sewage and decreasing the efficiency of the treatment process. Data on leakage is relatively easy to attain in areas where water meters have been installed in households. Otherwise, the municipality or other actors may have possibly made estimations, but this data should be viewed critically. Decreasing leakage not only decreases costs and increases revenue, it may also prove to be a vital way of increasing the water supply in 'dry' regions, without having to increase the withdrawal from scarce water sources. This indicator has a direct effect on the amounts of wastewater produced.

6.3.8. Reuse

In areas approaching the limits of their freshwater resources, even wastewater must be seen as a resource. Therefore, reusing it becomes important in achieving sustainability. Industries can reuse their wastewater, if necessary after treatment. Households can do the same by using gray water and treated wastewater for non-potable uses. Reusing wastewater for agricultural irrigation enables a recyclic use of not only water but also plant nutrients, although care should be taken so that it does not contain other components that may have detrimental effects on human and/or environmental health (*e.g.* heavy metals).

6.3.9. Wastewater production

An increased production of wastewater can be caused by an increased water usage or an increased leakage of infiltration water and stormwater. This may have a number of detrimental effects: untreated water may be released into the environment due to combined sewage overflows, sewage may be treated at a decreased efficiency, the amount of chemicals and energy used for sewage treatment may increase, etc. The minimization of wastewater, *i.e.* only true sewage is treated, is therefore important for the environmental sustainability. Large flows may be due to stormwater in combined systems, and to change the pipe system is an expensive task, but this may prove important when choosing a system (separate or combined) for new connections.

6.3.10. Combined sewers

Using a combined sewage system, where surface runoff from impermeable areas (*i.e.* pavement, etc.) is carried to a wastewater treatment plant (WWTP), increases the volumes received at the WWTP during rains. It also dilutes the sewage, making the treatment process less efficient, causes combined sewer overflows (releasing raw sewage into the environment), and pollutes the sewage sludge (due to road traffic), decreasing the possibility of recycling nutrients.

6.3.11. Treatment performance

WWTPs are built to treat collected wastewater. Their task is to reduce the amounts of pollutants in the wastewater before being released into the environment. The initial focus was on human health, but more recently the environmental health has become part of the agenda. The data on a WWTP's treatment performance is available for larger systems, and is commonly used within the sanitation sector. Yet, this indicator says nothing about the sensitivity of the ecosystem, the cost or resource use for treatment, nor of the fate of removed nutrients.

6.3.12. Loads to receiving waters

To reach sustainability, the releases of BOD, phosphorus and nitrogen into the environment need to be within what nature can cope with. The total load should also include agriculture and other non-point sources as well as WWTPs, individual sewage septic systems and combined sewage overflows. Data for this indicator is easy to find for larger systems, although for non-point sources (*e.g.* agriculture) data can be more difficult to find. This indicator serves as an early warning signal as increasing emissions of nutrients or oxygen demanding substances will affect receiving waters at some point.

6.3.13. Chemical and energy use for wastewater treatment

This is in line with the demands of an increased efficient use of chemicals and energy, in order to reach a sustainable development. The excessive dosage of certain chemicals (*e.g.* chlorine) may also have a detrimental effect on receiving waters and human health. Data exists on the energy and chemicals used in the treatment process at most WWTPs.

6.3.14. Resource use per removal of nutrients

Measuring the efficiency of energy and natural resources used in the removal of nutrients from wastewater, as the efficiency should be continuously improved as the technology allows. Data exists on the energy and chemicals used in the treatment process at most WWTPs, and this can be compared to the amount of nutrients removed.

6.3.15. Recycling of nutrients

The recycling of resources is a pillar of SD and this naturally applies to water and wastewater as well. The recycling of sludge as fertilizer decreases the need for commercial fertilizer, which requires large amounts of mined phosphorus, a limited resource. Commercial fertilizer also contains nitrogen, and as it is only the ammonia and nitrate forms of nitrogen that plants can use, the fixing of atmospheric nitrogen to these forms for use in agriculture demands large inputs of energy. An increased usage of sludge as a fertilizer will decrease the energy and resources used in agriculture.

6.3.16. Quality of sludge

To ensure the reuse of sludge as fertilizer without jeopardizing human health, it must fulfil the public and legislative requirements. There are many aspects of interest when considering the quality of sewage sludge as fertilizer, but the main subject of debate and possibly an important reason for reservations to its use has been the cadmium content in sludge, as well as that of other heavy metals. More recently in Sweden, the possible contamination of parasites, bacteria and viruses has lead to increased concern. Therefore, qualitative measurements of sludge quality play an important part in the future recycling of nutrients and reuse of sewage sludge.

6.3.17. Energy recovery

Substantial amounts of energy are used for the collection and treatment of wastewater, and energy (and biogas) is also produced in the treatment process. Recovering some of it is in line with SD. This can be done via *e.g.* biogas or heat pumps. The amounts of energy recovered by a plant should be recorded and available, although this may prove to be an uncommon practice in South Africa.

6.3.18. Access to safe drinking water

The previous indicators have been developed with the urban systems of Europe and the US in mind. In the developing area of this case study, other parameters must also been considered in order evaluate the sustainability of the water and wastewater system. The following SDI have been proposed by the UN Commission on Sustainable Development in their Working List of Indicators of Sustainable Development (UNCSD, 1999).

Safe drinking water is of the utmost importance when lowering the fecal risk and the frequency of associated diseases. "Safe" water does not contain biological or chemical agents at concentration levels directly detrimental to health. Access is defined as availability in the home or within reasonable distance. This is defined as within 15 minutes walking distance, although a more proper definition may be less than 200m, when in urban areas. An adequate amount of water should satisfy metabolic, hygienic and domestic requirements, and this is usually defined as 20 liters per day. (UNCSD, 1999)

The WHO (2000) recommends a minimum of 15 – 20 liters of clean water for consumption (drinking and food preparation) and sanitation (bathing, cleaning, *etc.*).

6.3.19. Access to adequate sanitation

This indicator represents information useful for assessing SD, especially human health. The accessibility to adequate excreta disposal facilities is fundamental to decrease the fecal risk and the frequency of associated diseases. This indicator can also provide evidence of inequity when studied from a geographic, social or economic point of view (UNCSD, 1999). This may prove to be especially interesting in South Africa, due to the country's history of apartheid.

A sanitary facility is defined as a unit for disposal of human excreta, which isolates feces from contact with people, animals, crops and water sources. Suitable facilities range from simple but protected pit latrines to flush toilets with sewerage. All facilities, to be effective, must be correctly constructed and properly maintained. (UNCSD, 1999)

7. The Case Study

7.1. Background information

7.1.1. The Eastern Cape Province of South Africa

The most south-eastern part of the country, the Eastern Cape Province (see Figure 3) includes the eastern half of the Cape Province of the old South Africa, as well as the ex-"homelands" of Ciskei and Transkei. Historically, this is where dissatisfied citizens, *trekking* eastwards from Cape Town, first met the amaXhosa, the agricultural and pastoral peoples native to the Eastern Cape. There had been trading contacts between the Europeans and the amaXhosa since early in the 18th century, but friction developed between the two peoples in the last quarter of that century over grazing grounds, water rights, and the terms of cattle trade. In 1779, the 1st Cape Frontier War started and seven more Cape Frontier Wars followed, first between settlers of Dutch descent and the amaXhosa, and later on also involving British and other European settlers and the British colonial power. Most of these battles took place in the area between Fort Hare-King William's Town-East London, and the area still carries the "Frontier" name. (Compton's Encyclopedia, 2000)

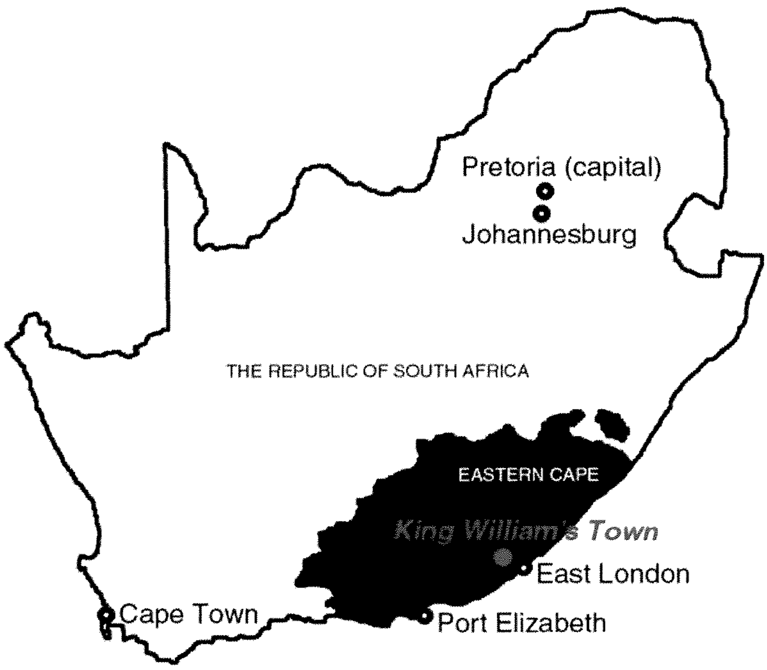
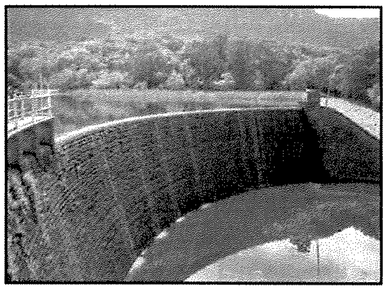


Figure 3. Map of South Africa and the location of the study area.

Today, approximately 6.3 million people live in the Eastern Cape, which comprises an area of 170,000 km^2. 84% of its inhabitants are Xhosa-speaking peoples, while 10% speak Afrikaans and less than 4% have English as their mother tongue, although many more speak this language as well. Port Elizabeth-Uitenhage is the largest industrial and economic center. The provincial capital is Bisho and other important cities include East London, Grahamstown, King William's Town (KWT), Cradock and Graaf-Reinet (South African Government, 1998). Outside the previously predominantly 'white' areas of the old South Africa, societal functions are poorly developed. Concentrating on the water and sanitation aspect, less than 20% of the households have access to the World Health Organization's minimum standard of drinking water and 87% of the population does not have access to adequate sanitation (Provincial Government, 2000).

7.1.2. The Buffalo River

The Buffalo River provides water and transports waste effluent in one of the most populated areas of the Eastern Cape Province. The catchment supports today an ever-growing population of approximately 311,000 people, of which most live in the towns and townships of KWT, Zwelitsha, Mdantsane and East London, and all receive water from the river.


The Maden Dam

The Buffalo River rises in the Amatola Mountains and flows southeast for 125 km to the sea at East London. The river can be divided into three different sections: The upper region which reaches down to KWT, where the mountain stream winds it way through forested areas down to the Maden Dam and continues through the foothills and agricultural land downstream of the Rooikrans Dam; the middle region, which includes the urban and industrial areas of KWT and Zwelitsha to Laing Dam and also an agricultural area downstream of Laing; and the lower region downstream of the Bridle Drift Dam, comprising coastal forestry and the estuary, which includes the harbor of East London.

The agriculture section in the Buffalo River is split between forestry, compromising an area of 90 km^2 and a relatively minor area of 31 ha of irrigated land. Water for environmental needs is not at present being released from the dams, but downstream releases from Rooikrans Dam through the Pirie trout farm, do partially fulfil this requirement. (O'Keeffe *et al.*, 1996)

Research done by the Water Research Commission has shown that there has been concern about the water quality in the Buffalo for many years, and considerable worry about the middle (incl. the study area) and lower regions. Laing Dam, which supplies the large areas of Zwelitsha, Ilitha and Phakamisa with raw water, is located shortly downstream of the study area and receives treated domestic and industrial effluent from King William's Town and Zwelitsha. Salinification and eutrophication have been the major concerns (O'Keeffe *et al.*, 1996). Therefore, all effluent being released into it must comply with the Special Standard Limits[4] of South Africa (see Appendix 1).

7.1.3. King William's Town – Yesterday and Today

The first white settlement in the modern KWT area was the Brownlee Mission Station, established in 1826 (Zituta, 1997). The settlement was declared a Borough in 1861 and was the first formally established urban settlement in the area. During the establishment of the 'independent homeland' of Ciskei in the early 1970's, KWT was carefully left out and a land bridge stretching inland from East London kept the valuable property and industries of the town in the old Republic of South Africa. After the re-incorporation of Ciskei into the democratic Republic of South Africa, the new TLC includes areas with extreme differences, both ethnically and economically.

The Eastern cape has long been associated with a high unemployment rate and, in this regard, the unemployment rate for KWT is estimated to be in the order of 45.3%. 40% of the household incomes are below the minimum subsistence level, defined as R931.82 per month (*ca.* 1250 SEK) for a household of 5 members in the KWT sub-region. (Setplan, 1997)

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[4] E-mail communication with Mr. P. Kempster of DWAF.

7.1.4. King William's Town TLC – The municipality

The KWT Transitional Local Council (TLC) was established in 1994 and is now the seat of the Provincial Government of the Eastern Cape. It includes the previously independent municipalities of King William's Town, Bisho and Ginsberg, as well as the four towns of Zwelitsha, Phakamisa, Ilitha and Dimbaza. Breidbach and Schornville are the previously 'Colored' areas of the old King William's Town municipality. The rural village of Tyutyu has been part of the TLC since 1995, while other rural villages within the area have elected not to be included. (Davidson *et al.*, 1996)

A report prepared by Setplan (1997) for the KWT TLC estimated the population at some 150 000. The populations of the study area's communities are marked in white in table 4.

Table 4. Population, households and household sizes of the TLC. (PDG, 1998)

Area	Population[1]	Total households	Average household size
Bisho	5840	1465	4.0
Breidbach	6490	1105	5.9
Dimbaza	39150	6386	6.1
Ginsberg	5860	1623	3.6
Ilitha	9210	1822	5.1
KWT/ Schornville	23120	3018	7.7
Phakamisa	8920	1316	6.8
Tyutyu	6920	1165	5.9
Zwelitsha	40560	9291	4.4
Sweetwaters	na	344	Na
TOTAL	147070	27535	5.3

[1] Population estimation from 1997.

The TLC includes an estimated 27 535 households, of which some 10 730 are resident in either backyard shacks, informally on formal sites, or on informal sites. (PDG, 1998)

The population is mostly poor and expected to grow fairly rapidly at approximately 3% per year. The economy of the area is relatively small, and only a modest rate (2%) of economic growth is expected within the next ten years, resulting in a slowly worsening income profile for the households of the TLC. (PDG, 1998)

7.2. The urban water system of the study area

The two dams (Maden and Rooikrans) supply the three areas of King William's Town, Ginsberg and Breidbach via the KWT Water Purification Works. Domestic and industrial sewage is sent to the Schornville STW, where it is treated before being released into the Buffalo River. Domestic sewage from the Breidbach area is treated by the Breidbach STW, which is located on the banks of the Yellowwoods River, a tributary to the Buffalo.

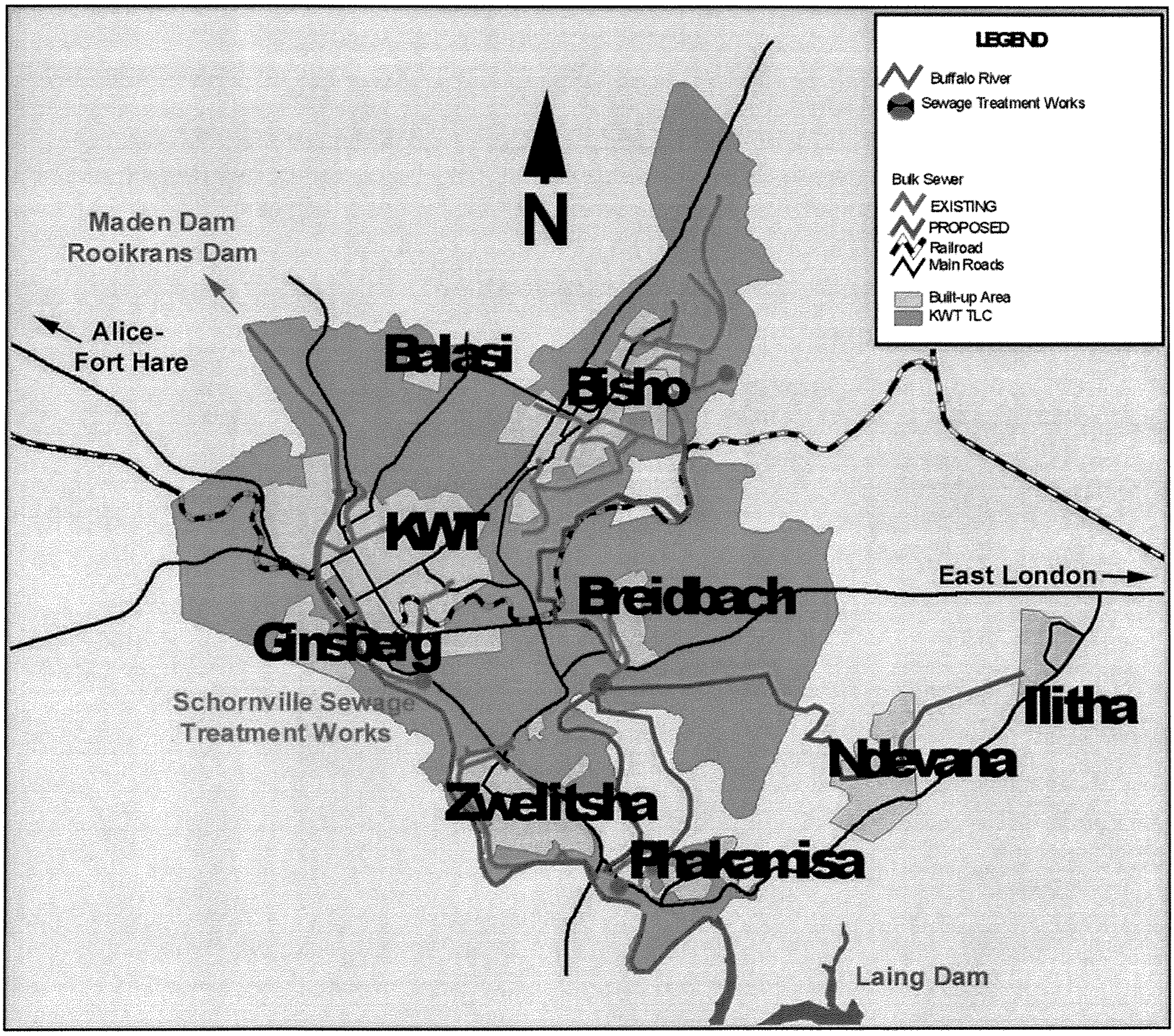
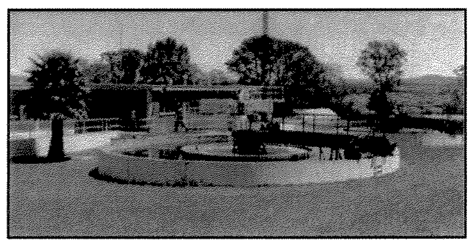


Figure 4. Map of the TLC and its wastewater system. (Supplied by Setplan of East London)

7.2.1. King William's Town Water Purification Works

The KWT Water Purification Works (WPW) receives raw water from the Maden and Rooikrans Dams and supplies King William's Town, Breidbach and Ginsberg. The raw water is purified with lime, chlorine and aluminum sulfate and uses clarifiers and sand filters. The treatment plant reached 88% of its design capacity in March 1994, and peak water demands push the works into overload mode (Setplan, 1997).



The KWT Water Purification Works

7.2.2. Schornville Sewage Treatment Works

This is the larger of the two WWTPs and is located within KWT proper, in an area of the town called Schornville (see Figure 4). Built in the 1960's, it initially only applied mechanical and biological (biofilter) treatment but was updated and expanded in the 1980's with a separate activated sludge treatment step. Today, the intention is that 60% of all incoming raw sewage should pass through the more effective activated sludge treatment step with phosphorus removal through chemical coagulation (further on referred to as the NEW section of the STW), while the remaining 40% passes through the OLD section of the WWTP, with traditional sedimentation tanks, a biological treatment step, a sludge digester tank as well as sand filters (GIBB, 1999). The exact distribution between the two is unknown, as the separate flows are not measured. All effluent to the Buffalo River is also treated with chlorine, for reasons of sanitation.

Approximately 11% of the sewage is of industrial origin, while the remainder is domestic (GIBB Africa, 1999). Although the received sewage is intended to be of pure household and industrial origin, as a number of backyard tap drains are damaged, surface runoff enters the system during heavy rains.

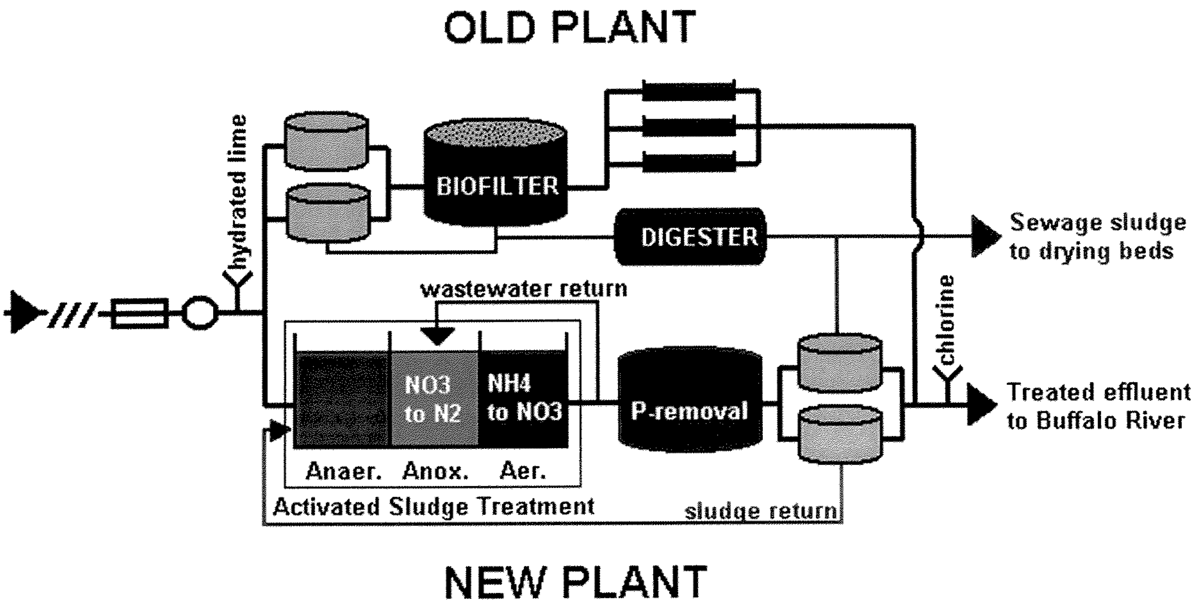
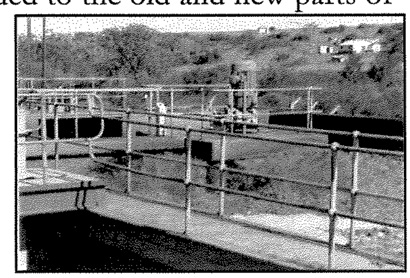


Figure 5. A schematic picture of the Schornville Sewage Treatment Works.

The sewage enters the works and first passes through the mechanical filters (see Figure 5). The mechanical screens were once automatically cleaned, but as they had started to break down quite often, causing costly maintenance, they have been replaced by ones that are cleaned manually. Next, the flow is divided temporarily into three flows that pass through a grid filter. Following this is the flow counter, as well as the addition of hydrated lime for pH-adjustment. Here the flow is divided to the old and new parts of the WWTP. The old part starts with two parallel sedimentation tanks, which lead on to a biological treatment step. Afterwards, sludge is de-watered and digested in a sludge digester tank, while the wastewater passes through three parallel sand filters. The newer section of the plant includes the three steps of the activated sludge treatment: anaerobic, anoxic and aerobic. Ferric chloride is also added to this flow for phosphorus removal, through chemical coagulation and consequent



The aerobic step of the new plant

sedimentation. Two parallel sedimentation tanks (a.k.a. clarifiers) follow. Both the old and new flows are then treated with chlorine before being released to either the Buffalo River, although 20% of the incoming flow is diverted to a local industry, King Tanning and the KWT Golf Course for irrigation prior phosphorus removal and chlorination (not shown in Figure 5).

During our visits to the treatment works, notes were kept over which parts were malfunctioning and waiting for repairs. These included:

- The sludge digester of the old plant. The sludge intended for this step was instead sent to the activated sludge treatment step.
- One sedimentation tank.
- The anoxic step in the activated sludge treatment process.

Breakdowns occur quite often at the plant, one at least every three months[5], and replacements and repair crews can take a while before arriving.

7.2.3. Breidbach Sewage Treatment Works

The Breidbach area is served by a waterborne sanitation system, where sewage is conveyed to oxidation ponds. The WWTP is on the east banks of the Yellowwoods River, a tributary of the Buffalo. Its capacity is 800 m^3/day.

The works consists of a set of two primary and four secondary oxidation ponds. The effluent overflows into an irrigation pond prior to disposal by irrigation. The effluent is irrigated onto sportsfields. The average sewage flow in 1993 was 514m^3/day. The oxidation pond system is not capable of producing effluent, which meets the Special Phosphate Standard, which applies to the Yellowwoods; hence the effluent is irrigated. Although no effluent should flow from the works, periodic discharges occur due to runoff from the irrigated lands and due to pond seepage (Department of Public Works, 1994).

7.2.4. Greater King William's Town Regional Sewerage Scheme

The greater King William's Town TLC area (see Figure 4) is currently served by a total of five existing WWTPs, located in Bisho, Breidbach, Schornville, Zwelitsha and Ilitha. As some of the treatment plants are too small, or non-functioning, untreated or partly treated sewage is discharged into the Buffalo River and its tributary, the Yellowwoods River. These rivers discharge into the Laing Dam, the main drinking water supply for the large settlements of Zwelitsha, Ilitha and Phakamisa.

The idea of building a Greater King William's Town Regional Sewerage Scheme has existed for a number of years, and been the subject of a number of scoping reports (*e.g.* Department of Public Works, 1994; Setplan, 1997; GIBB, 1999). Building a larger-scale WWTP for the TLC will allow the implementation of new treatment technology, otherwise not appropriate for smaller-scale systems.

The latest report (GIBB, 1999) recommends the existing Zwelitsha STW as the most advantageous site, opposed to sites suggested at Breidbach, Tshatshu and Fort Murray. Note that the proposed site for the new large-scale treatment plant indicated in Figure 4 (blue dot) is not the Zwelitsha site, as this figure was taken from a earlier study (Setplan, 1997).

[5] Estimation by Ms. Daria Dolley, Schornville Sewage Treatment Works.

7.3. Data quality assurance

7.3.1. Collected data and data sources

Quantitative and qualitative data has been collected from the following state departments, municipal offices and private companies: The KWT Water Purification Works, the Schornville Sewage Treatment Works, the Amatola Water Board (Nahoon Dam office, East London), the Deptartment of Water Affairs and Forestry (DWAF) in East London and other offices, and Setplan in East London, in addition to the numerous reports mentioned in the list of references. The following describes the quality (*i.e.* data gaps and estimations) and quantity (temporal span) of the data.

• King William's Town TLC Framework Plan

A great deal of background information, concerning technical and socio-economic aspects of the study area, was found in a report produced by the private consulting company Setplan of East London. Setplan was appointed by the TLC "to formulate an integrated Framework Plan for the TLC area that identifies the broad, overarching socio-economic and spatial development issues which need to be focused on, in order to ensure that the prerequisites for SD within the TLC area are better met in the future." The report includes a development overview with its historical background, a description of the spatial and economic context of the TLC, information on its natural features, population, socio-economic development status, land use, engineering services, transportation and institutional/administrational organizations. The report was published in September 1997.

• Yellowwoods Regional Sewerage Scheme: Feasibility Report

In November 1993, HKS Consulting Engineers of East London was commissioned by the Department of Public Works to investigate possible future schemes of wastewater treatment, as many WWTPs in the area were not able to produce effluent that complied with the General Standard, either due to overloading or malfunctioning. The report was published in May 1994.

• Greater King William's Town Regional Sewerage Scheme: Initial Scoping Report

With the reconstruction of the country of South Africa, and the creation of the KWT TLC, the TLC agreed that investigations into a regional sewage treatment works should continue. GIBB Africa (formerly HKS) was commissioned to perform an Environmental Impact Assessment (EIA) to assist in the decision-making of the future process. The EIA involved an Initial Scoping process, which was published in August 1999.

• KWT Water Purification Works

Obtained data includes readings of the inflow meters for water taken from the Maden and Rooikrans Dams (September 1992 through December 1996, complete), and monthly reports of the chemical usage and the inflow of raw water from the dams (November 1996 through December 1998, complete).

• Schornville Sewage Treatment Works

Sewage inflow data and the separate outflows (Buffalo River, KWT Golf Course, King Tanning) was recorded in monthly reports for the period September 1992 to December 1996 and has been collected. The sewage inflow values can be assumed to be correct, although the outflow values to the river may be incorrect as the meter has been malfunctioning, and outflow readings to the Golf Course and King Tanning are missing for a number of months.

For the years 1994 and 1995, the daily reports on in- and outflow volumes, chemical usage (lime & chlorine), and NH_3-measurements was collected. Due to a lack of time, calculating monthly averages was done by using the first five measurements of each month.

The same principle was applied to data covering chemical measurements (pH, electric conductivity, alkalinity, nitrate, ammonia, orthophosphate, residual chlorine, permanganate value and COD) of the raw sewage inflow and new and old plant outflows for the period April 1996 through May 1998. For the following period, June 1998 through February 1999, all daily reports were collected and used for averaging.

All monthly reports for the period August 1996 through February 1999 (with some months missing) and August 1999 have been collected. These contained data on: total inflow, maximum and minimum daily inflow values, total usage of lime, chlorine and ferric chloride.

• Breidbach Sewage Treatment Works

Monthly inflow values been obtained for the period December 1993 to November 1998. This data was found stored at the Schornville STW.

• Department of Water Affairs and Forestry

Data on the raw water quality of the Rooikrans Dam was collected for a large number of parameters, reaching as far back as 1968 (see Appendix 2). Old measurements of the effluent values from Schornville were also acquired for the older biofilter plant (1975 – 1985, 1988 – 1993) and for the newer activated sludge plant (October 1987 through September 1993). These tests were only performed approximately once a month.

• Engineering Section, KWT TLC

The Engineering Section (located in Bisho) supplied us with copies of the Setplan Framework Plan and the Yellowwoods River report by the old Department of Public Works.

• Howard Pim Library, University of Fort Hare

Multiple reports, like those from the Water Research Commission (WRC), were acquired from this library.

7.3.2. Comments on data reliability

The quality and reliability of data sets has been evaluated where possible, and through this process a number of measurements and certain data sets have been exempted from the following analyses on the grounds that they have been found to be unreliable or misleading. As for flow data, which is an important piece of information for a number of indicators, all data on the outgoing flows from the Schornville STW have been exempted as they do not correlate to the ingoing flows, and personnel at the plant were of the opinion that only the inflow data was correct. For certain months, more than 50% of the inflow "disappears" and is not found among the three outflow destinations: the Buffalo River, King Tanning, and the KWT Golf Course. Instead, the outflow volumes to the

Buffalo River have been calculated as 80% of the inflow, according to a report by GIBB Africa (1999).

Certain data on the measured chemical content of untreated and treated wastewater have also been exempted, in cases where the values seemed not probable and extreme. In general, the collected data on the chemical content of treated and untreated wastewater seem to have some flaw. Although it is natural for these measurements to vary, mostly depending on the volumes of water in the sewage, the actual loads of pollutants should be fairly stable, especially considering that the small amount of sewage originating from industries. Figures 6 & 7 show the calculated loads of phosphorus and COD arriving at Schornville. The large variances in these loads may be due to the sampling procedure, which is done manually and possibly at different times of day. In fact, the time of sampling can affect the results enormously, as the concentrations of pollutants vary over a day.

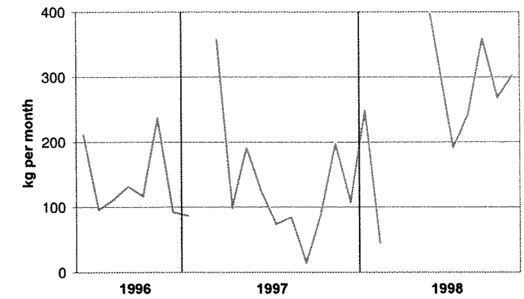


Figure 6. Loads of P arriving at Schornville STW.

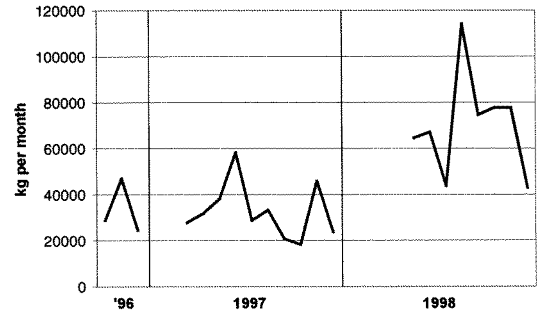


Figure 7. Loads of COD arriving at Schornville STW.

7.3.3. Data used in this study

Of the collected data previously mentioned, the following data sets listed in Table 5 have been used for the indicator calculations of this report.

Table 5. Data sets, types and temporal periods used for indicator calculations.

Data set	Type	Period
Population estimation of the TLC. Population growth estimation.	Estimation from 1997	N/A
Raw water quality at Rooikrans Dam. See also App. 2.	Samples taken several times per month.	1968 (earliest) – 9 Sep. 1999
Recorded inflow at the KWT Water Purification Works (WPW) from the Rooikrans and Maden Dams.	Monthly reports	Sep. 1992 – Dec. 1998
Chemical usage at KWT WPW.	Monthly reports	Nov. 1996 – Dec. 1998
Energy use at KWT WPW.	Monthly reports	Jan. 1997 – June 1999
Tap water quality tests.	Random tests	10 tests in 1998
Inflow volumes at Schornville STW.	Monthly reports	Sep. 1992 – Feb. 1999
Inflow volumes at Breidbach STW.	Monthly reports	Dec. 1993 – Nov. 1998
Chemical measurements (COD, P, NH_3, NO_3^-) of influent and effluent at Schornville STW.	First five measurements used for monthly averages	April 1996 – May 1998
Chemical usage at Schornville STW.	Monthly reports	Aug. 1996 – Feb. 1999
Energy use at Schornville STW	Monthly reports	Jan. 1997 – June 1999

7.4. Indicator results of the case study

7.4.1. Withdrawal

South Africa is poorly endowed with ground water, as it is mainly underlain by hard rock formations, which do not contain any major ground water aquifers (Basson, Van Rooyen, 1998). Surface water remains as the only economically viable source of fresh water.

Estimations[6] of the annual available volume of raw water in the Maden and Rooikrans Dams put it at a total of 3.1 million cubic meters. Previously, water was taken directly from both dams, but in 1996 the pipes from Maden Dam were stolen and have not yet been replaced. Fortunately, the Maden Dam is situated upstream of the Rooikrans, and the overflow from the former is collected by the latter before being piped to the KWT Purification Works.

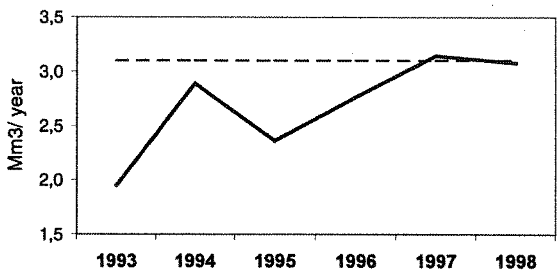


Figure 8. Total freshwater withdrawal as compared to estimated annual available amount.

As these two dams are now working in series, the total withdrawal volume has been used. The collected data shows that the withdrawal volume increased by 50% between 1993 ($2x10^6 m^3$) and 1998 ($3x10^6 m^3$). The 1998 withdrawal equals approximately 100% of the total annual available volume (see Figure 8).

Additional water is also taken to supply the Rooikrans Water Treatment Works, which supplies some small villages with clean drinking water and the small Pirie Trout Farm, downstream of the Rooikrans Dam.

Although the possibility of water shortages is clearly apparent, the Engineering Section of the TLC is not excessively worried, as it considers the problem to be "a lack of pipes". Future plans include reconnecting the two dams with pipes (reducing losses due to infiltration and evaporation) and a further interconnecting of dams, such as the large Wiggleswade Dam north of Bisho. This is believed to cover the future raw water needs of the TLC. The Engineering Section is though also aware that future increases in withdrawal will meet a limit.[7]

At a national level, full utilization of all the significant water resources is expected to be around 2025. (Basson, Van Rooyen, 1998)

7.4.2. Raw water quality

Also see Indicator Graphs 1-3 in Appendix 4.

The two dams are currently monitored by different authorities; Rooikrans falls under DWAF jurisdiction, while the Maden Dam is monitored by the TLC. DWAF currently measures 16 parameters to establish the raw water quality of the Rooikrans Dam (see Appendix 2)

The raw water quality of the Rooikrans Dam has been satisfactory for the entire period 1968 – 1999. Only slight increases of the concentrations of NO_3 + NO_2, orthophosphate and dissolved SO_4 have been measured. Although the dissolved sulfate most probably originates from long-distance sources of air pollution, the increased levels of nutrients may be due to the decreasing water levels in the dam. This may allow the nutrients imbedded in the sediment to return to the water due to enhanced circulation.

[6] Personal communication with Mr. S. Russeau, Amatola Water Board on 991110.
[7] Personal communication with Mr. Hetem, Engineering Section, KWT TLC on 991112.

The natural exchange of nutrients between the sediment and water will also increase with decreased volumes of water.[8]

Although no data from the smaller Maden Dam was acquired, it is assumed to have the same quality of water. In favor of this assumption is the dam's vicinity to Rooikrans, and the quality of the water received at the waterworks.

7.4.3. Protection

No formal protection of the two raw water sources was identified, but both the Rooikrans and Maden Dams are located approximately 20 km from the main urban area of KWT, of which almost 10 km is by gravel road, *i.e.* this is a remote area. No further development of the area is planned[9], and the Maden Dam is currently also used for trout fishing, while sailing is allowed on the Rooikrans.

No evidence of an existing contingency plan for the eventuality of an accident that would pollute these sources beyond usage was found, although water is already drawn from the Laing Dam in periods of drought. A "Disaster Committee", with members from the Department of Environmental Affairs and Tourism and from the Health Department of the TLC, among others, is responsible for actions during times of crisis.[10]

7.4.4. Water use

Also see Indicator Graph 4 in Appendix.4.

Due to the history of the region, population estimations have been educated guesses at best, and usually underestimating. The TLC's Framework Plan (Setplan, 1997) includes the latest population estimation and is assumed to be accurate.

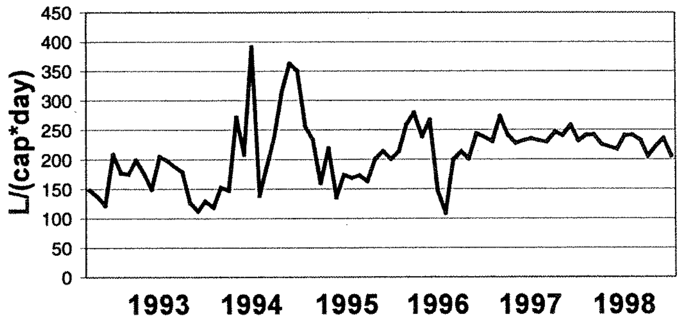


Figure 9. Water use per capita and day

The population of KWT (incl. Schornville, Ginsberg and Breidbach) served by the Waterworks in 1997 was estimated at approx. 35 500, increasing annually by 3%.

Consumption was calculated by dividing inflow values at the KWT Purification Works by the Setplan population estimation, which was adjusted according to projected population increases.

The water consumption (incl. industries and leakage) has increased from approx. 175 l/cap*d (mid-1993) to the peak of 1995 at over 250 l/cap*d, and now seems to be stabilising at around 230-240 l/cap*d. Deduction of the largest water-using industry receiving water from the Purification Works, King Tanning (2109 m^3/month, from O'Keeffe *et al.*), and leakage (20%) results in a domestic consumption of just under 200 l/cap*d. Note though that the withdrawal from King Tanning equals less than 1% of the total water use.

An interesting observation was made concerning the seasonal variations. Since 1994, these variations seem to decrease in magnitude (see Figure 9). It was suggested by Mr. Hetem of the Engineering Section of the TLC that this may be due to certain

[8] Personal communication with Mr. Häggström, senior lecturer at Water Environment Transport, Chalmers University of Technology, Göteborg, Sweden on 000317.

[9] Personal communication with Mr. Kooverji, DWAF, East London on 991105.

[10] E-mail communication with Ms. Katrin Ottoson, NV, 991220, currently posted in KWT.

demographic changes in the study area. As a large portion of the white community has left the TLC in recent years, and been replaced by a black and colored population, a decrease in the use of water for gardening purposes may be assumed.

The water consumption is well in excess of WHO minimum requirements.

7.4.5. Drinking water quality

The TLC employs Pollution Control Technologies in East London to perform regular water quality tests. Their results were difficult to attain, due to a question of who was to pay for the extra work of collecting and sending these, but some analyses of nitrate and residual chlorine done in 1998 were obtained from the Schornville STW.

The levels of nitrate in tap water are well below WHO recommendations of 45 mg NO_3^-/ l and 10 mg NO_3-N/l (Haglund, 1984).

The concentrations of chlorine seem to occasionally reach inappropriately high levels. A measurement of the free chlorine in tap water at the Civic Centre in central KWT (981203) was 0.79 mg/l. This can be compared to Swedish regulations of a maximum of 0.4 mg/l (VA-Verket, 1997). Although this one measurement should not warrant unnecessary concern, it indicates the importance of making other measurements accessible to researchers.

Wayne Selkirk[11] at Pollution Control Technologies, as well as others, speaks highly of the drinking water quality in King William's Town. Apparently, a Total Count (TTC) above 7/ml has not been measured since 1992, and there is never a problem with either coliforms or *e.coli* at the treatment works. The turbidity in recent years has varied between 1 and 5, but is usually below 2.

7.4.6. Chemical and energy use for drinking water treatment

Data on the usage of chemicals at the waterworks has been obtained for the period Nov. 1996 to Dec. 1998. During this period, the withdrawal of raw water has been stable at around $3x10^6$ m^3/y, or 230 l/cap*d. The dosage of chlorine and lime has as well been relatively stable during this period (2 mg/l and 8 mg/l respectively), while the dosage of aluminum sulfate has increased from approximately 17 to 20 mg/l.

The total amount of chemicals used in 1997 (see Figure 10) was for AlSO4 53 tons, increasing by 15% to 61 tons in 1998; for lime from 27 to 26 (-4%); and for chlorine from 5.6 to 5 (-11%).

Energy efficiency has decreased since 1997, when the consumption was approximately 12 Wh per m^3 (see Figure 11). In 1998, this has reached approximately 15 Wh per m^3. This applies of course to the total energy use

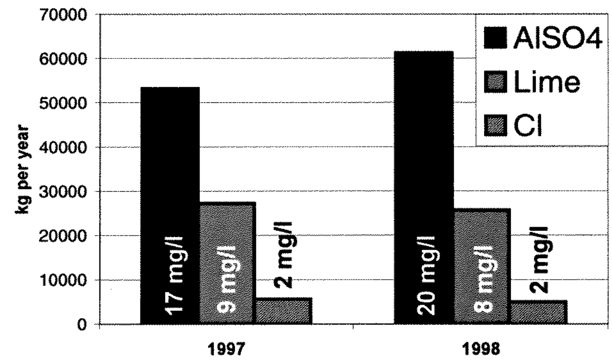


Figure 10. Chemical use and dosage at KWT WPW.

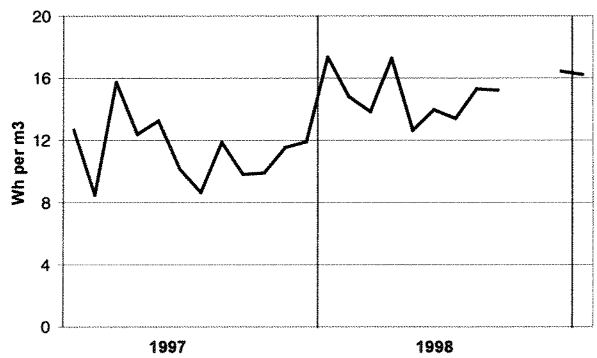


Figure 11. Energy efficiency at KWT WPW.

[11] Telephone interview on November 18, 1999.

as well, which has increased from 3000 kWh per month in 1997 to around 5500 kWh per month in 1999.

Future efficiency improvements are to be expected, as the dosing equipment at the KWT Water Purification Works is imprecise, making it difficult to optimize dosing according to need[12], but new equipment is hoped to be installed in the near future[13].

7.4.7. Leakage

The leakage in the water/wastewater system has been estimated at 20%[14], which is also the estimate for Göteborg (VA-verket, 1997). This estimate for the TLC is also confirmed by the Palmer Development Group (PDG, 1998).

As to whether this indicator is improving or not, sufficient information was not collected to make any assertion.

7.4.8. Reuse

No domestic reuse of water was found, but King Tanning and the KWT golf course receive approximately 20% of the effluent (prior phosphorus removal and chlorination) from the Schornville STW for irrigation purpose (GIBB, 1999). Both received individually just under 0.2 million m^3/year, for the years 1993-1996, but since then the meters have been malfunctioning. Also, all effluent treated at the Breidbach STW is irrigated onto sportsfields.

7.4.9. Wastewater production

Also see Indicator Graph 5 in Appendix 4.

The produced wastewater, received at the Schornville STW, has been fluctuating for the past six years with an extraordinary peak in 1996. The fluctuations are in sync with the summer rains, although not in magnitude (see Figure 12). This suggests that stormwater does enter the system, possibly through sabotaged standpipe drains, increasing the volumes of wastewater. In 1996 the inflow volume was 2.6 million m^3, equaling 250 l/cap*day. This decreased in 1998 to just under 1.5 million m^3 or 135 l/cap*day.

The Schornville STW is overloaded, with its design capacity of only 4800 m^3/d (GIBB, 1999). For example, in June 1996 the average daily load was 7875 m^3/d and in June 1997 was 5690 m^3/d.

The much smaller Breidbach STW received during the period 1995-97 approximately 0.2 million m^3/y, equaling 90 l/ day and person connected. This is less than the design capacity of 800 m^3/d or 0.3 million m^3/y (GIBB, 1999).

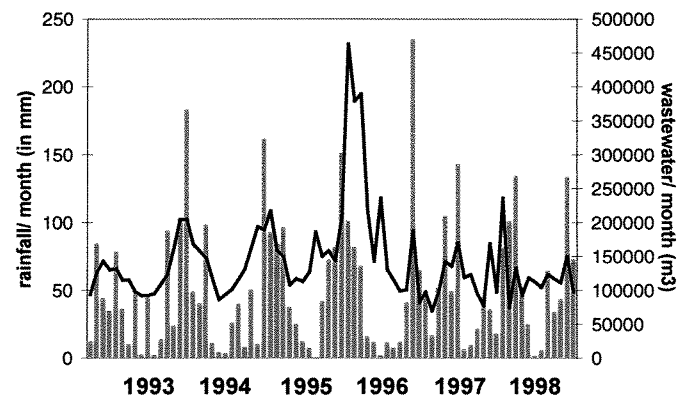


Figure 12. Wastewater production (line) and rainfall (bars).

[12] Personal communication with Mr. Braweni of the KWT Water Purification Works on 991102.

[13] Personal communication with Mr. Hetem of the KWT TLC's Engineering Section on 991112.

[14] Based on personal communication with Mr. Hetem, Mr. Kooverji (DWAF, East London) and a report by the Dept. of Public Works (1994).

7.4.10. Combined sewers

The standard in South Africa is separate systems, with one set of pipes for the domestic and industrial sewage, and another for the surface runoff. KWT is no exception. One problem is that backyard tap (standpipe) drains, which are built so that no rainwater can enter, are sabotaged. This may result in large volumes of rainwater entering the sewage system during heavy rains (see Figure 12).

7.4.11. Treatment performance

The Schornville STW's treatment performance has been calculated for the removal of the orthophosphate (as P) and chemical oxygen demand (COD), where a comparison was made of the concentrations of these parameters in the in- and outflows on a monthly basis, from which annual averages where calculated. A number of values were disregarded in the analysis, on the grounds that they were either obviously incorrect (*e.g.* P-removal in biofilter plant = 91% in April 1996) or the value had a dominating effect on the end result (*e.g.* P-removal in biofilter plant = -201% in July 1997).

The removal of phosphorus in the old biofilter plant has been low (see Figure 13), varying from 3% in 1996 to 18% in 1998. The new plant, which applies ferric chloride to chemically coagulate P, showed significantly higher results of around 50% for the period 1996-1997 (see Figure 14), although these dropped drastically in 1998 to 17%. The reason for this decrease in performance is proposed in Chapters 8.4.13 and 8.5.7. Combining and weighing the two flows (40/60), results in an overall treatment performance for the entire WWTP of around 35% for 1996-1997 and 17% for 1998.

The removal of substances causing a chemical oxygen demand (COD) has been more effective in the new plant (82%-91%) than the old (69%-84%), resulting in overall treatment performances ranging from 78%-86%, without any clear trend being obvious.

Determining the actual removal percentage of the total nitrogen content proved difficult, as data on organic nitrogen was lacking. Instead, the transformation of ammonia to nitrate has been calculated, as this is a prerequisite for a proper removal of total nitrogen. Also, the removal of inorganic nitrogen has been estimated by comparing the in- and outflow concentrations of ammonia and nitrate. Both the transformation and removal percentages may be viewed upon as conservative, as organic nitrogen in the inflow may form ammonia during its residence time in the WWTP, increasing the measured concentrations of NH_3 (as N) in the outflow. As some of the concentration measurements of NH_3 and NO_3^- (as N) were of questionable reliance, values perceived as extreme and not probable have been removed from the analysis, and this applies to four monthly averages of the inflow concentrations of ammonia, ranging from 1.4 to 3.5 mg/l.

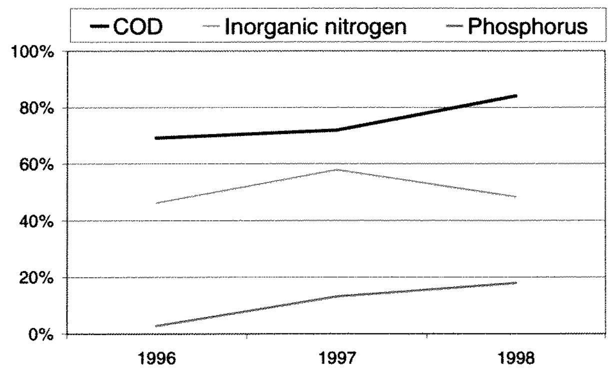


Figure 13. The treatment performance of the old plant.

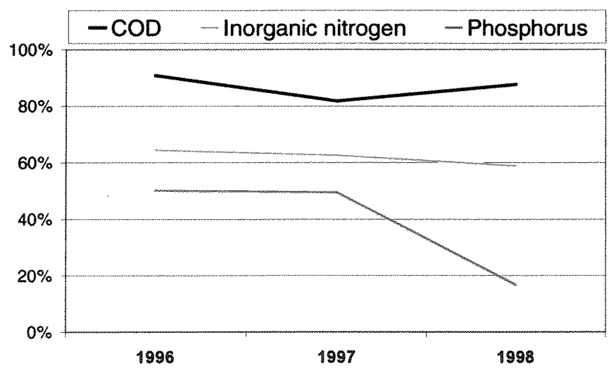


Figure 14. The treatment performance of the new plant.

The transformation of ammonia to nitrate seems to have functioned well during the period of this study; 58%-71% in the old biofilter plant, 70-79% in the new AST plant, resulting in an overall transformation ranging from 65% to 76%.

The removal of inorganic nitrogen has been somewhat less effective. In the old plant, removal rates are around 50%, while in the new plant these are approximately 60%. Adding the two flows in regard to their size differences, the overall removal of inorganic nitrogen has been estimated at approximately 67%. The actual removal of the total nitrogen content should be a bit higher than these values, as the lack of data concerning organic nitrogen has a negative effect on the calculations of (especially) ammonia removed.

In general, the overall treatment performance has been relatively stable for COD and decreased slightly for nitrogen, but decreased significantly for phosphorus. This difference most probably lies in the decreased use of ferric chloride (almost –50% since 1996), which is used in the removal of phosphorus, while the nitrogen/COD removal relies on biological/physical techniques (biofiltration/activated sludge/ sedimentation).

7.4.12. Loads to receiving waters

The following values were calculated by multiplying the measured concentrations in the outgoing effluent by 80% of the incoming volumes of wastewater, which is the estimated volume of treated wastewater being released into the Buffalo River (GIBB Africa, 1999).

The concentrations of both ammonia nitrogen and nitrate nitrogen in the Schornville STW effluent consequently exceeded the Special Standard limits of 1 and 1.5 mg/l respectively, which apply to the Buffalo River. Of the whole period of study (April 1996-Feb. 1999), only one monthly average (April 1997) was within the limits for nitrate, and two (Nov. and Dec. 1996) were within the limits for ammonia. Typical effluent values for this period were 6 mg/l for ammonia (as N) and 4 mg/l for nitrate (as N).

Approximately 400 kg of nitrate (as N) enter the Buffalo River every month from the Schornville STW (see figure 15), and an additional 700 kg of ammonia (as N), although this trend increased sharply in 1998 to around 1200 kg per month. This adds up to a total inorganic nitrogen (as N) load of around 1100 kg per month for 1996 and 1997, and approximately 1500 kg per month for 1998.

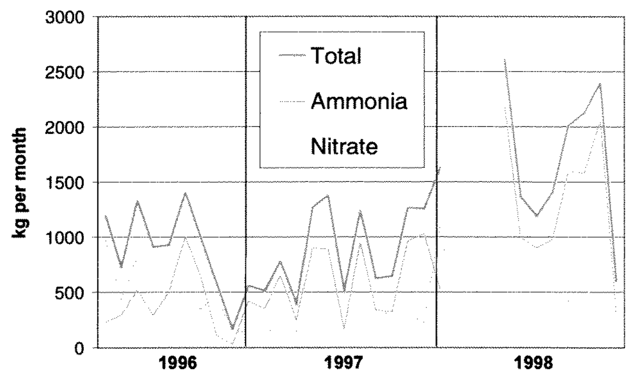


Figure 15. Loads of inorganic N to the Buffalo River.

Phosphorus effluent levels were at acceptable levels during 1996 and 1997, but these levels shot up above Special Standard regulations of 1.0 mg/l in 1998 to around 1.7 mg/l and were increasing during the first two months of 1999 to around 2.3 mg/l. This also applies to the total loads of P. In 1996 and 1997 this added up to approximately 70 kg/month, and jumped to over 150 kg/month in 1998 (see Figure 16).

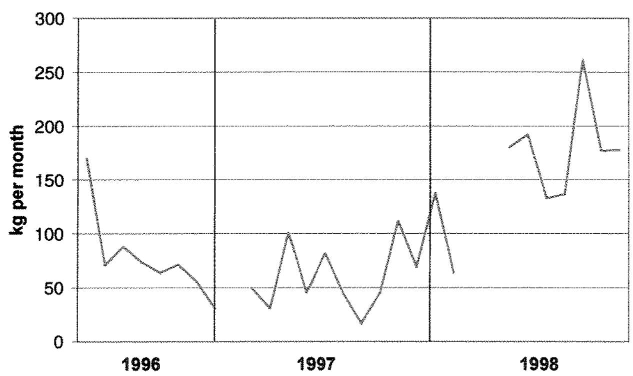


Figure 16. Loads of P to the Buffalo River.

The effluent levels of COD have as well been above the Special Standard Limits of 30 mg/l for the years 1996-1999. In 1996 and 1997 the average effluent contained 6 tons of COD per month and this increased to a maximum of 12 tons in October 1998 (see Figure 17).

Although the Breidbach STW does not intentionally release any effluent to the Yellowwoods River, periodic discharges take place due to run-off from irrigated lands and pond seepage, although the extent of this is not known.

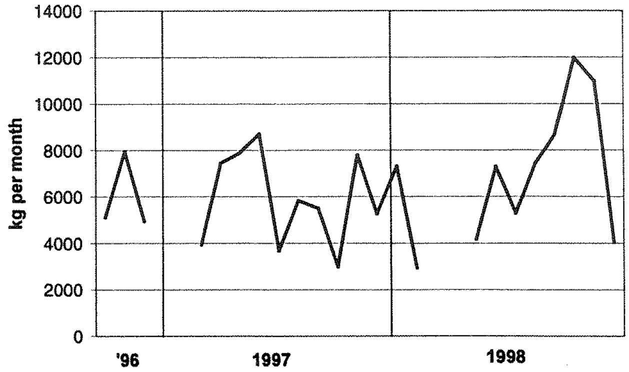


Figure 17. Loads of COD to the Buffalo River.

7.4.13. Chemical and energy use for wastewater treatment

At the Schornville STW, lime is first applied to the incoming effluent to adjust the pH. 20% of the flow is diverted after primary treatment to King Tanning and the golf course, while 60% of the remaining flow (equaling 48% of the incoming flow) passes through the activated sludge and phosphorus removal steps, where ferric chloride is added. Both internal flows (from the new and old plants, 80% of the total incoming flow) are finally treated with chlorine prior release into the Buffalo River.

The annual chemical use at the WWTP was estimated by averaging the available (<12) monthly values of one year and multiplying this by twelve.

The use of chemicals has decreased considerably over the last few years (see Figure 18). Ferric chloride has decreased from 73 tons (1996) to 44 tons (1998), lime from 47 (1996) to 39 tons (1998) and chlorine from 11 (1996) to 5 tons (1998).

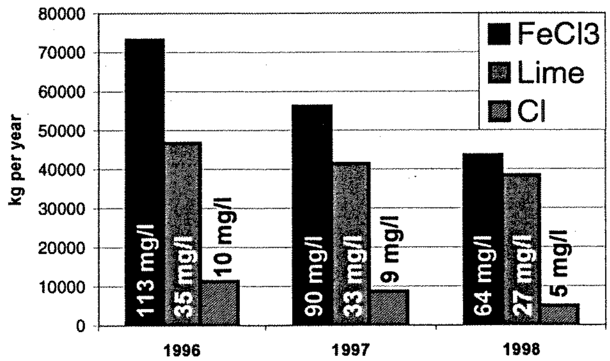


Figure 18. Chemical use and dosage at the STW.

Even considering the usage per volume of treated wastewater, the trends are the same. The dosage of $FeCl_3$ has decreased from 113 to 64 mg/l, lime has decreased from just 35 to under 30 mg/l, and chlorine has decreased from 10 to around 5 mg/l. The decreased dosage of chlorine may be inappropriate, as the ammonia concentrations in the effluent have been increasing, ranging between 5 and 20 mg/l in 1998. As a rule of thumb[15], 10 mg chlorine per mg NH_4^+

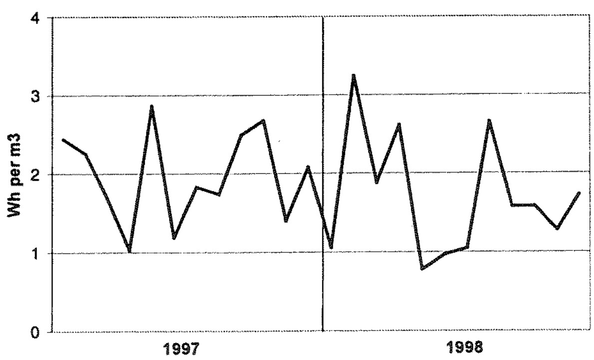


Figure 19. Energy efficiency at the STW.

[15] According to Prof. W. A. Pretorius at the University of Pretoria, South Africa.

(with a contact time = 30 min. at 15-20°) should be applied in order to achieve sufficient sterilization. The current dosage is considerately below this.

Energy efficiency and usage has been relatively constant, at approximately 2 Wh per m^3, totaling 200 kWh per month (see Figure 19).

7.4.14. Resource use per removal of nutrients

As previously described, 48% of the incoming wastewater to Schornville is treated with ferric chloride to chemically coagulate and precipitate phosphorus. The efficiency of this process has been calculated by determining the amounts of phosphorus removed (inflow and new plant effluent concentrations times 48% of incoming volumes) and comparing this with the amounts of ferric chloride applied. Of the acquired results, those judged as extreme (>400 kg $FeCl_3$ per kg P removed, 4 occasions) were removed.

The calculated efficiency of this removal increased considerably for each year (see Figure 20): 180 kg $FeCl_3$/ kg P in 1996, 131 kg $FeCl_3$/ kg P in 1997 and 84 kg $FeCl_3$/ kg P in 1998. The efficiency of this process may be worse though, as some of the phosphorus is removed in the sedimentation tanks, without the aid of chemical coagulation. The increased efficiency must be viewed in the light of a decreased dosage of ferric chloride in a period of increasing influent and effluent levels of orthophosphate.

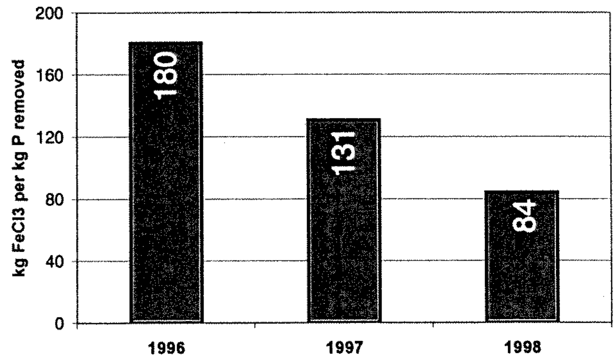


Figure 20. Resource use efficiency at Schornville STW.

In order to evaluate the efficiency of this process further, help has been taken from Prof. W.A. Pretorius, an expert on water treatment options at the University of Pretoria in South Africa. According to him, attempting to attain a 75% removal rate (the highest rate at Schornville is 50%) of wastewater containing 1.5 mg P/l (a typical value for this study) should require a dosage of approximately 8 mg $FeCl_3$/l, with an efficiency around 12 kg $FeCl_3$ per kg P removed. In the light of these values, the efficiency at the Schornville STW must be viewed upon as poor.

7.4.15. Recycling of nutrients

Dried sludge is given away to any farmers who are willing and able to collect it themselves from the Schornville STW. This ends up with a very erratic pattern of usage, as few have the possibility of transporting any considerable amounts. The percentage of sludge used for agricultural purposes was estimated at between 30-50%[16], with the remainder being deposited at local dumpsites. Additional nutrients are recycled through the reuse of treated effluent being irrigated onto the KWT Golf Course (from Schornville STW) and onto sportsfields (from Breidbach STW).

7.4.16. Quality of sludge

There are at the moment no measurements performed on the sludge to ensure the quality. As sludge is currently being distributed to local agriculture, this leads to some concerns. A discussion concerning this matter is found in the Chapter 7.5.8.

[16] Through personal communication with Ms. D. Dolley and Mr. C. Mhambi of the Schornville STW.

7.4.17. Energy recovery

There are no such facilities at the Schornville STW.

7.4.18. Access to safe drinking water

About 5 million urban residents in South Africa live more than a quarter of a kilometer from the nearest source of available water according to the most recent municipal survey of water provision. An additional 4.4 million people have access to a communal standpipe at a distance of less than 250m (Goldblatt, 1999). This is largely due to pre-democracy development policies, which were most outspoken in areas previously referred to as "homelands". At present, the South African government has committed itself to ensuring that all people will have access to at least 25 liters per capita per day of clean water (DWAF, 1994).

As the study area was not included in the Republic of Ciskei, it has attained levels of development equal to those of the larger cities of South Africa. The access in the study area is 100 %[16], and all consumers are metered and charged according to consumption (PDG, 1998). The consumed water per capita is well in excess of the WHO minimum of 50 liters per day and capita.

7.4.19. Access to adequate sanitation

Sanitation is waterborne and assumed[17] to accommodate 100 % of the population in the study area. This is not to be assumed to apply to the country as a whole, where although 98.8% of the white urban population has in-house water connection, only 56.1% of the non-whites in urban areas have the same level of service (Goldblatt, 1999).

7.5. Summary of indicator results and future recommendations

7.5.1. Future shortages of freshwater resources

The annual withdrawal has approached the estimated available volume for the past six years and even exceeded this level in 1997. Although the Engineering Section of the TLC does not expect severe water shortages, due to future plans of the interconnection of local dams, the current situation is moving towards unsustainablity. As the full utilization of all freshwater resources in expected to occur around 2025 (Basson, Van Rooyen, 1998), future increase in the water demand must be avoided. Several methods of reducing the consumption of water may be suggested: installing water efficient taps and toilets in new buildings (and the new RDP[18] development areas), reusing grey water where applicable and educating the public of methods of saving water. It is also questionable if the current policy in South Africa, where residents in RDP-areas pay flat monthly rates for their water, no matter how much is consumed, is in line with the goal of decreasing the water demand. Without installing meters, the public is unaware of the value of water, and large amounts of this resource may be wasted.

7.5.2. Possible decreases in raw water quality

The decreasing levels in the Rooikrans Dam (and possibly the Maden Dam as well, although no data on this was acquired) may also have some detrimental effects on the raw water quality as well. With decreased volumes, the circulation of water may increase, stirring up nutrients embedded in the sediment. The natural exchange of nutrients between the sediment and the water will also increase, as a consequence of less water in the dam.

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[17] Estimation by Ms. Daria Dolley of the Schornville STW.

[18] The Reconstruction and Development Programme (RDP) in a governmental initiative with the goal to provide adequate housing and services for all South Africans.

7.5.3. Lack of protection for freshwater resources

The lack of formal protection for the dams, as well as the non-existence of a contingency plan in cases of emergency, are problems that need immediate attention. The formal protection is needed to minimize the risks of accidents occurring, and a contingency plan is proper way of preparing those concerned for the eventuality of an accident, so that the consequences can be minimal for both the public and the environment. The "Disaster Committee" would be an appropriate body for the construction of a contingency plan.

7.5.4. Difficult to attain tap test data

It was unfortunate that the drinking water quality measurements from Pollution Control Technologies proved so difficult to collect. These should be made more easily accessible for researchers and the public alike, so that the drinking water quality can be confirmed. In this regard, concern may be warranted for the high levels of chlorine in the drinking water. Current research has indicated that chlorine acting with the Assimable Organic Carbon (AOC) or Biodegradable Dissolved Organic Carbon (BDOC) can form trihalomethanes in water treatment plants, and this may have mutagenic effects on human cells.[19] Therefore, it is important that researchers are given easy access to data on drinking water quality tests, as to confirm the beliefs of its high quality.

7.5.5. Increased use of chemicals and energy at KWT Water Purification Works

The chemical usage at the KWT Water Purification Works was fairly stable for the period November 1996 to December 1998, except for an increased use of $AlSO_4$. As the raw water in the Maden and Rooikrans dams is of relatively good quality, it is unsure if this increased dosage was necessary. A future study into the required dosage of the waterworks and new equipment might allow for future decreases in the chemical usage at this plant, saving both money and resources. An examination of the possible reasons for the sharp increase of energy used over the past two years should also result in multiple efficiency improving recommendations.

7.5.6. Erratic wastewater production possibly due to leakage

The wastewater production has been erratic, and not at all followed the trends of the raw water withdrawal from the Rooikrans and Maden Dams. This may be due to leakage in the wastewater system, although the extreme peak of the (South African) summer of 95/96 has yet to be explained.

7.5.7. Decreased chemical usage at Schornville STW increases loads

The chemical usage at the Schornville STW has decreased considerably for all three chemicals used. The decreased usage of ferric chloride has been unfortunate, as the concentrations of phosphorus (as well as nitrogen and COD) in the raw wastewater have increased, although this has improved the otherwise poor efficiency of the phosphorus removal process. The consequence has been increased effluent concentrations and total loads to the Buffalo River.

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[19] Personal communication with Prof. G. Morrison of Water Environment Transport at Chalmers University of Technology, Göteborg, Sweden on 000316.

7.5.8. Fertilizing with dried sewage sludge – possibilities and associated risks

According to estimation, between 30 and 50% of the dried sewage sludge is used as an agricultural fertilizer in the study area. Although this amount is considerate, future improvements are clearly possible. The use of sludge as a fertilizer is, though, currently under fierce debate in many countries, and the following discussion includes some of the pro's and con's, and recommendations for future action.

The recycling of nutrients is important in attaining a sustainable development, while using artificial fertilizer depletes the limited resources base of phosphorus and requires substantial amounts of energy for its nitrogen content, which is done through the fixing of atmospheric nitrogen. Currently, only economically-strong farmers collect the sludge, while those with little or no money who run small-scale farming have access to neither sludge nor artificial fertilizer. This, of course, leaves them with a low level of agricultural production. By delivering the sludge to these small-scale farmers, the TLC can aid in the agricultural and overall development of the area. This may result in considerable improvements of the local agricultural output. Government backing may also be attained, as this is in line with the national Reconstruction and Development Plan.

There are, though, a number of risks coupled with the use of sludge as a fertilizer, and it is these that limit its use in several countries. In Sweden for example, the use is regulated by an agreement between several agricultural and sanitary organizations and authorities; the so-called "Sludge Agreement" or *Slamöverenskommelsen*. This allows the use of sludge that meets the limits and recommendations found in table 6.

Table 6. Swedish requirements for the use of sludge as an agricultural fertilizer. (NV, 2000)

Regulated maximum content mg/ kg dry substance	
Lead, Pb	100
Cadmium, Cd	2
Copper, Cu	600
Chromium, Cr	100
Mercury, Hg	2.5
Nickel, Ni	50
Zinc, Zn	800
Recommended maximum content mg/ kg dry substance	
4-Nonylphenol	50
Polyaromatic Hydrocarbons, PAH	3
Polychlorinated Biphenyls, PCB	0.4

The detrimental effects of the listed heavy metals and chemical compounds are well documented, although the actual effects of using sludge containing these pollutants has yet to be asserted. Several factors are currently being researched, *e.g.* availability, actual crop uptake, long-term effects on human health as well as other uncertainties. Possible sources of, at least, the heavy metals have been identified in the study area: King Tanning and the textile industries.

More recently, viral and bacterial risks associated with sludge application have been of concern, especially roundworm, salmonella and EHEC[20] (Albihn, 1999). The warm climate of the area may allow for a more a rapid eradication of pathogens during sludge

[20] *Enterohemmoragic Escherichia coli*, a disease cause by the EHEC bacteria that produces a powerful toxin that leads to diarrhoea and possibly organ damage, especially to the kidneys.

storage, but as there are more parasite diseases in warm climates, special care should be taken when handling the sludge, *e.g.* when distributing it on fields.[21]

In order to guarantee the public health and the future usage of sludge as a fertilizer, measurements like those done in Sweden, as well as of the viral and bacterial content are of the utmost importance. These must be done on a routinely basis and the results should be made easily accessible for all those interested. Tests of the nutrient content are also necessary, in order to be able to spread the sludge on agricultural fields in appropriate amounts.

Last but not least, as human nature would have it, a large part of the community may have strong hesitations to using human excrement and urine as a fertilizer. It is therefore necessary to educate the intended users (farmers) and consumers (who eat the food produced by the farmers) of the positive and negative sides of this practice. Testing the sludge may also increase the public's interest in maintaining the quality, which the public affects through their behavioral patterns (*i.e.* what is flushed down the toilet).

8. Evaluation of the applied indicators

8.1. Evaluation criteria

The 19 indicators used in the study have been consequently evaluated on the basis of the five criteria listed below believed to have importance for urban water systems in general, and the study area in particular. Many urban water system designs are similar to each other, therefor the suggested indicator topics are believed to have relevance for similar systems. The specified parameters, on the other hand, have be chosen to fit the case study area's specific conditions, problems and possibilities, and may need to be reviewed before being applied in another geographic area. The evaluation criteria have been based on the previously described indicator characteristics (Gallopín, 1997) and criteria (Lundin *et. al.*, 1997), where the indicator's possibility of assessing the sustainable development of the UWS has been given utmost importance. Other aspects considered include how easy the SDI is understood by different audiences, where a reduction of the total number of SDI would aid in being able to communicate all the different aspects of SD covered by the indicators; if any goals for the indicators exist, thereby easing in an assessment of the current situation; as well as an evaluation of the quantity, quality and availability of data. The evaluation criteria are as follows:

1. Does the indicator show the current trend direction as to moving towards or away from a sustainable development, including its technical, developmental and environmental aspects?
2. Does the indicator cover an aspect of sustainable development, without overlapping another indicator? A limited number of SDI is necessary in order to easily communicate information to professionals, researchers and the general public.
3. Do any goals or objectives readily exist for the quantities or qualities measured by the indicator? If not, can they be researched and developed?
4. Was data of sufficient quantity and quality available in order to provide spatial and temporal trends? Was it easily accessed?
5. Can professionals, researchers and/or the general public easily understand the information relayed by the indicator? If so, can this have an effect on future actions taken?

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[21] Information through e-mail communication with Dr. A. Albihn (Vet. Med.), National Veterinary Institute, Stockholm, Sweden

8.2. Indicator evaluation

8.2.1. Withdrawal

The withdrawal indicator acts as a powerfully informative indicator. It is easily understood by policy-maker and citizen alike, and may influence future policy and behavior. By including the approximate maximum withdrawal level, the current consumption and trends can be identified as sustainable or not. The information was readily accessible.

Suggested parameter: Total withdrawal compared to available amount.

8.2.2. Raw water quality

Information for this indicator was easy to collect. Communicating the raw water quality to the general public may be more difficult, especially in the form of coliform counts or phosphorus concentrations. A comparison with raw water quality targets, should these exist, would probably aid in the understanding of the situation. Also, as a large number of parameters are measured, the volume of information may be too large to communicate. The most important parameters should be identified and highlighted. In this area these may be parameters concerning salinification, eutrophication and coliform counts.

As to its relevance to sustainability, this state indicator does indirectly show how well the protection of raw water resources is, so as to assure the quality for future generations. Raw water of sufficient quality requires also little treatment for drinking purposes, minimizing the necessary use of energy and resources.

Suggested parameters: Dissolved sodium compared to target, nitrogen compared to target, coliform counts compared to target.

8.2.3. Protection

The collected information suggested a total lack of formal protection, as well as the existence of a contingency plan, consequently giving a poor indicator result. The presentation of this indicator is, though, a difficult matter, as it is not easily quantified. One possibility is to evaluate the situation and grade it, possibly on a 1 (no protection) to 5 (well protected with contingency plan) plan, which should make it easily understood by the general public, although professionals may prefer a more technically evaluating indicator. Although the protection of raw water sources is important, it is questionable if this information is suitable for indicators.

8.2.4. Water use

This information is ideal for SDI-use, and provides a good picture of current use and future trends. It illustrates sufficiency as well as over-consumption, both vital for a sustainable development. By introducing targets, the public would also have a better idea of the current situation and future scenarios. Data is easily collected and the indicator is easily calculated.

Suggested parameter: Water use (m^3/month) compared to target.

8.2.5. Drinking water quality

Although this is not a major problem in this area of South Africa, the indicator is still useful in tracking changes in the drinking water quality. Informing the public of the importance of high quality drinking water, and relating the current situation in regard to regulations may also increase concerns of its preservation and protection. The information was difficult to collect for this case study, but can be made more accessible for the public, researchers and professionals alike if published on the Internet, for example.

Suggested parameter: Percentage of tap tests within regulation.

8.2.6. Chemical and energy use for water supply

The increased efficiency of chemical and energy use is important in regards to SD, but neither aluminum sulfate nor lime qualify as limited resources, and as such may not have to be included as indicators. An excessive use of chlorine does have a detrimental effect on the environment and human health, and as such should be included. This information is also easily communicated, although the informative value may be limited. The data is almost readily available.

Suggested parameters: dosage of chlorine (mg/l), Wh per m^3.

8.2.7. Leakage

Only estimations were available for this indicator, and it is uncertain what informative qualities this indicator has. As the new RDP-areas currently being built are connected to the water system without meters, it will prove increasingly difficult to estimate the leakage accurately. Although excessive leakage is of course unsustainable, this indicator has a direct influence on the water use and wastewater production indicators, and may therefore be unnecessary as it partly overlaps.

8.2.8. Reuse

The reuse of water is not widely practiced in the study area (except for the irrigated effluent from the Schornville and Breidbach STWs), although will undoubtedly prove to aid in future improvements in the effective use of this resource, and increase the sustainability of this urban water system. The amounts reused should be recorded and promoted, but as it effects the water use and wastewater production indicators directly, it is unsure if an indicator for this point is necessary.

8.2.9. Wastewater production

Monitoring the production of wastewater has several positive effects, *e.g.* making sure that WWTPs do not receive more than they can handle (as the situation is at present), indicating if a massive leakage of stormwater into the sewage pipes is occurring, measuring the effects of using low-flush toilets, etc. The indicator with its current parameters is blunt, though, as it is impossible to identify the individual sources of the produced wastewater. The data for this SDI is readily available from the treatment plant, and is useful for comparisons with other systems. Professionals and researchers easily understand its relevance.

Lundin (1999) suggests a comparison between the volumes of wastewater received with the volumes treated, thereby monitoring any overflowing volumes and assuring that all wastewater and only wastewater is treated. In this case study, the information available did not make such an analysis possible.

A possible third alternative of evaluating this indicator topic is, in addition to monitoring the produced volumes, also to compare the actual incoming loads of nutrients and oxygen-demanding substances (measured as BOD) with estimations of how large these loads should be, depending on the size of the connected population and on which industries also use the WWTP. The comparison might use a functional unit (f.u.), suggested as 70 g BOD, 14 g N, and 3 g P per capita and day.

Suggested parameters: liters per capita and month, f.u. deviation from estimations of incoming loads

8.2.10. Combined sewers

While many wastewater systems in Sweden apply combined systems, where surface run-off from impermeable surfaces is collected and transported to a WWTP together with domestic and industrial wastewater, the norm in South Africa is to use separate systems, where surface run-off is collected and transported separately. Therefor, an indicator of this kind is not necessary for the study area.

This leaves a lack of information of the volumes and quality of urban surface run-off, which can be polluted by *e.g.* traffic. The development of an additional indicator for this purpose may be necessary.

8.2.11. Treatment performance

The calculations for this indicator proved difficult, mostly due to the erratic data collected and believed to be a result of under-maintained treatment equipment and possible measurement practice errors. The actual performance is not of extraordinary importance for the goals of SD.

The fact that many WWTPs do calculate their treatment performances for N, P and BOD leaves the indicator to have some importance none the less, if only for comparative studies of the intended treatment performance and with other treatment plants and technologies. The information is of interest to professional in the field of sewage treatment technologies.

Please note that the biological oxygen demand (BOD) of the effluent is not currently measured at the Schornville STW, while the chemical oxygen demand (COD) is.

Suggested parameters: removal of N (%), removal of P (%), removal of BOD (%).

8.2.12. Loads to receiving waters

The collection of information for this indicator demanded many hours, as the sample data was on a day-to-day basis. The following calculations, on the other hand, were easily performed.

The indicator relays the actual loads being released into the Buffalo River, which is important in regards to sustainablity, although the actual informative value of this is uncertain. Comparing the loads to the river's critical load would be more useful and informative. For these ends, a study into the river's carrying capacity would be necessary.

As mentioned before, it has been revealed that the largest threats to Buffalo River are eutrophication and salinification, and it is these loads that should be compared to the critical loads. Researchers (ecologists and limnologists in particular) could have substantial use of this information.

Suggested parameters: Loads of N, P and sodium compared to the critical load for the Buffalo River. (%)

8.2.13. Chemical and energy use for wastewater treatment

As with the previous efficiency indictor for the water treatment plant, the use of ferric chloride and lime, which are not limited resources, may not have to be included as indicators. An inappropriate dosing of chlorine does, though, have detrimental effect on the environment and human health, and as such should be included. Promoting a minimal use of energy is also in line with SD. This information is also easily communicated, and is useful for professionals in this field.

Suggested parameters: dosage of chlorine (mg/l), Wh per m^3.

8.2.14. Resource use per removal of nutrients

In the case study this only applied to the use of ferric chloride in the removal of phosphorus. As ferric chloride does not qualify as a limited resource, the indicator may be superfluous, although it does communicate the how efficient or inefficient the use is.

8.2.15. Recycling of nutrients

This indicator proved to be very difficult to calculate since there were no records of the amounts of sludge used in agriculture, although it is possible. Should the use of dried sewage sludge be more carefully monitored, it would be possible to calculate the theoretical percentage of recycled nutrients, which is very closely linked to SD. It is already possible to calculate the actual amounts of nutrients removed from the wastewater. This information would be of use for policy-makers who wish to decrease the use of commercial fertilizer, by instead using dried sewage sludge.

Suggested parameter: % of nutrients recycled and reused

8.2.16. Quality of sludge

As there are no available measurements concerning the sludge quality (*i.e.* concentration of heavy metals), the indicator is currently impossible to calculate. As to its importance, the debate is far from over. The detrimental effects of heavy metals on human health have been proven in multiple studies (*e.g.* McLaughlin, 1998), the actual impact of using sewage sludge as a crop fertilizer is uncertain. McBride (1998) and Senesi *et al.* (1999), among others, recommend caution in using sludge fertilizer with a high heavy content until further assertions concerning the risks have been made. Nonetheless, proper measurements of its nutrient content are a prerequisite for an adequate use of it in agriculture. As sludge is currently being used as a fertilizer, it is of the utmost importance that some form of quality testing start in the immediate future. All audiences have an interest (more or less) in this subject.

Suggested parameter: % of sludge quality tests within regulation and recommendations.

8.2.17. Energy recovery

As this is not currently practiced, there is no need for an indicator at the moment, but with the potential of installing *e.g.* biogas collection at the WWTP, a future usage may be expected. These potential amounts of recovered energy may greatly aid in the area's SD, and also bring economic revenue to the plant. It is possible to integrate this information into the previous indicator "Energy use for wastewater treatment", where the recovered energy is viewed upon as a negative usage of energy.

8.2.18. Access to safe drinking water & access to adequate sanitation

Although these indicators are already at 100% for the study area, a larger study area would reveal different results. They cover vital developmental and social aspects of SD, and are easily understood by the public. The data is readily available from the local government.

Suggested parameters: % of population with access to safe drinking water, % of population with access to adequate sanitation.

8.3. Evaluation summary

Of the 19 tested SDI for urban water systems, 13 were found to be useful for the current situation of the study area. With this list of indicators, it should be possible to assess and communicate the current state and future trends of the urban water system of the study area to policy-makers, engineers and the general public alike. Should changes occur (*e.g.* equipment improvements, new research), then the choice of indicators should be re-evaluated.

For future studies, a working list of these 13 indicators has been provided (see Appendix 3).

9. Conclusions

Through the performed case study, SDI were proved as being useful in assessing the temporal changes of the urban water system, thereby verifying the same conclusion made in the Göteborg case study (Lundin *et. al.*, 1999). Although not all of the indicators are based on ideas of sustainable development, but some instead on more technical aspects (such as technical performance), the recommended set of SDI (see Appendix 3) is believed to cover all important points concerning the UWS's performance, usage of limited resources and energy, environmental loads and developmental progress. Therefor, the suggested indicator topics should be suitable for measuring the sustainability of similar UWS, while the individual SDI parameters may need to be reviewed to fit a new area's specific conditions.

Several possible improvements were identified as being able to increase the analytical and communicative properties of the indicators. Targets for the raw water quality and water use indicators would aid in evaluating progress towards sustainability. The evaluation of the wastewater production indicator may be improved by also comparing the actual loads of nutrients and BOD being received by the WWTP, with estimation of the connected population's and the industries' production of these substances, possibly by using functional units. Research into the Buffalo River's critical loads of several pollutants would make the evaluation of the WWTP's contribution more meaningful. An additional indicator may be necessary for the monitoring of the volumes and quality of the produced urban surface run-off, which may be considerably polluted by *e.g.* traffic. Regulation and/or recommendations concerning the nutrient and heavy metal content (as well as other parameters) of the sewage sludge, and periodic measurements of these, would make an evaluation possible, as well as contribute to a correct and adequate application of sludge in agriculture and avoid the human health risks associated with its use.

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Appendix 1. Effluent standards

General and Special standards for effluent discharge in terms of the South African Water Act No. 54 of 1956 as amended.

Parameter	General standard limits[1]	Special standard limits[1]
Colour, odour, taste	Nil	Nil
pH	5,5-9,5	5,5-7,5
Dissolved oxygen (% Saturation)	75	75
Temperature (°C)	35	25
Typical faecal coli (per 100 ml)	Nil	Nil
Chemical oxygen demand	65	30
Oxygen adsorbed	10	5
Conductivity (mS/m)	250; 75% above intake	250; 15% above intake
Suspended solids	25	10
Sodium	90 above intake	50 above intake
Soap, oil and grease	2,5	Nil
Residual chlorine (as Cl)	0,1	Nil
Free and saline ammonia (as N)	10	1
Nitrate (as N)	Not specified	1,5
Arsenic (as As)	0,5	0,1
Boron (as B)	1,0	0,5
Chromium (total, as Cr)	0,5	0,05
Copper (as Cu)	1,0	0,02
Phenolics (as phenol)	0,1	0,01
Lead (as Pb)	0,1	0,1
Sulphides (as S)	1,0	0,05
Fluoride (as F)	1,0	1,0
Zinc (as Zn)	5,0	0,3
Soluble orthophosphate (as P)	Not specified	1,0[2]
Iron (as Fe)	Not specified	0,3
Manganese (as Mn)	0,4	0,1
Cyanides (as Cn)	0,5	0,5
Cadmium (as Cd)	0,05	0,05
Mercury (as Hg)	0,02	0,02
Selenium (as Se	0,05	0,05
Hexalent chromium (as Cr)	0,05	Not specified

Notes:

1.All units mg/l unless specified otherwise.

2.In terms of Government Notice No. 991 of 18 May 1984, effluents draining to certain sensitivity areas must have soluble orthophosphate (as P) concentration of less than 1,0 mg/l

Appendix 2. Water quality parameters

The table lists the water quality parameters that the Department of Water Affairs and Forestry has historic data on and/or is currently monitoring (as of November 25, 1999) in the Rooikrans Dam. The fields marked in grey show historic data and are not currently monitored.

Determinant	Parameter	# of analyses	First analysis	Last analysis
123	Magnesium – dissolved	61	19960605	19990901
1101	pH	303	19680711	19990901
1106	pH	2	19961204	19970306
5101	Boron – dissolved	17	19850603	19890825
6101	Carbon – dissolved organic	17	19811223	19890825
7001	Nitrogen Kjeldahl	43	19811223	19890825
7101	Nitrate + Nitrite as N	156	19680711	19890825
7103	Ammonium as N	143	19770305	19890825
7106	Ammonium as N	147	19920526	19990901
7107	Nitrate + Nitrite as N	147	19920526	19990901
7113	Nitrate + Nitrite as N	2	19961204	19970306
7115	Ammonium as N	2	19961204	19970306
8101	Dissolved oxygen	1	19760306	19760306
9101	Flouride – dissolved	299	19680711	19990901
9105	Fluoride	2	19961204	19970306
10101	Total alkalinity as $CaCO_3$	303	19680711	19990901
10105	Total alkalinity as $CaCO_3$	2	19961204	19970306
11101	Sodium – dissolved	271	19680711	19960731
11103	Sodium – dissolved	34	19960828	19990901
11107	Sodium	2	19961204	19970306
12101	Magnesium – dissolved	303	19680711	19990901
12107	Magnesium	2	19961204	19970306
14101	Silicon – dissolved	143	19770305	19890825
14105	Silicon – dissolved	147	19920526	19990901
14107	Silicon	2	19961204	19970306
15001	Phosphorus – total P	43	19811223	19890825
15101	Phosphate – PO_4 as P	148	19750227	19890825
15104	Phosphate – PO_4 as P	147	19920526	19990901
15106	Phosphate – PO_4 as P	2	19961204	19970306
16101	Sulphate – dissolved	156	19680711	19890825
16104	Sulphate – dissolved	147	19920526	19990901
16106	Sulphate	2	19961204	19970306
17101	Chloride – dissolved	156	19680711	19890825
17104	Chloride – dissolved	147	19920526	19990901
17107	Chloride	2	19961204	19970306
19101	Potassium – dissolved	261	19750227	19960731
19103	Potassium – dissolved	34	19960828	19990901
19107	Potassium	2	19961204	19970306
20101	Calcium – dissolved	303	19680711	19990901
20107	Calcium	2	19961204	19970306
100101	Temperature	38	19750227	19960710
101101	Electrical conductivity	303	19680711	19990901
101111	Electrical conductivity	2	19961204	19970306
103101	Total dissolved salts	292	19770305	19990901
104101	Sodium adsorption ratio	269	19680711	19961002
107201	Total suspended solids	5	19950110	19950328

Appendix 3. Working list of SDI for urban water system

A working list of Sustainable Development Indicators (SDI) for urban water systems, evaluated through a case study of the urban water system of King William's Town, South Africa, in 1999 by Eric Zinn, M.Sc. student of Chalmers University of Technology, Göteborg, Sweden.

Indicator	Parameter(s)	Suggested reference value
Category: Freshwater resources		
Withdrawal	Total withdrawal compared to available amount	Less than 100%
Raw water quality	Concentrations of dissolved sodium and nitrogen, and coliform counts compared to targets	Moving towards targets
Category: Drinking water		
Water use	Water use (m^3/month) compared to target	Moving towards target
Drinking water quality	% of tap tests within regulation	100%
Chemical and energy use for water supply	mg chlorine per liter Wh per m^3	Appropriate dosage Increasing efficiency
Category: Wastewater		
Wastewater production	Liters per capita and month	Comparable to water use
Chemical and energy use for water supply	mg Cl/l and Wh/m^3	Increasing efficiency
Treatment performance	Removal of P, N and BOD (%)	At least according to regulation
Loads to receiving waters	Loads of N, P and sodium compared to the critical load for the Buffalo River (%)	Less than 100%
Category: Plant nutrients		
Recycling of nutrients	% of nutrients recycled and reused	Increasing towards 100%
Quality of sludge	% of sludge quality tests within regulation and recommendation	100%
Category: Development		
Access to safe drinking water	% of population with access within 200m	100%
Access to adequate sanitation	% of population with adequate and appropriate sanitation	100%

Appendix 4. Indicator graphs & source data

Indicator Graph 1: Raw water quality (Rooikrans Dam). $NO_3 + NO_2$ as N.

Indicator Graph 2: Raw water quality (Rooikrans Dam). Orthophosphate as P.

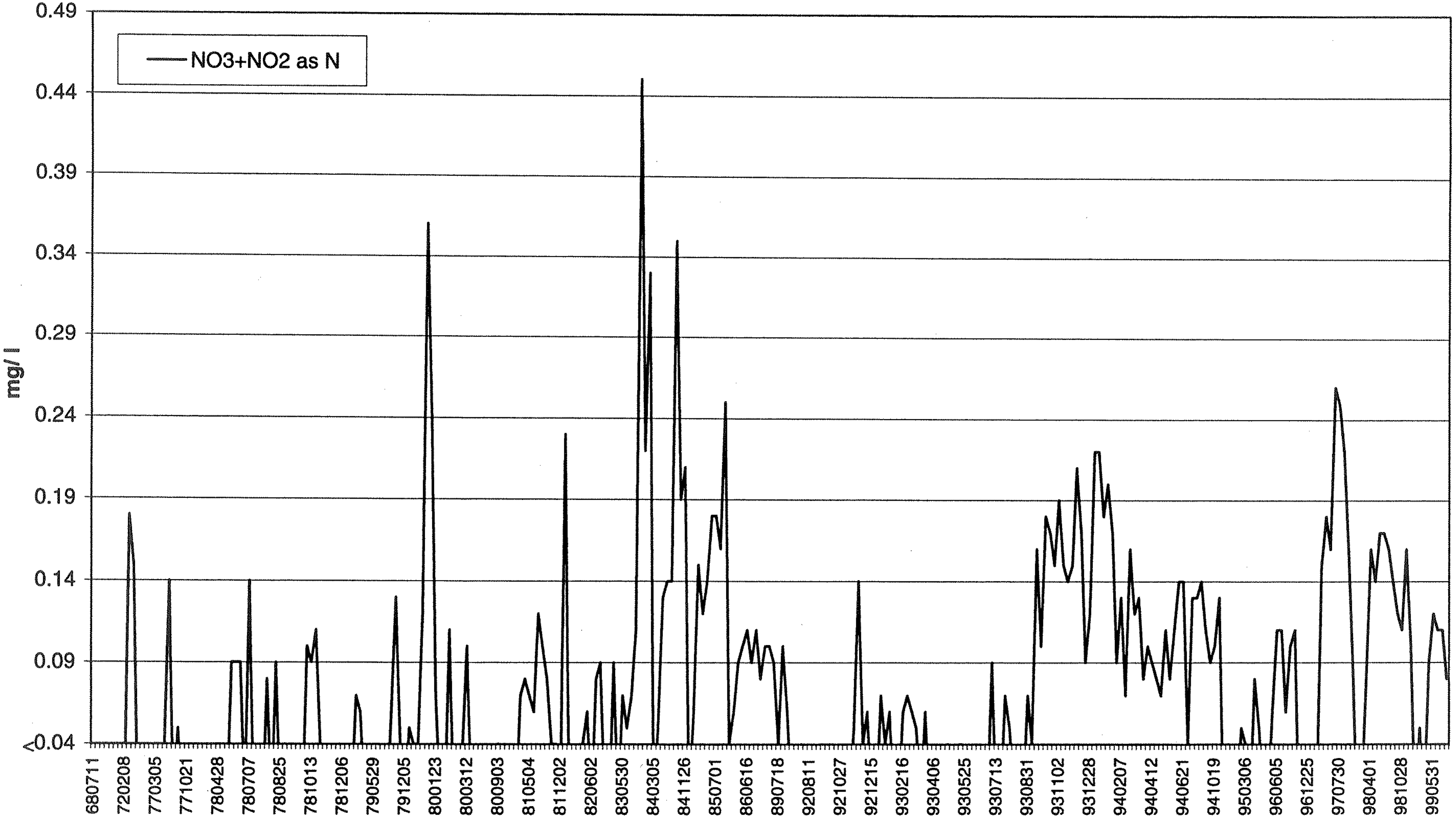
Indicator Graph 3: Raw water quality (Rooikrans Dam). Dissolved sulphate.

Indicator Graph 4: Water consumption.

Indicator Graph 5: Wastewater production (Schornville STW).

Source data.

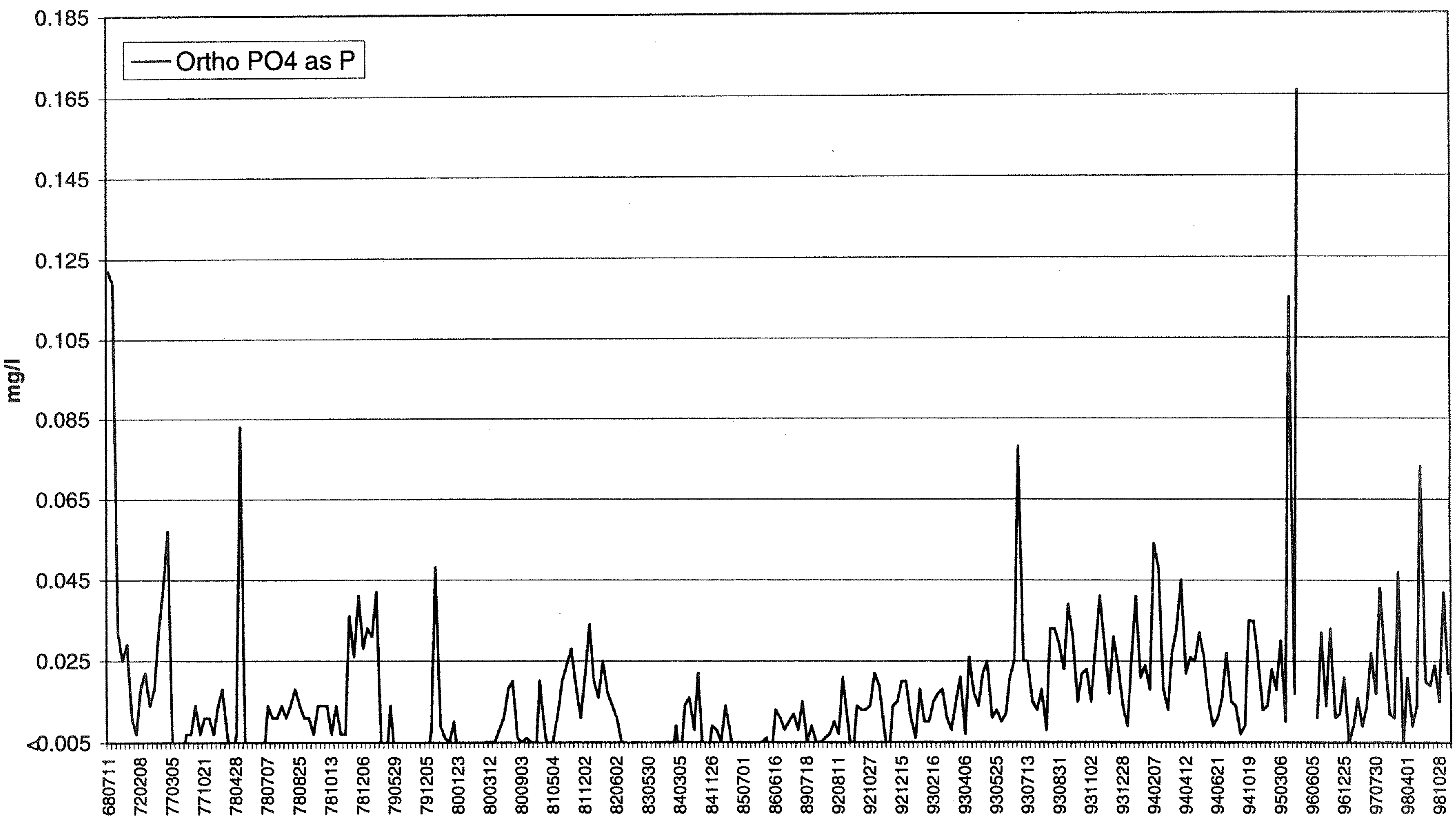
Raw water quality (Rooikrans Dam)



Source: Data from Department of Water Affairs and Forestry. (HYDRO STATION NO: R2R002Q01)

Indicator Graph 1

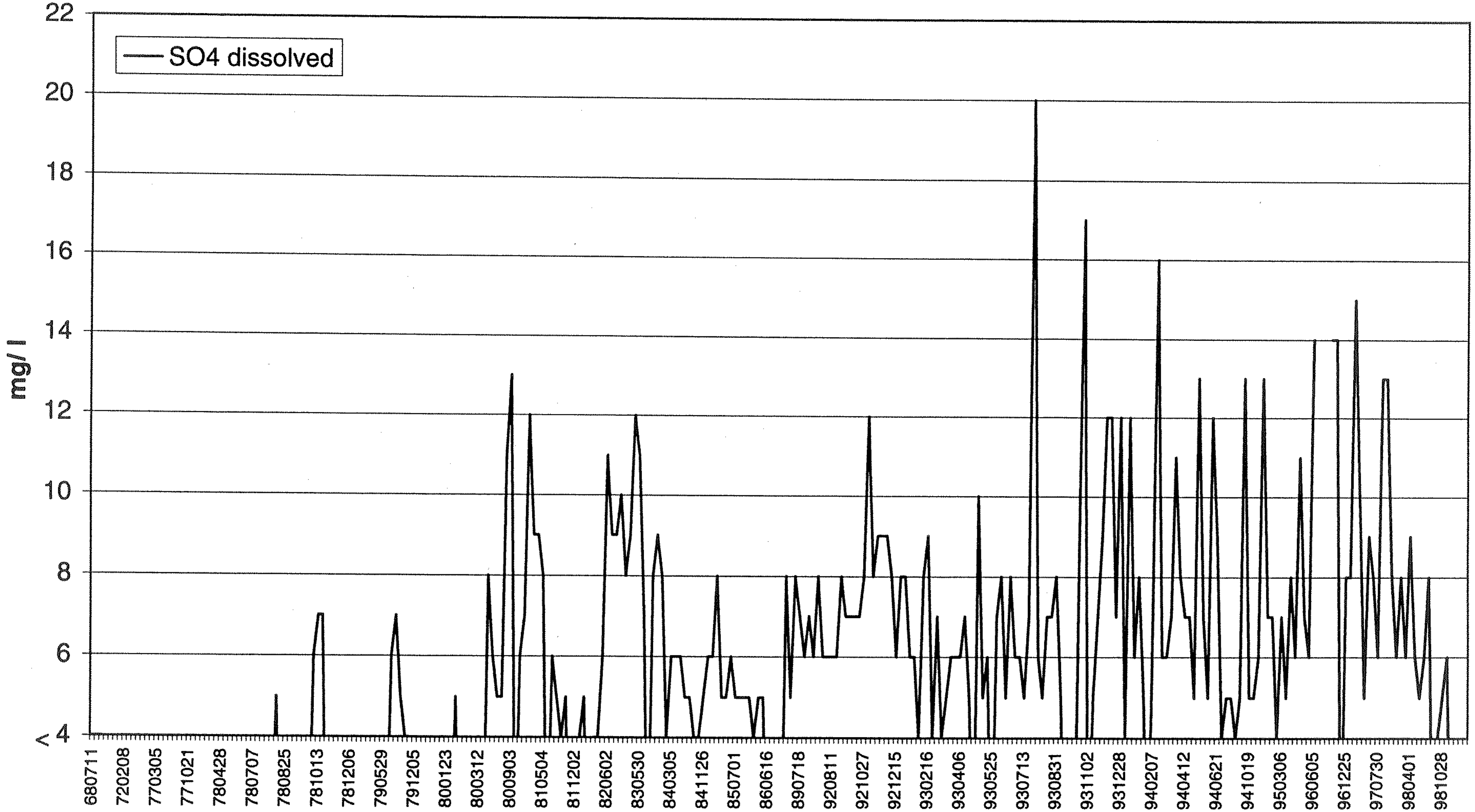
Raw water quality (Rooikrans Dam)



Source: Data from Department of Water Affairs and Forestry. (HYDRO STATION NO: R2R002Q01)

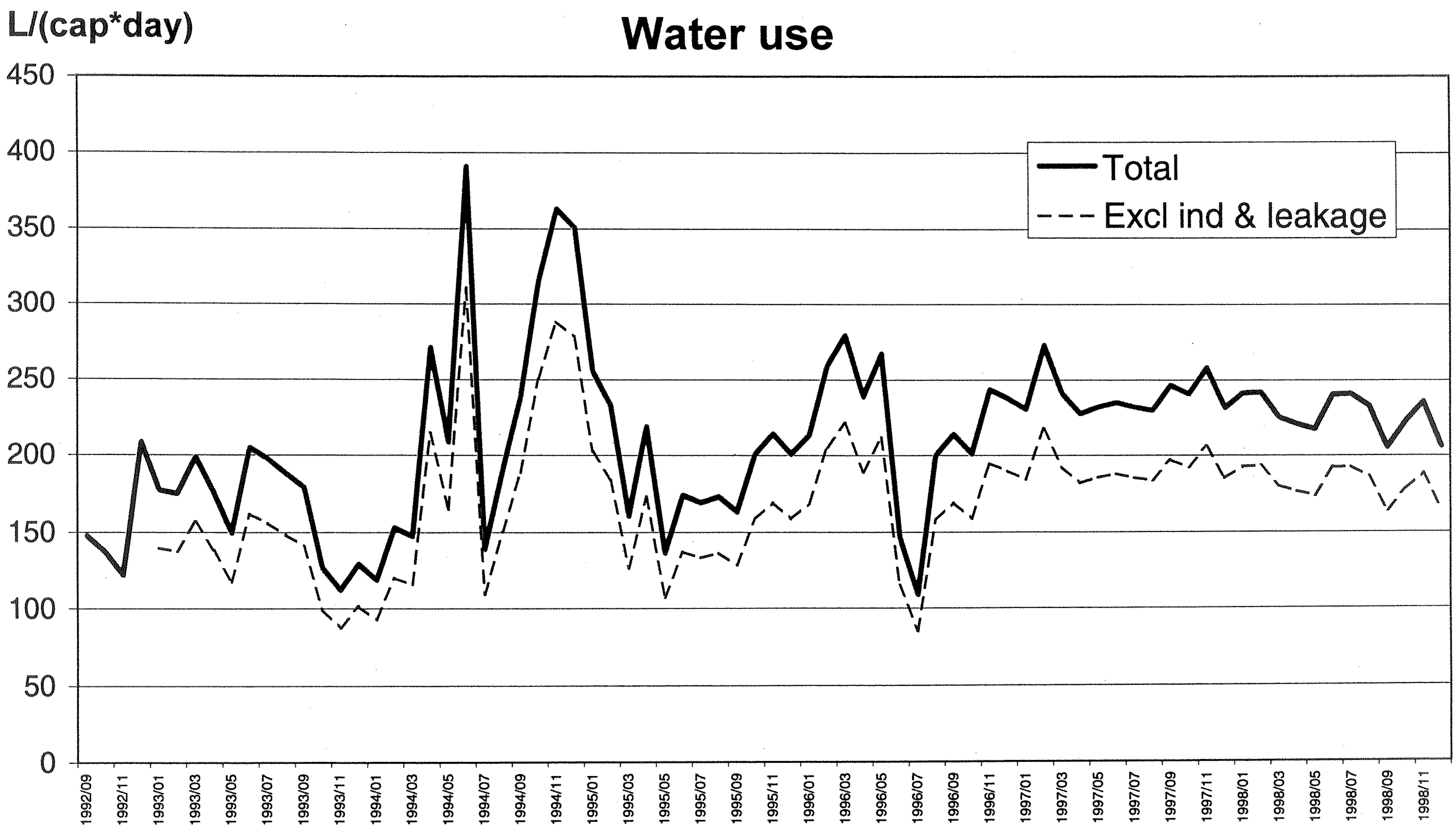
Indicator Graph 2

Raw water quality (Rooikrans Dam)



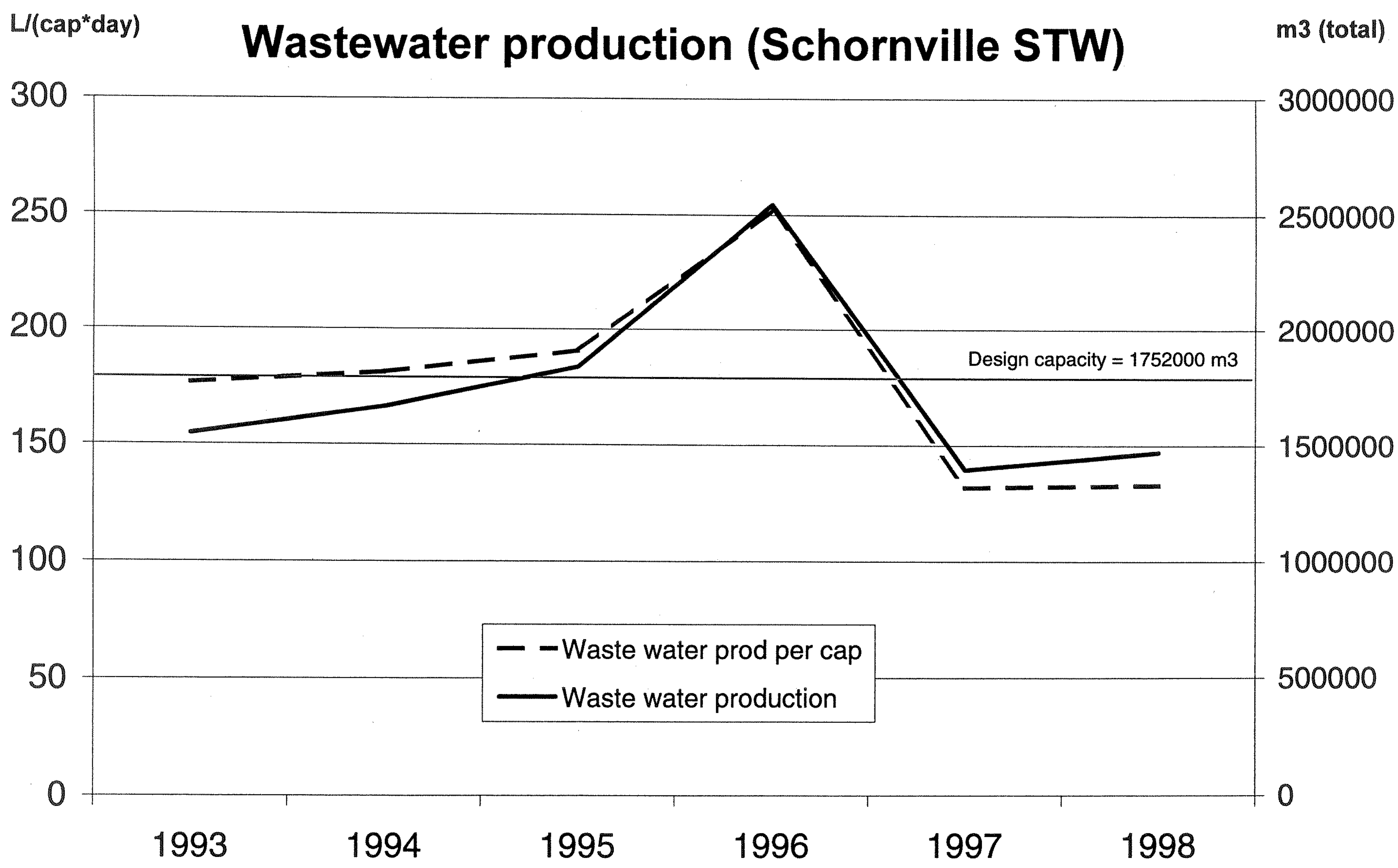
Source: Data from Department of Water Affairs and Forestry. (HYDRO STATION NO: R2R002Q01)

Indicator Graph 3



Source data: Inflow of raw water to the KWT Purification Works (PW). Population served by PW, estimation by Setplan (1997). Flow to King Tanning taken from WRC Report No. 405/1/96. Leakage estimated at 20 %, various sources.

Indicator Graph 4



Source data: Wastewater inflow to Schornville STW. Population estimation accroding to Setplan (1997).

Indicator Graph 5

Month/Year	Freshwater withdrawal m3/month	Chemical use at KWT WPW AlSO4 kg/month	Lime kg/month	Chlorine kg/month	Energy use at KWT WPW kWh	Wastewater production Breidbach STW m3/month	Schornville STW m3/month	Chemical analyses at Schornville – Influent NH3 as N mg/l	NO3 as N mg/l	PO4 as P mg/l	COD mg/l	Effluent from old plant NH3 as N mg/l	NO3 as N mg/l	PO4 as P mg/l	COD mg/l	Effluent from new plant NH3 as N mg/l	NO3 as N mg/l	PO4 as P mg/l	COD mg/l	Chemical use at Schorville STW FeCl3 kg/month	Lime kg/month	Chlorine kg/month	Energy use at Schornville STW kWh
Nov-94	361957					16683 *	193650																
Dec-94	361957					26498	188974																
Jan-95	264502					22923	216959																
Feb-95	218271					16380	158272																
Mar-95	167066					14060 **	149788																
Apr-95	220899					21205	107998																
May-95	142495					23500	116725																
Jun-95	176511					23815	112840																
Jul-95	177719					25333	127586																
Aug-95	182261					28883	186310																
Sep-95	166741					18709	150039																
Oct-95	212429					21915	157778																
Nov-95	220046					26083	143337																
Dec-95	213579					17810 ***	206853																
Jan-96	227543					17218 ****	463004																
Feb-96	250448					26441	378889																
Mar-96	299332					15599	389228																
Apr-96	248350					1599	217635	19.84	1.50	4.63		2.05	7.43	0.41		0.81	4.33	0.45					
May-96	287916					24503	142431	2.71	1.40			2.78	3.76			2.41	3.86	0.40					
Jun-96	153165					24123	236250	2.75	1.37	0.90		2.75	3.40	0.90		2.75	4.97	0.90					
Jul-96	117877					26599	130137	3.50	1.40	0.74			8.80	0.70		4.68	4.06	0.66					
Aug-96	216807					11722	115808	15.85	1.58	0.97		9.53	5.23	1.18		2.65	4.25	0.80		6880	3850	1120	
Sep-96	225241					11766	98964	25.40	1.38	1.34		10.68	7.60	1.42		14.00	3.54	0.59					
Oct-96	219108					19743	100965	28.73	1.44	1.16	286.0	8.77	5.43	1.28	105.50	7.53	3.60	0.46	35.00	4490	3650	971	
Nov-96	257944	4500	2025	376		23468	188446	1.36	2.08	1.27	248.5	1.40	3.53	0.64	75.50	0.33	2.80	0.36	37.50	6507	3875	1033	
Dec-96	260502	4700	1650	376		13215	82305	13.05	1.77	1.13	297.0	0.32	3.35	1.15	75.00	0.46	1.33	0.63		6507	4225	655	
Jan-97	253364	4530	1700	413	3211	15014	97509	29.10	1.85	0.90		4.00	2.40	0.63		6.30	1.43	0.23		8378	4325	886	238
Feb-97	271498	3950	1550	435	2307	12213	69697	16.33	1.73							10.53	4.80	0.00		3088	4275	858	157
Mar-97	266172	3750	1850	493	4188	12864	97437	23.90	2.06	3.68	284.5				75.00	13.88	2.98	0.63	34.00	7634	3900	800	163
Apr-97	243967	4350	2375	446	3022	14260	142628	16.03	1.33	0.70	223.0	2.58	0.74	0.31	58.00	1.85	1.63	0.24	70.00	6733	3500	848	147
May-97	257702	5000	2200	355	3416	12811	135193	31.25	1.40	1.42	282.0	14.33	2.77	1.40		4.30	3.85	0.63	73.00	5115	3750	983	387
Jun-97	253184	4950	2025	542	2573	15650	170749	23.88	1.64	0.73	340.5	8.72	4.26	0.21	82.00	5.08	3.12	0.41	51.50	1353	1508	540	203
Jul-97	258803	4450	1875	612	2236	11991	118636	15.12	1.86	0.63	242.0	3.24	4.42	1.90	66.00	0.61	3.10	0.18	20.67	3619	2919	634	217
Aug-97	257160	4400	2800	541	3056	12251	123173	22.72	1.68	0.69	270.0	7.58	3.28	0.35	74.00	11.06	2.78	0.51	49.20	6361	4650	866	214
Sep-97	267477	4250	2875	422	2622	12578	95601	19.08	1.56	0.16	216.8	6.62	4.12	0.29	103.20	2.95	3.50	0.16	51.00	3937		670	238
Oct-97	270514	4100	2500	434	2683	13716	77334	49.20	1.18	1.16	235.8	12.44	6.44	1.25	60.33	0.37	4.44	0.37	40.25	3686		947	207
Nov-97	281418	5350	3075	498	3251	13716	168778 '	26.40	3.50	1.18	271.0	12.78	3.53	1.20	95.00	3.39	1.40	0.58	32.60	3686		358	236
Dec-97	261593	4150	2425	424	3116	13716	97509 ''	28.00	1.58	1.10	243.0	7.24	5.84	1.12	101.25	17.20	0.94	0.72	45.00	2570	2250	278	203
Jan-98	273342	4900	2625	403	4742	13716	236286 '''	34.00	1.78	1.06		5.78	6.26	1.12	53.80	0.73	5.64	0.47	28.60	5115	2000	256	250
Feb-98	248061	4300	2275	320	3670	13716	74389		2.74	0.61	311.3		3.50	0.39	74.50		3.84	1.52	32.67	3198	2050	735	241
Mar-98	256477	6550	2350	460	3550	13716	133001													4622	2625	90	250
Apr-98	243977	6050	2275	305	4214	13716	92253													4273	688	420	241
May-98	248807	5900	2325	415	3143	13716	118349	41.50	3.20	3.90	546.0	32.80	4.43	2.43	58.00	16.75	4.53	1.55	35.00	6512	1650	438	92
Jun-98	267044	4850	2075	391	3727	13716	112875	57.50		2.91	593.8	17.69	4.01	2.57	107.60	6.57	4.18	1.83	62.80	4579	4325	443	109
Jul-98	277050	4250	1850	435.9	3715	13716	103941	45.09		1.85	420.0	13.20	3.81	1.67	88.90	9.31	3.21	1.54	46.82	2066	4475	479	109
Aug-98	268727	3850	2500	404	4109	13716	123570	56.56		1.96	923.6	12.07	5.49	1.58	103.83	8.46	3.62	1.25	55.99	1436	4375	468	328
Sep-98	229583	5700	2350	658	3491	13716	116751	42.64		3.09	638.2	14.32	6.77	2.95	84.00	18.84	2.97	2.71	98.60	4419	4500	154	184
Oct-98	257646	5850	1700	397		13716	111396	43.83	3.75	2.41	697.5	12.92	5.18	1.81	95.50	20.95	6.73	2.10	160.20	1847	4200	548	176
Nov-98	265017	5800	1975	380		13716	149677	32.59		2.03	519.3	12.51	3.90	1.74	94.22	20.31	2.24	1.31	90.00	1847	4325	542	191
Dec-98	240000	3200	1450	424	3941		97509 ''	15.62		2.30	439.6	3.48	4.47	1.70	58.00	4.44	3.12	1.18	48.00				168
Jan-99					3579							6.96	4.46	2.15	86.25	2.87	3.96	1.92	36.60	1847	4575	503	
Feb-99					4446							12.22	2.47	2.81	72.00	3.66	3.26	2.34	37.67	1847	4125		

Comments:

* = average of values for November 1995 - 98
** = average of values for March 1994, 1996 - 98
*** = average of values for December 1994, 1996 - 97
**** = average of values for January 1994, 1996 - 97

' = average of values for November 1994 - 96, 1998
'' = "estimated flow" written in log
''' = average of values for January 1994 - 97

Source data