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Evaluation of the Environmental Impact on the Keiskamma River in Keiskammahoek TLC, South Africa

Utvärdering av miljöpåverkan på Keiskammafloden i kommunen Keiskammahoek, Sydafrika

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Abstract

Urban and semi-urban areas in developing countries are among the most severely polluted areas in the world with many outbreaks of disease. An improper sanitation system is one of the most serious problems in these areas, with disease spreading through inadequate or non-existent wastewater treatment. Groundwater and other freshwater sources can be polluted when untreated wastewater is discharged. Lack of funds for improvements, maintenance and operation of the treatment works increases the problems.

A Case Study was carried out in a rural development, Keiskammahoek (Eastern Cape, South Africa), where a rapid increase in population has not been matched by improvements in the existing wastewater treatment works. Effects on the receiving river of discharges from the insufficient wastewater treatment works and other sources were studied trough a measurement campaign was conducted in 1999, with special focus on nutrients and oxygen demanding substances.

The Keiskammahoek treatment works consists of a series of anaerobic/aerobic treatment ponds, which relies almost entirely on natural processes for removal of nutrients, oxygen-demanding substances and pollutants. The effluent is released into the Keiskamma River, which is the freshwater source for the region and is used by settlements downstream.

The results showed that the effluent from the wastewater treatment works exceeds the legislative levels several times with failure of the treatment works to achieve an acceptable level of treatment. Simple, cheap and natural ways to improve the treatment works were studied and evaluated, since the municipality can not afford a conventional treatment works. A constructed wetland might be the best way to upgrade the wastewater treatment.

Keywords: Wastewater, Treatment Ponds, Natural Treatment, Nutrients

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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 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.

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Glossary

Aerobic	Conditions with oxygen present
Anaerobic	Conditions without oxygen present
Black water	Wastewater mixed with human waste
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
DWAF	Department for Water Affairs and Forestry Authority who sets the effluent standards from treatment works
Grey water	Wastewater from cleaning, washing and cooking
Grit	Hard, sharp granule (of ex sand) and material composed of such materials. Grit may also include large organic particles as eggshells, bone chips and other food rests
KWWTW	Keiskammahoek Wastewater Treatment Works
Nguni	The African people that is believed to have migrated from central Africa to form tribes such as the Xhosa and the Zulu
RDP	Reconstruction and Development Programme The South African government finances a better housing situation for people with low incomes by subsidising the construction of cheap, simple houses
Rhizosphere	Soil that surrounds and is influenced by the roots of a plant
SBA	Stemele Bosch & Associates, South African consulting firm
Sludge	Sludge consists of settled organic and inorganic solids, which has settled and precipitated mainly in the primary treatment ponds in water and sewage treatment processes
S.S. Gida hospital	Local Hospital in Keiskammahoek
Substrate	The base on which an organism lives, the soil for example is the substrate of most seed plants
TLC	Transitional Local Council, works as a community
Vertebrates	Animals with a spinal column
WWTW	Wastewater Treatment Works

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1. Introduction

1.1 Background

This report evaluates the present sanitation system in the town of Keiskammahoek, which is situated in the rural areas of the Eastern Cape, South Africa. Although the problems of the present sanitation system have been known for a long time it has been thought of as secondary problems.

"The domestic water-supply of the villages comes mostly from the streams which, owing to the lack of proper sanitary precautions, are often polluted.". Hobart Houghton wrote this in 1955 and it concerned the village of Keiskammahoek.

The problems escalated in 1997 when 443 RDP-housing units were connected to the wastewater treatments works without any re-construction of the works. Problems with bypassing due to overflows have occurred regularly since then, (Precious 1999).

The present treatment works is built as an anaerobic/aerobic pond system, which relies almost entirely on natural processes in water, soil and on plants for treatment without human involvement. An anaerobic/aerobic pond system is a form of treatment works that have been popular in the past but is today considered inadequate. (Warren and Hammer, 1998) This fact added to the problem that too many people are connected might result in poor purification and as a result pollution of the recipient.

The recipient is Keiskamma River that runs from the Amatola Mountain Range and then makes its way through Keiskammahoek on its way to the Indian Ocean. The population throughout the area uses this river for different purposes such as, freshwater source, fishing, swimming and other recreational activities. It is therefore of great concern that the river remains healthy. Another fact that needs to be pinpointed is the location of Sandile Dam downstream Keiskammahoek, which is used as a freshwater source. Pollution of the Keiskamma River will without doubt lead to increased use of treatment chemicals in the fresh water purification works.

This report concentrates on the nutrient load and oxygen demanding substances that affect the Keiskamma River. A measurement campaign have been worked out in co-operation with Olalekan Fatoki, Professor in Chemistry at the University of Fort Hare and Greg Morrison, Professor at department of Water, Environment and Transport at Chalmers University of Technology.

The measurement campaign was conducted for 3 weeks in November 1999 together with Lennart Persson, also student at Chalmers University of Technology in Gothenburg, Sweden. The project was financed within the framework of the Minor Field Study (MFS) Scholarship Programme by Sida (Swedish International Development Cooperation Agency).

Stemele Bosch & Associates (SBA) made in January 1999 an environmental scooping investigation for the transport, treatment and disposal of wastewater in the town of Keiskammahoek on behalf of the municipality of Keiskammahoek. This report has been used as a source of information and for comparison in this measurement campaign.

1.2 Aims

The major aim of this report is to evaluate the impacts of Keiskammahoek Waste Water Treatment Works (KWWTW) and to a certain extent Keiskammahoek TLC regarding nutrient load and oxygen demanding substances affecting Keiskamma River. This aim have been subdivided into:

- Plan and conduct a measurement campaign in the area of Keiskammahoek TLC.
- Describe the area and identify potential problems affecting Keiskamma River in the vicinity of Keiskammahoek TLC,
- Present results from the measurement campaign,
- Evaluate results, compare with current legislation, impact on Keiskamma River etc.
- Understand the processes occurring in natural wastewater treatment
- Evaluate possible natural treatment methods and suggest an alternative method

2. Keiskammahoek

The town of Keiskammahoek falls beautifully into the Amatola mountain range, which is situated in the former homeland Ciskei in the Eastern Cape Province in the southeastern parts of South Africa. Geographically it is located 45 km northwest of King Williams Town (KWT), 34 km south west of Stutterheim, 18 km north of Dimbaza and 43 km northeast of Alice and the University of Fort Hare.

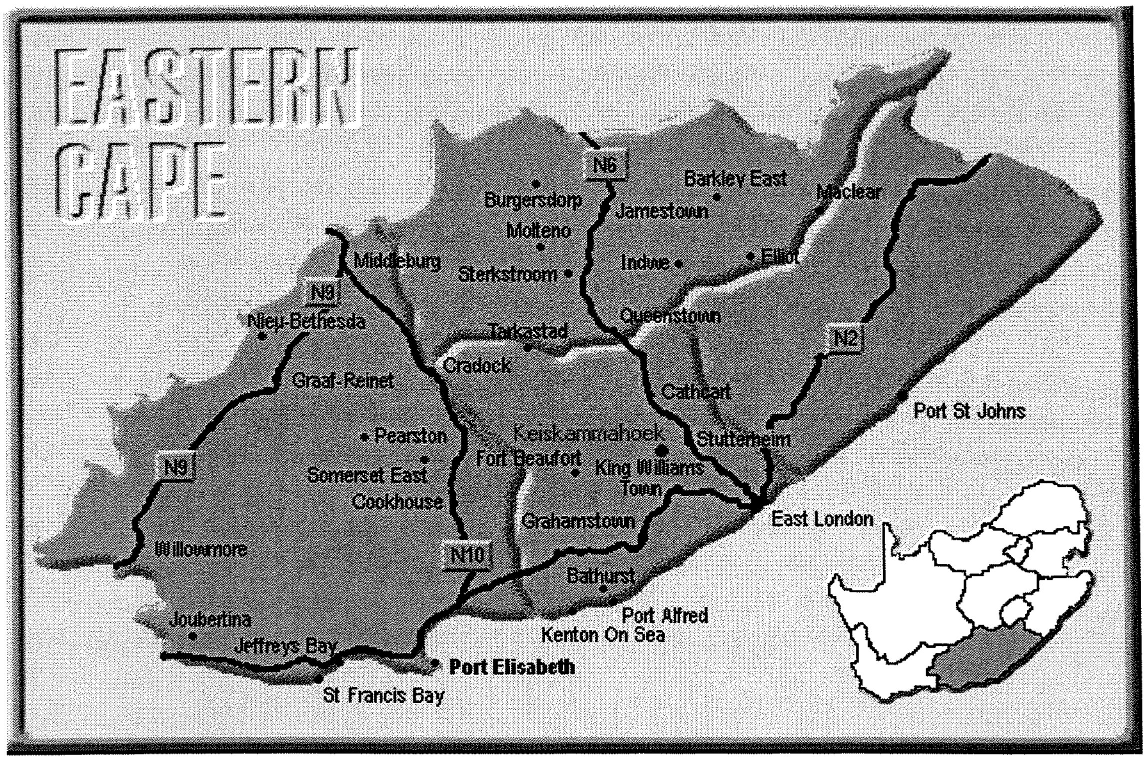

Figure 1: Keiskammahoek in a map over Eastern Cape, with major cities and national roads (web page 1)

2.1 History

The presence of the Xhosa speaking southern Nguni people in this area historically dates back to the great migrations, which originated from Central Africa in the 15th century (Oosthuysen, 1989). The British conquered the Xhosa people in 1853 and added the area to the Cape Colony (Houghton, 1955). Conflicts between Xhosa people and white farmers resulted in nine frontier wars between 1779 and 1878 (Oosthuysen, 1989). The town Keiskammahoek was a centre for military occupation in the area (Houghton, 1955).

The British established the settlement of Keiskammahoek as a military post in 1853. "Keiskamma" is Xhosa and probably means 'glistering and sparkling water or river', "hoek" is a Dutch word meaning bend and together they represent the interaction of cultures through history in the area around Keiskammahoek (de Wet and Whisson, 1997).

The area around Keiskammahoek was settled with a small number of British and German settlers and a very considerable number of Mfengu. Mfengu were also of Nguni origin, but driven away from their land in Natal by Zulu leader Tshaka's wars and had allied themselves with the British and received conquered land in award (de Wet and Whisson, 1997; Houghton, 1955). The motive behind the intermixed settlements of white and black were both military and economic, designed to effect more secure control against uprisings and to ensure adequate labour for European farmers.

Keiskammahoek Town developed as an administrative and commercial centre. The European population showed a gradual decline over the years, mainly due to the Native Trust and Land Act from 1936 where white farmers were obliged to sell their farm to the government, which converted the land into Trust settlements for blacks. (de Wet and Whisson, 1997)

2.2 Demography

The area around Keiskammahoek consists of 12000 people with an expected 2.3% net population growth through to 2005. 56% of the people are under the age of 19 years. One third of the population falls within the potentially economic active age group. 65% of the economically active population is unemployed. Most employment opportunities are in the government sector followed by a significantly smaller chance for employment in the private business and domestic sectors (SBA, 1999).

De Wet and Whisson studied the income levels in three rural villages not far from Keiskammahoek (ca 10 kilometres), the total average income in the three villages varied between R4000 and R12000 per year. Almost half of all rural income comes from absent household members, including short-term commuters who live away from the village but return at least once a week. The remittances are either in the form of cash or other kinds like goods or account payments. Pensions from the government are an important income for the families, 20 to 30% of the income were pensions depending on the village. Men over 65 years of age and women over 60 were granted pensions of R300 every second month (1991) as well as those with a disability grant (De Vet and Whisson, 1997). 1311 households had a low income when SBA did a survey in 1998 (SBA, 1998b) and 7880 people in the Keiskammahoek TLC were government beneficiaries (3580 in the informal settlements in Tshoxa, marked D in figure 2).

50% of the population is functionally illiterate, while 11% have progressed beyond a Junior Secondary level of education (SBA, 1999).

2.3 Keiskammahoek TLC

The Keiskammahoek TLC consists of the town of Keiskammahoek and 7 surrounding villages, TLC means Transitional Local Council and works as a community. In total there are 12000 people living within the TLC, and 5000 of them are connected to the treatment works in Keiskammahoek (KWWTW). There are 2 different ways of collecting and transporting the sewage to the treatment works, the "flush and discharge"-and "drop and store" systems, personal communication with Ms Precious 14/11/99.

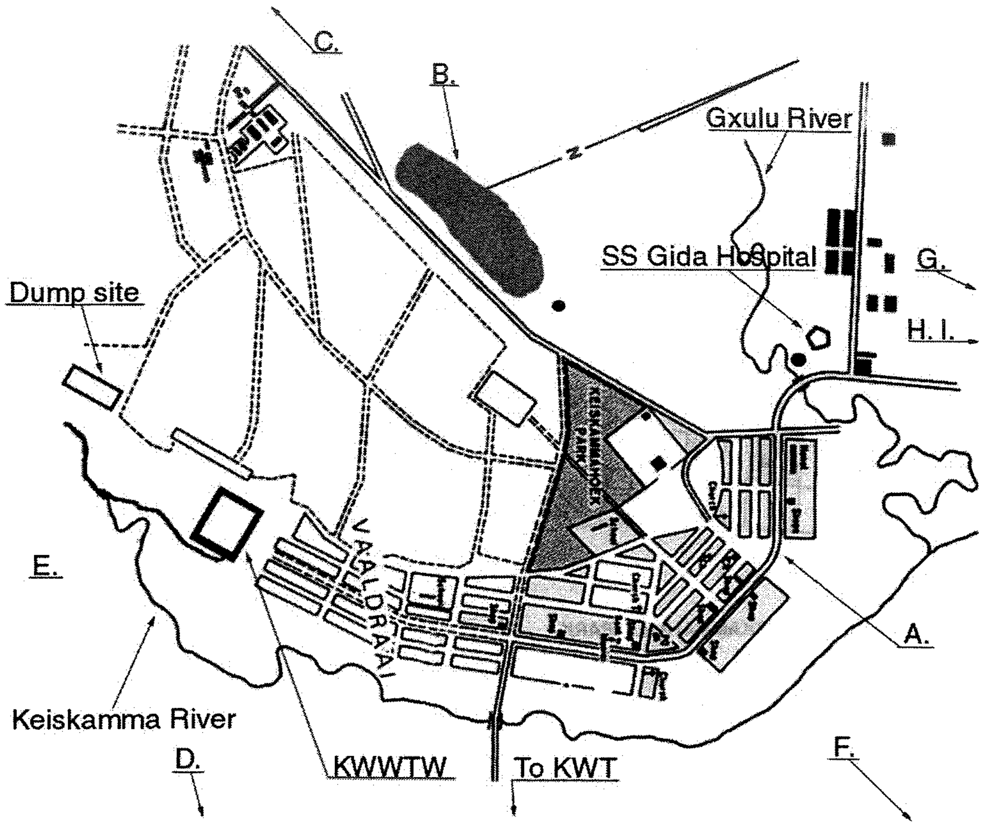

Figure 2: Keiskamma TLC with its different villages and wastewater system (described below), modified map, originally from de Wett and Whisson 1997

The different parts of the Keiskammahoek TLC are shown in figure 2 above and described together with used sewage system below (Precious, 1999).

Keiskammahoek town:

- *Vaal Draii* uses a bucket system and septic tanks, marked with name in figure 2
- *Keiskammahoek Park* uses the waterborne wastewater system, marked with name,
- *Main Street/Old Town* uses a bucket system and septic tanks, marked A.

Surrounding villages:

- *Sophumelela Township*, is the newly built RDP housing units (totally 443 houses) uses the waterborne wastewater system, marked B,
- *Masincedane* uses pit toilets, they are not connected to the treatment works but sometime uses the vacuum pump locally known as "honey sucker", marked C,
- *Tshoxa* uses ventilated improved pit latrines (VIP toilets) and is marked D,
- *St. Peter's* is not connected to the Keiskammahoek treatment works, uses pit toilets, marked E,
- *Ngqudela* is not connected to the Keiskammahoek treatment works, uses pit toilets, marked F,
- *Bumbane* is not connected to the Keiskammahoek treatment works, the SS Gida treatment works is situated in this village, uses pit toilets, marked G,
- *Ngxalawe/Kom* is not connected to the Keiskammahoek treatment works, uses pit toilets, marked H,
- *Nompha* is not connected to the Keiskammahoek treatment works, uses pit toilets, marked I.

2.4 Geography and Climate

The source of the Keiskamma River is the mountains surrounding Keiskammahoek, the greatest heights are found in the north in a line from the Hogsback in the northwest direction to Mount Thomas with an altitude of about 1500 m above sea level (Doni, 1997). Before Keiskammahoek the Gwili-Gwili River connects to the Keiskamma River and at Keiskammahoek the Gxulu River normally delivers a considerable amount of water. The altitude of the river drops to about 500 m within a distance of 30km resulting in steep slopes and narrow valleys where it is hard to do any cultivation. The river then flows down to the coastal plateau, from here and onwards the river flows over a relative flat land making the river meander.

North-westerly winds are predominantly all year round with an annual rainfall of 630mm. The bulk of rainfalls are in the spring/summer period between August and March, measured in King William's Town (45km) and in Dohne (38km) from Keiskammahoek (SBA, 1998b), se figure 1. Austin, 1989 measured the annual rainfall in Keiskammahoek to 650 to 700mm per year with the majority falling in the summer from October to March.

The mean average temperature in King William's Town during January is 22.1°C with a maximum of 36.9°C. In Dohne the average temperature in January is 19.8°C with a maximum of 36.9°C. In July the average temperature is 13.8°C in King William's Town and 12.8°C in Dohne (SBA, 1999).

3. Wastewater-systems and problem identification

3.1 Wastewater-systems and Problem Identification

Both "flush and discharge" and "drop and store" sanitation systems are used in Keiskammahoek at present.

In an ordinary waterborne "flush and discharge" system, sewage (human excreta, washing water etc.) is mixed with clean water. As a result all of the wastewater needs to be treated in the same way, which is expensive (in different ways) and can be seen as a waste of resources.

The "drop and store" system has the base in storing sewage in the ground. However, there are a number of different techniques that can be used e.g. pit toilet, which is the most common sanitation system in the world (Winblad, 1998). Septic tanks and conservancy tanks collects the waste in a tank for later collection by the municipality. Criteria for "drop and store systems" are, access to the ground and a soil that can be dug, a low ground water table and an area that is free from flooding. Examples of disadvantages are bad odours, fly breeding and soil and water contamination.

"Drop and store"

At the moment there are 65 bucket systems, 4 pit latrines, 5 french drains, 89 conservancy tanks and 10 septic tanks in Keiskammahoek (SBA, 1999). The remaining households are connected to the public sewage system and this should add up to approximately 5000 persons according to Ms Precious, 14/10/99.

The bucket system means that excreta is discharged directly into a bucket or a small container, which has to be emptied regularly. In the conservancy tanks night soil is stored until municipal collection. The septic tank allows the solids to separate from the liquid by sedimentation and the liquid is allowed to leave the tank by percolation into the soil. The collected solids in the tank must regularly be pumped out. The pit latrines is a simple pit dug in the ground and a simple structure to protect from view, as in the septic tank the water is allowed to seep out through the walls and the solids are collected in the pit. When the pit is full it is either covered and a new pit is dug or it is emptied and reused.

The collection of buckets and night soil from the conservancy tanks and septic tanks is made by the municipal "honey sucker" and the content is supposed to be discharged into the inlet of the Keiskammahoek WWTW (SBA, 1999). The "honey sucker" is a vacuum tank pulled by the tractor owned by the municipality, which is seen in figure 3. When visiting KWWTW at the 11/11/99 was the "honey sucker" discharging its contents directly into the primary aerobic pond instead of discharging into the inlet. However this could be due to the re-construction that is taken place close to the inlet, which prevents access. But this action lowers the purification rate, it should be investigated if this discharge point is frequently used.

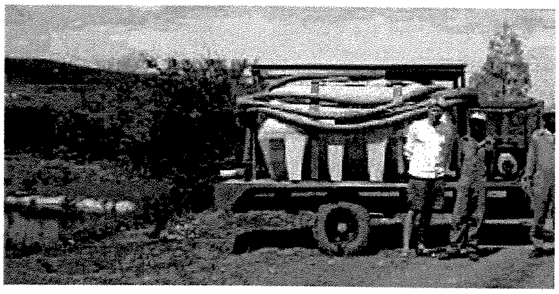

Figure 1: Lennart Persson in front of "honey sucker" at KWWTW

Another potential source of pollution is the cleaning of the buckets that have contained human excreta. After being emptied into the inlet of the treatment works they are transported to the bucket washing facility, which is situated at the landfill area approximately 700 meters in a westerly direction. (SBA, 1999) Here they are cleaned and the water makes its way down to Keiskamma River untreated. No estimations have been made on possible pollution potential from this source. When visiting the bucket cleaning facility at 21/10/99 there were no signs of a ditch leading the cleaning water down to Keiskamma River. However this is potential source of pollution that needs to be investigated in further studies.

There are some additional problems connected to the use of "drop and store" systems. Keiskammahoek has shallow groundwater and the use of these systems is a potential pollution of the groundwater (Wright, 1999). It is difficult to make predictions on how much the discharge of pollutants from "drop and store" systems affects Keiskamma River. No estimations have been made regarding the impact in this report.

"Flush and discharge"

There are 3 sewage systems in Keiskammahoek that are built according to the principle of "flush and discharge", where the sewage is mixed with water and then transported in pipes to the treatment works:

1. An old military camp is located in the area of Ngqudele, but this treatment works is not used anymore, so this point source has been disregarded, marked F in figure 2.
2. S.S. Gida Hospital is situated in the vicinity of the Keiskammahoek town centre. This Hospital has its own treatment works in the village *Bumbane*, marked G in figure 2. To reach the treatment works the wastewater needs to be pumped.
3. An estimated population of 3000 is connected to the KWWTW via a black and grey waterborne system.

When visiting the village of Keiskammahoek and the S.S. Gida Hospital pump station at 21/10/99 it was noticed that the pumps were out of order. At the Treatment Works Mr Sontshi, employee at S.S. Gida gave us the information that the pumps had been out of order for 9 months. The low water table in the treatment ponds verified the statement. The consequence is that raw wastewater by passes the pumps and discharges straight into Gxulu River. S.S. Gida Hospital serves a big area, approximately 30 000 humans and the malfunction of the pumps make the hospital a severe potential polluter of Keiskamma River.

In the planning phase of the measurement campaign a point downstream the discharge from S.S. Gida's pump station was chosen in order to evaluate the environmental impact. However at the start of the measurement campaign (01/11/99), it was noticed that the bypass of wastewater had stopped and that the pumps were running. A site visit at S.S. Gida treatment works was conducted, a discussion with Mr Mbilase (pump technician at S.S. Gida Hospital) gave the information that the pumps had been repaired the previous day. The measurement campaign was transformed and this point excluded, however the function of the pumps was checked at every sampling occasion. A site visit was also done at 18/11/99 to the S.S. Gida treatment works. No effluent could be spotted then as a result of the long malfunction of the pumps that have lowered the water table in the ponds. An effluent is expected in January according to Mr Mbilase.

There is a pump station connected to the RDP-housing units that provides a threat to the water quality of Keiskamma River. In case of malfunction of the pumps, a small pond will store the wastewater. But within a few days overflow will occur and wastewater will seep down reaching the Gxulu River.

3.2 The Keiskammahoek wastewater treatment works (KWWTW)

The WWTW in Keiskammahoek was constructed in 1983 and it is built as an anaerobic/aerobic waste stabilisation pond system, for location see figure 2. (SBA, 1999) It is built for a population of 950-1000 persons but at the moment approximately 5000 persons are connected. The treatment works receives both black and grey water. A common problem with this sort of treatment works due to overloading is odour (Warren and Hammer, 1998). Raw fresh sewage from the waterborne sewage system is usually grey in colour without a repulsive smell. Aged sewage from ex septic ranks is more offensive and the sewage is almost black (Davis and Cornwell, 1998).

The inflow to the pond is so high that it overflows occasionally, which means discharge of wastewater into the river. The reason for the overflow is the combination of an under dimensioned treatment works and rainfall (Precious 1999). Another apparent impact in the vicinity of the treatment works is odour, which was substantial at all sample dates.

No chemicals are added in KWWTW, which means that treatment occurs naturally. The treatment works is designed to carry 100 m^3/d, with peak flows of 220 m^3/d in wet weather. (SBA, 1999)

The WWTW consists of a grit screen where large particles in the raw sewage are removed, marked (A) in figure 4. The removed grit and other rubbish are buried on site. The sewage is then lead into two parallel anaerobic settling ponds where the sewage is settled, marked (B). Screenings, grit and primary sludge removed from the screen and anaerobic settling ponds is buried on-site. The sewage is then lead through a primary aerobic settling pond (C) to a second aerobic settling pond (C) and eventually runs trough a three-stage maturation pond system, marked (D). No tertiary treatment occurs and the final green-coloured effluent flows over a floodplain for approximately 700m before discharging into the Keiskamma River (SBA, 1999). The effluent is green coloured due to the fact of all algae formed in the natural treatment process. The municipality did unfortunately not have any records of size and depth of the different ponds, figure 4 is just a rough sketch to understand how they are situated.

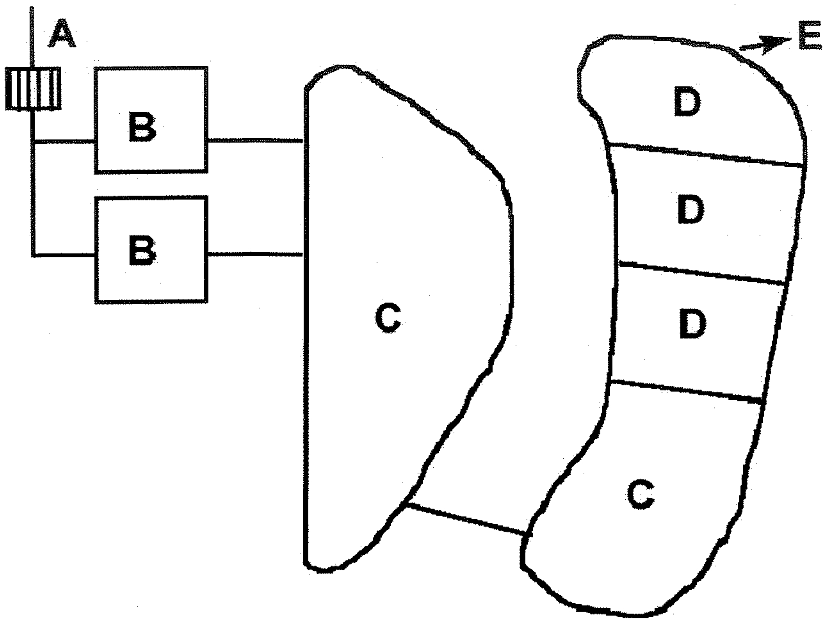

Figure 4: Rough sketch over Keiskammahoek treatment works

Upgrading of Wastewater Treatment Works

Stemele Bosch and Associates, 1999 conducted an investigation to upgrade and/or remove the present treatment works in a detailed feasibility study and environmental scoping report. Several alternative natural treatment methods were studied, Stemele Bosch recommended that the Keiskammahoek Waste Water Treatment Works (KWWTW) should be upgraded with an activated sludge plant, which would comply with DWAF general standards. It was chosen because of land constraints, the inability to treat wastewater to the General Standards with stabilisation pond systems as well as financial constraints.

The upgraded works would be able to treat $470m^3d^{-1}$ of mainly domestic sewage, with a peak flow of $1000m^3d^{-1}$. It would be possible to install the activated sludge treatment plant on the same area as the existing treatment ponds site. The existing concrete lined ponds (the anaerobic settling ponds, marked B on figure 4) would be used one at a time as sludge settling ponds. The other one would be allowed to dry out and the sludge would then be buried on site or distributed to farmers in the area for use on pastures and non-consuming crops (SBA, 1999).

The secondary and tertiary treatment ponds would be used to polish the effluents before discharge into the Keiskamma River. A chlorination facility would also be constructed for microbiological treatment.

Other recommendations from SBA included for the wastewater treatment system in Keiskammahoek included:

- The S.S. Gida treatment works should be closed and the sewage would be led to KWWTW
- The RDP and S.S. Gida pump stations should be decommissioned

- Installation of a gravity sewer from the RDP pump station to Keiskammahoek Park
- Construction of a sewer reticulation system within town including two pump stations
- The bucket cleaning facility should be moved to the treatment works

They also suggested an alternative site for the WWTW to approx. 700m downstream present WWTW on the current solid waste disposal site. The reasons were the topography, land availability, proximity to Keiskammahoek and financial costs of the project (SBA, 1999).

3.3 Other Potential Point Sources

There are no industries of significance in the area except for the sawmill, which is situated close to the S.S. Gida Hospital. Although, this industry has not been considered as a polluter in this report, measurements and evaluations between sample point 6 and 7 verifies this theory. The refuse dump situated downstream the treatment works has also been excluded as a result of a site visit. Since the measurement campaign takes place during the dry season, surface flow is seldom occurring. No estimations considering groundwater leachate have been carried out. Besides mentioned point sources there have not been any other potential point sources identified in the area of Keiskammahoek.

3.4 Non-point sources

Urban and agricultural runoff are characterised by multiple discharge points and are often described as non-point sources. Often polluted water flows over the surface of land via natural drainage channels to the nearest water body. Even when this water is collected in pipes or channels it is often transported to the nearest recipient without treatment (Davis and Cornwell, 1998).

There are some non-points sources in Keiskammahoek that may affect Keiskamma River. Previously, the stormwater system has been inadequate and as a result left water lying on the streets for days. This allowed the water to evaporate. The stormwater system is now being reconstructed and this will result in drainage of the streets and discharge into the Keiskamma River. (SBA, 1998a) Examples of pollutants from non-point sources such as, urban runoff are oxygen-demanding substances, nutrients, salts and toxic metals. (Davis and Cornwell, 1998) Another problem related to urban runoff is pouring of washing water into the street of Keiskammahoek to prevent rapid filling of the septic tanks (SBA, 1998a). Washing powder has polyphosphates as a constituent and will have a eutrophic effect on the river.

There are also some irrigation schemes for the agricultural fields in the valley that may have an affect on the river since these types of activities usually use fertilisers. Examples of pollutants from agricultural runoff are oxygen demanding substances, nutrients, salts and toxic organic chemicals (Davis and Cornwell, 1998).

4. Natural Treatment Processes

Municipal wastewater consists of 99.9% percent water, the remaining materials include suspended and dissolved organic and inorganic matter as well as microorganisms. Domestic wastewater varies widely from community to community, depending on water quality, use and conservation practices, cultural attributes and if any industries are present.

Waste stabilisation ponds are large shallow lagoons, which treat the sewage by entirely natural processes involving both algae and bacteria. Organic matter in the sewage will decay naturally, the treatment ponds just accelerate the natural decay process and neutralise the waste before discharging it into the receiving waters. The processes are rather slow and a long retention time is needed, 10 to 50 days is common (Mara, 1996). Advantages such as low costs and maintenance have made stabilisation ponds the most important sewage treatment method in developing countries. Major disadvantages are large required land area, odour and poor effluent quality (Qasim, 1999). Climate can drive the bio-oxidation reaction at different rates and the composition of the incoming sewage is significant a factor in the usage of stabilisation ponds. These are important parameters to understand during the construction of a waste stabilisation pond system and they are hard to influence (Arundel, 1995).

There are three main types of stabilisation ponds: anaerobic, facultative and maturation and they are often arranged in series for best removal efficiency. The classification is based on the nature of the biological activity taking place. Other factors like depth, detention time and organic loading varies between the different types.

The Keiskammahoek WWTW consists of a grit screen, two anaerobic settling ponds followed by a primary and a secondary aerobic pond followed by a three stage tertiary maturation pond (SBA, 1999).

Primary Treatment Grit screen

Primary treatment includes a bar rack and a grit chamber or a settling pond. The major goal of primary treatment is to remove those pollutants in the wastewater that will either settle or float. Primary treatment will remove around 60% of the suspended solids and 35% of the BOD_5 (Davis and Cornwell, 1998). Accumulations of grit and sludge in the treatment pond will decrease the efficiency of biological treatment by generating dead mass in the ponds. Grit consists of heavy solid materials (like sand and gravel) with a substantially greater gravity than those of organic solids found in the sewage. Grit may also include large organic particles, eggshells, bone chips and other food wastes typically found in municipal sewage (Cheremisinoff, 1995).

Anaerobic Settling Ponds

Anaerobic ponds are extremely efficient at removing BOD, they are used as a preliminary treatment process for municipal wastes containing high concentration of organic materials. BOD_5 removals of 50% to 70% are achievable depending on loading and temperature (Cheremisinoff, 1995). A minimum of 1000 mg/l COD is required for successful anaerobic treatment. (Droste, 1997)

There is little or no oxygen present or consumed in an anaerobic process. The pond reaches an anaerobic condition when the sewage has a higher oxygen demand than the oxygen concentration produced from photosynthesis by algae plus transferred from the air. Suitable depth for an anaerobic treatment pond is between 2.5 and 5 meters deep (Qasim, 1999). Excess undigested grease and foam floats to the top creating a heat-retaining and relatively airtight cover.
Methane is formed in the last step in the anaerobic metabolism, if the process is stopped in an earlier step the effluent will contain soluble products with the same oxygen demand as the initial material (Droste, 1997).

Anaerobic treatment ponds are designed to have a detention time of 20 to 50 days (Qasim, 1999).

Facultative Ponds

Facultative ponds are by far the most common type selected as wastewater treatment systems for small communities. Approximately 25% of all municipal treatment works in USA are facultative ponds and over 90% of them are situated in small communities with less than 5000 people (Davies and Cornwell, 1998). They are popular because of their long detention time, 10 to 30 days, because long detention times can manage large fluctuation in wastewater flow and strength with little or no effect on the effluent quality.

Facultative ponds are designed with a depth of 1.2 to 2.5 meters deep, this depth creates an anaerobic layer in the bottom where suspended solids in the sewage settle. Both acid fermentation and methane formation occurs as in the anaerobic treatment pond. Some of the products are then utilised by bacteria and algae in the upper parts of the pond. A removal rate of overall 70 to 90% BOD_5 is not unusual in a facultative pond (Qasim, 1999).

A facultative zone develops just above the anaerobic zone, which means that the zone does not have dissolved oxygen all the time. Generally the zone is in an aerobic condition during the daylight hours and anaerobic during night.

The top layer of the facultative pond is usually dark green in colour, this is due to the large amount of micro-algae that grow naturally and profusely in it. During daylight hours do the photosynthesis process produces large amounts of oxygen and during the dark hours wind mixing of the shallow water generally provides a high degree of surface re-aeration. Algae are responsible for most of the dissolved oxygen found in the pond through their photosynthestoc activities, which in a generalised equation where algae utilise sunlight for the reaction are:

$CO_2 + H_2O \rightarrow \text{carbohydrate} + O_2$ (Mara, 1996)

Maturation or Aerobic Treatment Ponds

Maturation ponds or as they also are called, aerobic ponds, maintain dissolved oxygen throughout their entire depth. They are usually 30 to 45 cm deep to allow sunlight to penetrate the full depth of the pond (Reed ET al, 1990).

These ponds are designed to polish the final effluent by settling the suspended solids and stabilise the low concentration of influent soluble organics. Maturation ponds are also designed to remove faecal bacteria in the effluent from the facultative ponds before discharge into the recipient (Mara, 1996). Faecal coliform bacteria are used as the indicator organism for faecal pathogens. The maximum number of faecal coliforms is 1000 per 100 ml of pond effluent for both fish culture and agriculture, if the effluent is to be discharged into surface water (stream, river or lake).

4.1 Organic decomposition

Anaerobic decomposition

Anaerobic digestion involves a complex mix of microorganisms, (Droste, 1997) suggests that the biochemical processes as well as the microbial species involved can be divided into three categories.

1. Hydrolysis
   Anaerobic bacteria cannot directly metabolise large molecules and suspended solids. Hydrolysis is the breakdown of large, complex soluble and insoluble molecules into smaller molecules that can be transported into the cells and metabolised.

2. Acetogenesis and Acid Formation
   The end products of hydrolysis are fermented into organic acids, other low molecular weight compounds, hydrogen and carbon dioxide. The same micro-organisms as in the hydrolysis make the fermentation and the major product of this fermentation is acetic acid. As shown in figure 5, a significant amount of hydrogen is produced when hydrolysis products are degraded. The methane formers that make the final conversion of organics into methane are relatively sensitive to changes in pH and need a pH near 7. (Droste, 1997)

3. Methanogenesis
   Methane can be formed in two separate ways, the major route is the fermentation of acetic acid to methane (CH_4) and carbon dioxide (CO_2). Acetoclastic (or acetophilic) bacteria are the bacteria involved in the acetic acid fermentation, which is the primary product in the acid forming phase. The overall reaction is:

$CH_3COOH \longrightarrow CH_4 + CO_2$ (Cheremisinoff, 1995)

Some methanogens are able to use hydrogen to reduce carbon dioxide to methane (hydrogenophilic methanogens) with an overall reaction of:

$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$ (Droste, 1997)

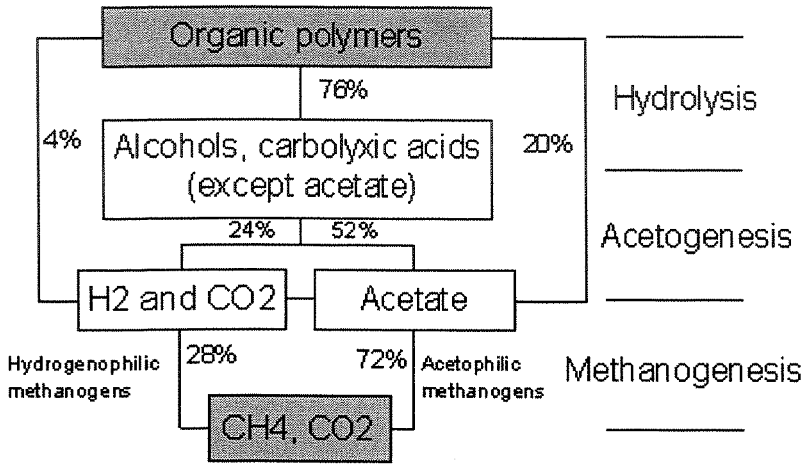

Figure 5: Anaerobic decomposition of organic matter, from Droste 1997

The normal composition of end products from anaerobic processes ranges from 60 to 70% methane and a balance of 30 to 40% carbon dioxide. Small amounts of hydrogen sulphide (H_2S), ammonia, water vapour and other gases are also present (Droste, 1997). Hydrogen sulphide is one of the common odours produced at anaerobic conditions, it can also cause aquatic toxicity (Cheremisinoff, 1995).

Anaerobic treatment ponds are designed to have a detention time of 20 to 50 days and a depth of 2.5 to 5 meters deep (Qasim, 1999).

Aerobic decomposition

A wider spectrum of organic material can be oxidised aerobically than any other type of decomposition. End products oxidised into low energy levels result in more stable than other oxidation systems (can be disposed without damage to the environment) Because of the large energy released in aerobic oxidation, rapid growth rates and the production of many new cells, more biological sludge is produced than other form of oxidation. (Davies and Cornwell, 1998)

Aerobic decomposition is the choice for treatment of large quantities of diluted wastewater with a BOD less 500 mg/l because it is a rapid, efficient process and with a low odour potential. In wastewater with a BOD over 1000 mg/l aerobic decomposition is not suitable, because it is difficult to supply enough oxygen needed and excessive amount of sludge is produced. The heterotrophic bacteria in the pond to remove oxygen-demanding substances in the water use the oxygen produced in the algae photosynthesis. The bacteria and algae have formed a mutual benefit relationship in the upper layers of the facultative pond as can be seen in figure 6. A generalised reaction where bacteria are involved:

$BOD + O_2 \rightarrow$ oxidised waste $+ CO_2$ (Mara, 1996)

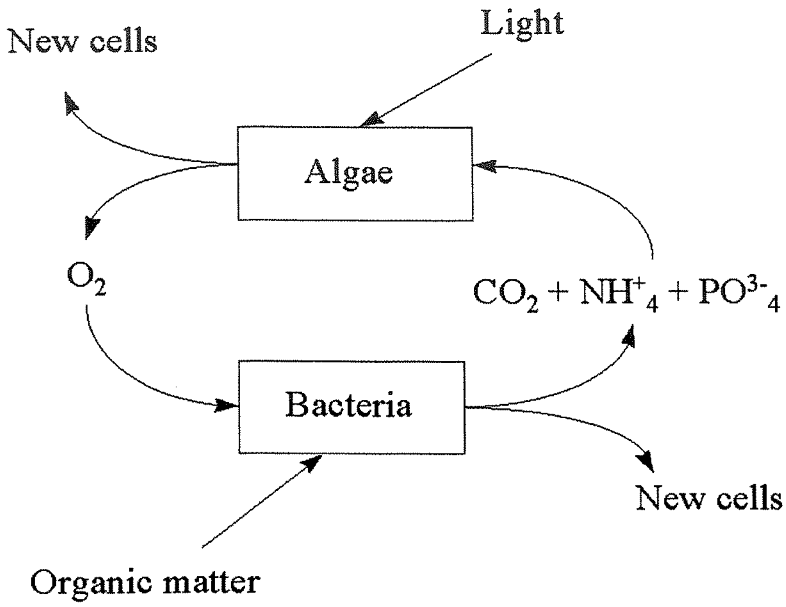

Figure 6: The mutual relationship for bacteria and algae in the upper layer of a facultative pond originally from Mara 1996

4.2 Nutrient Removal

Oxygen demanding substances are the most important pollutants in the effluent from a sewage treatment works. The second most important pollutant in receiving water bodies is nutrients. High nutrient load can cause excessive plant growth, plants are requiring carbon, nitrogen, phosphorus and a variety of trace elements for their growth. Plant growth is possible where there are sufficient quantities of all nutrients available. By limiting the concentration of any of the nutrients further plant growth is prevented. A water body rich in nutrients are called eutrophic and have a high productivity compared to an oligotrophic water body with low productivity. Eutrophic waters are characterised by the presence of highly dense phytoplankton crops called algal blooms, which make the water turbid. This increased productivity can change the entire ecosystem of the water body due to the greater food output and reduced oxygen in deep waters. When the algae dies they fall to the bottom and when they are decomposed by bacteria large amounts of oxygen is required, the result is often oxygen depletion. Fish and other organisms living close to the bottom dies due to they cannot live in an environment with little or no oxygen (web-page 2).

The causes for eutrophic conditions for lakes have all anthropogenic sources. The most frequent causes of eutrophication are sewage effluent and agricultural runoff, both containing large amounts of nutrients without any treatment. Municipal wastewater treatment works have in recent years been upgraded to remove nitrogen and phosphorous.

Nitrogen and phosphorous are removed by a number of processes in a stabilisation pond. Some of the nutrients are assimilated into algae, plant and bacteria biomass. Phosphorous uptake by algae is lower than nitrogen, this because the nitrogen content of the algae is approximately ten times higher than the phosphorous content (Nurdogan and William, 1995).

Nitrification

Nitrification is a two-step oxidation of ammonia nitrogen to nitrate biologically in aerobic conditions. Primary products of oxidation of organic matter will be carbon dioxide (CO_2), water (H_2O) and ammonia (NH_3). The ammonia is then oxidised to nitrate (NO_3) in a two-stage reaction. If, ammonia is released into the recipient it poses an oxygen demand on the water. In the first step is ammonia oxidised to nitrite with help of nitrosomonas bacteria, the reaction looks as follows:

$NH_3 + 3/2\ O_2 \rightarrow NO_2^- + H^+ + H_2O$ (Droste, 1997)

Nitrite is not thermodynamically stable in natural waters and is soon transformed into nitrate. Nitrobacter bacteria with the following reaction do the second oxidation from nitrite to nitrate:

$NO_2^- + 1/2\ O_2 \rightarrow NO_3$ (Qasim, 1999)

The organisms responsible for the nitrification are not responsible for the oxidisation of carbon, they use carbon dioxide as a source of carbon and gets their energy from the nitrification reactions. At normal pH values is ammonia released in the form of the ammonium cation (NH_4^+) (Davies and Cornwell, 1998).
The dissolved oxygen (DO) concentration may affect nitrification process, for best process design should the DO be between 1 and 3.0mg/l, the nitrification process have a steady increase. A minimum DO of 2.0mg/l is recommended for process design (Qasim, 1999).
Alkalinity is consumed in the nitrification process, approximately 7.3g $CACO_3$ is consumed for each gram of NH_4^+ - N. The effect of low pH on reaction is significant, optimum range is pH 7.2 to pH 8.6. Nitrification stops at pH below 6.3 (Qasim, 1999). Low temperatures have adverse effects on the nitrification process.

Denitrification

Denitrification occurs in anoxic conditions with little or no oxygen present and an excess of nitrate present. With denitrification are nitrates reduced to nitrogen gas, when a carbon source like methanol, is present and acts as an electron donor. Facultative heterotrophic bacteria called denitrifers carry out the denitrification process. Facultative bacteria can survive with or without the presence of oxygen. These bacteria prefer oxidising organic matter with oxygen rather than by reduction of nitrate or nitrate (Chermisinoff, 1995). Anaerobic conditions must then be maintained in a denitrification system. The carbon source is required for the growth of the bacteria. The total chemical reduction of nitrite:

$2NO_3^- + \text{organic matter} \rightarrow N_2 + CO_2 + H_2O$ (Davies and Cornwell, 1998)

Ammonia stripping

Nitrogen in the form of ammonia exists in two forms, as ammonia (NH_3) at pH above 7 and as an ammonium ion (NH_4^+) at pH below 7. Ammonia can be removed chemically from the water by raising the pH to convert the ammonium ion into ammonia. The ammonia partial pressure must also be low just above the water surface for an exchange, higher wind-speeds increases the exchange. In ponds without aeration can this be the most important process for nitrogen removal (Wittgren, 1994). A pH 8 level has been defined as a boundary when significant amounts of ammonia leave the water. The ammonia stripping reaction is

$NH_4^+ + OH^- \leftrightarrow NH_3 + H_2O$ (Davies and Cornwell, 1998)

The ammonia molecule can be toxic to fish at certain pHs, a maximum 0.02-ppm has been set as a water quality standard for aquatic wildlife (Chermisinoff, 1995). Ammonia nitrogen also exerts an oxygen demand on receiving water bodies as it slowly oxidises to nitrite and then nitrate.

Phosphorous

Phosphorous (P) occurs in natural waters and in wastewater solely as phosphates. These phosphates include organic phosphate, polyphosphate and ortophosphate. Ortophosphate (PO_4^{3-}) and polyphosphate (P_2O_7) constitute the major inorganic form and account for 70 percent of total phosphorous found in wastewater (Qasim, 1999). Aquatic organisms utilise ortophsphates for their growth and some organisms can store phosphorous in polyphosphate form for future use.
There are two ways to remove phosphorous by: chemical precipitation and the use of various biological treatment processes (Surampalli et al, 1995). Phosphorous is also removed by assimilation into the biomass of algae and cells in treatment ponds.

The phosphate ion is easily removed chemically through precipitation with ferric chloride ($FeCl_3$) or alum ($Al_2(SO_4)_3$) plus lime ($Ca(OH)_2$) (Wittgren and Hasselgren, 1992; Davis and Cornwell, 1998). If any of the chemicals are added, precipitation requires a reaction basin and a settling tank for the removal of the precipitate, otherwise will the phosphate leach from the sediment and no real removal has been achieved just a delay in time. Precipitation using aluminium and iron reduce the pH and lime increases the pH. Precipitation with alum and iron are most effective at pH between 5.5 and 7, while a basic pH is most favourable for lime (Davis and Cornwell, 1998). Water with a neutral pH and all three precipitators present is best to precipitate phosphate.

Particles in the soil and sediment can also bind phosphate if the particles contain iron or alum molecules. The particle size plays also an important role for the available precipitation, a soil with small particles can bind more phosphate due to their larger area for sorption. Organic particles in the soil can block the sorption's-surface on inorganic particles from binding phosphate.

An increase in pH during daylight hours due to the removal of carbon dioxide through algae photosynthesis can cause some precipitation of the phosphates. (Surampalli ET al, 1995) found significant phosphate removal (as calcium phosphate) in a pond because of the increasing pH.

5. Alternative natural treatment methods

Conventional ways of treating wastewater is often expensive in a small scale and are difficult to monitor and control. Biological ways of treating wastewater in a small scale are often cheaper and more ecological. The nutrients can also be collected and recycled more easily.

5.1 Activated sludge treatment

In an activated sludge process are micro-organisms (MO) mixed thoroughly with organic material in the incoming sewage so they can grow and stabilise the organic content in the sewage. When oxygen are supplied to a oxygen saturation of about 20% will the individual organisms clump together (flocculate) to form an active mass of microbial floc called activated sludge (Arundel, 1995; Qasim, 1999). The MO utilises the carbon and nitrogen in the wastewater as a food source. The role of thumb applies to activated sludge process is that the ratio of influent degradable matter expressed on an ultimate COD basis to nitrogen and phosphorous should be
COD : N : P = 100 : 5 : 1 on a mass basis (Droste, 1997). The pond where the flocculation occurs is often named the aeration pond due to the fact that extra oxygen is mechanically pumped into the wastewater, a generalised structure is shown in figure 7. The mixture of activated sludge and the wastewater in the aerated pond is called mixed liquor. The mixed liquor flows then to a secondary treatment pond where the activated sludge is settled. Some of the settled sludge is returned to the aeration pond to maintain the proper food-to-MO ratio to keep the breakdown of organic matter rapid. The rest of the settled sludge can be taken withdrawn for treatment and disposal (Qasim, 1999).

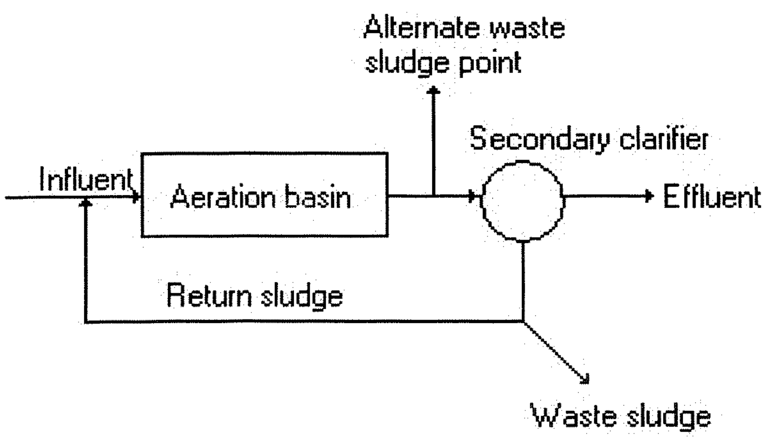

Figure 7: Overview of a basic activated sludge treatment system, from Qasim 1999

The collected sludge may be possible to use as a soil conditioner. Problems with toxicants like heavy metals determents if the sludge can be applied to grow crops for human consumption or only to land restricted for aesthetic or recreational use or collected at a dump site. The occurrence of heavy metals and other toxicants in the sewage depends on the presence of certain industries discharging untreated or partially treated wastes to the sewer system (Droste, 1997). Cultural and ethical reasons play also an important role.

5.2 Recirculation of wastewater in treatment works

The first pond in a series of stabilisation ponds or in the first part of a large facultative treatment pond is sensitive to overloading. The sewage introduced can create an anoxic or anaerobic condition in the surface in the first pond. The result could be malodours and reduced performance to remove organic matter. The organic loading becomes more evenly distributed over the treatment works and the treatment becomes more effective.
The introduction of recirculation of effluents from one of the last ponds in the series to the inlet of the first pond can reduce the land requirements, malodour creation and seasonal changes. It could be realised with relatively low energy costs and small investments, a pump plus some pipes. The positive benefits are larger than the added costs in most cases. Recirculation together with step-feeding was tried at the Wynberg-Muizenberg treatment works just outside Cape Town, South Africa. The treatment was markedly improved even if the loading had been doubled. Step-feeding means that the influent is divided and introduced at several places to the treatment pond, resulting in a more even loading to the treatment works and a more spread of the settled sludge along the pond bottom. The optimal recirculation ratio is between 1.5 and 2.5 times the inflow depending on the climate and loading rate (Shelef and Kanarek, 1995).

The advantages with recirculation are that the critical organic load on the first facultative pond can be three-fold and more compared to the existing series of treatment ponds without recirculation. Recirculation also feeds the first pond with active algae biomass and aerobic conditions can exist even during high organic loading.

5.3 Wetlands

Wetlands are defined as land where the water table is near the ground level for long enough each year to maintain saturated soil conditions or as a transition between dry land and deep water. Wetlands occur naturally throughout the landscape as transitional areas between aquatic ecosystems and uplands. Pollution removal in wetlands is based on the physical, chemical and microbial processes in water, soil and roots of the plants. Many of the larger wetlands systems double as bird and wildlife sanctuaries, earning the enthusiasm of local communities and perfect opportunities for environmental education.

There are two basic types of wetland systems for treating wastewater, natural and constructed wetlands. Natural wetlands are often less suitable to use for treatment of wastewater, they are considered to be part of the receiving waters with their requirements from a regulatory point of view. Natural wetlands are often found on unsuitable soils and a discharge would probably disrupt the ecosystem in the natural wetland.

Constructed wetlands offer all of the treatment possibilities found in natural wetlands, but without the constraints associated with discharging into a natural ecosystem. Constructed wetlands can be designed as a secondary treatment to remove BOD (biochemical oxygen demand) and suspended solids and/or as advanced treatment to remove nitrogen and phosphorous. The general components of constructed wetlands are (Farahbakhshazad, 1997):

- Substrates with varied, defined hydraulic conductivity (e.g. clay, sand and gravel)
- Aquatic, oxygenating plants adapted to water-saturated anaerobic substrates
- A water column (flowing inside the soil or above the surface of the substrate)
- Vertebrates and invertebrates
- Microbial community adapted to or tolerant of aerobic and/or anaerobic conditions

Vegetation provides a surface for attachment of the microbial population and aids in the filtration and adsorption of wastewater constituents. Vegetation also transports oxygen from their leaves to the roots, which provides a mixed aerobic/anaerobic condition suitable for microbial transformation of nitrogen.

A variety of aquatic plants have been used in wetlands for treatment of wastewater. Common reed (Phragmites australis) is the most common choice of plant in Europe. Reed is an indigenous plant with a high capacity for biomass production. Other examples are cattails (Typha sp.), rushes (Juncus sp.), bulrushes (Scripus sp.), and sedges (Carex sp.) (Farahbakhshazad, 1997).

There are two types of hydraulics of a constructed wetland, wetlands with water flowing on the surface (called free water surface wetland) or with a water flow below surface (called subsurface flow wetland).

A free water surface wetland acts as a treatment pond and uses the same principles for treatment, the only different is a faster nitrogen treatment. The dominating treatment processes are sedimentation, the plants filtration for particles in the water, microbial activity in the water and most important on surfaces to plants and sediment. Thanks to the increased area for microbial activity that the plants contribute compared to a pond the treatment rate is faster and a shorter detention time is required for the same treatment. Water has a tendency to form canals through the wetland, which can counteract the purpose of the wetland due to less time for treatment (Wittgren and Hasselgren, 1992).

A subsurface wetland system is based on the passage of water through the soil where it should contact the roots of the plants, it is naturally called a rootzone system. A rootzone consists of a basin with relatively dense walls and bottom to prevent seepage to groundwater. Seepage can be prevented with compact materials like fine-grained soils containing clay and silt or a plastic or rubber cover can be used. To have a more even distribution from the inlet should a segment with coarse sand or rocks be placed at the inlet and some aeration of the wastewater is also occurring (Farahbakhshazad and Awadi, 1994).
Common Reed (Phragmites australis) is the most effective plant for treatment in a rootzone (Farahbakhshazad and Awadi, 1994). The principle for water purification is several metabolic processes in the rhizosphere (the area close around the roots) organisms with help by the roots of the Reed. The Reed transports oxygen to the rhizosphere that, can provide an aerobic condition in an otherwise saturated, anaerobic soil and support microbiological removal of organic matter and nitrogen (Farahbakhshazad, 1997). Oxygen leaks from the root-tips because of the decreased gas-permeability of the root-walls. Only young growing roots release oxygen to the surrounding medium. Studies of existing rootzone systems in England and Denmark indicate that the effluent concentrations dramatically decreased during the first 4 years

and then levelled out. The density of vegetation increased on the same time, which shows the importance of vegetation as a filter for particulate substances and a base for micro-organisms (Wittgren and Hasselgren, 1992). Research done in Australia shows that if the plants are harvested once a month, calculations indicate 20-30% of the nitrogen and 10-30% of the phosphorous are utilised by the plants and removed.

The nutrient properties of the sewage are an important part of dimensioning a wetland. Phosphorous and nitrogen can be left to settle or be filtered away if the nutrients are bound to particles and algae. The ratio between ammonia and nitrate is also important for choosing the right design. Untreated sewage or sewage treated mechanically or chemically usually contains small amounts of nitrate (Wittgren, 1994). Wastewater with a phosphorous content over 2 mg/l is best treated with a subsurface flow wetland system where the water is flowing under the surface in a mineral rich soil (Wittgren, 1994).

According to Droste, surface flow wetlands and subsurface wetlands in California were found by bacterial and viral indicators to be removed in the range of 90-99%. Constructed wetlands could reduce total coliforms to 10^3 / 100ml or lower if secondary wastewater was being treated (Droste, 1997).

5.4 Recirculation of nutrients through irrigation

The spreading of the wastewater is the oldest disposal of wastewater. Crop irrigation is the widely used form of land treatment system, especially interesting in areas with a water shortage. Many major cities like Berlin, Melbourne and Paris have for at least 60 years used farms for waste treatment and disposal. Over 600 communities in the USA reuse effluents from municipal wastewater treatment works for surface irrigation (Davies and Cornwell, 1998). The wastewater is applied to the crops by spraying or through spreading on the surface. Spraying should not be used on raw wastewater, since it could pose a health risk by spreading the pathogen bacteria with the wind.

Sewage effluents not only contain water but also essential nutrients for the plants, making treated sewage an interesting alternative to chemical fertilisers. (Mara, 1996) reports a yield increase in India for wheat, rice and potato, when effluents from a waste stabilisation pond was irrigated instead of freshwater supplemented with NPK-fertiliser.

It has been accepted that there is a bacterial risk in every wastewater reuse practice, unrestricted irrigation of crops with wastewater poses a health risk. World Health Organisation recommends a bacteriological effluent quality of maximum 1000 E. coli bacteria per 100 ml and no more than one nematode egg per litre (Bastos and Mara, 1995) for unrestricted irrigation usage, e.g. including crops eaten uncooked. A survey in Portugal on lettuces and Radishes investigated the bacterial contamination in the crops from irrigation with wastewater in a hot and dry climate. The results showed that the crop contamination was closely related to soil contamination and both reflected the quality of the effluent used. When rainfall occurred could higher densities of E. coli and salmonellae be detected than usual, the increased moisture may have prolonged bacterial survival or even allowed bacterial growth (Bastos and Mara, 1995). The bacterial quality of the lettuces was similar to those lettuces found on sale at local markets.

The nutrient uptake by the crops is dependent on the nutrient needs by the crop, soil properties and climatic conditions. In Alberta, in dry semiarid conditions, was concentrated treated wastewater with nitrogen ammonia as the dominating nitrogen form added to a farmland. A 30% reduction of the nitrogen was achieved by harvesting of crops and 25% of the nitrogen was accumulated in the soil. Evaluations of results indicated that some denitrification also occurred during the 6-year analysis. Only small increases in salt concentrations could be detected, which could contaminate the soil (Wittgren and Hasselgren, 1992).

6. Measurement campaign

6.1 Measurement points

The measurement points have been chosen to evaluate the environmental impact on Keiskamma River that can be assigned to the wastewater treatment works and Keiskammahoek TLC. The measurement campaign has been optimised with as few sampling points as possible along the watercourse. Additional points for an evaluation of the treatment works were chosen as shown in figure 8, page 30.

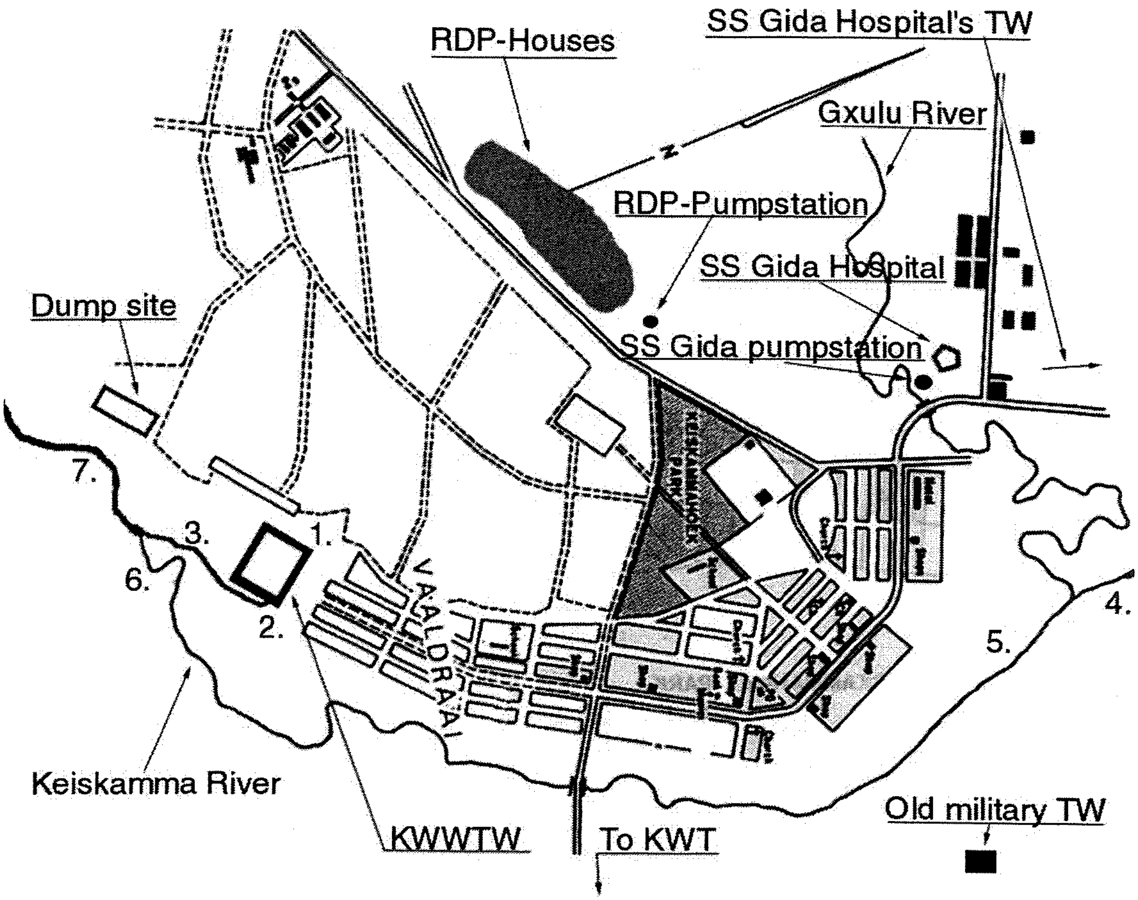

Figure 8: Keiskammahoek area with measurement points 1-7.

1. Measurement point 1 was placed after the inlet of KWWTW. Due to a low flow after the grit screen, samples were taken in one of the inlets to the primary settling ponds.
2. Measurement point 2 where placed in the outflow of the treatment works.
3. Measurement point 3 was placed approximately 135 meters after the second point. The outflow first merges with a ditch of water and then runs through a wetland like area. The sampling spot are situated just after the end of the wetland area.
4. Sample point 4 are referred to as the reference point, it is situated about 110 meter upstream the junction between Keiskamma and Gxulu River. The samples were taken from the shoreline of the river without water samplers.

5. The fifth point was placed 230 m downstream the merge point of Keiskamma and Gxulu River at an old constructed dam. Samples were taken in the middle of the river.
6. Measurement point 6 was chosen in order to investigate the impact from the town Keiskammahoek on Keiskamma River. The point is situated downstream Vaaldraai but upstream the merge point between Keiskamma River and the effluent from KWWTW. Samples were taken from the shoreline without water samplers.
7. Sample point 7 was placed approximately 100 m after the junction between Keiskamma River and KWWTW in order to analyse the environmental impact. Samplings were done in the middle of the river.

6.2 Measurement Equipment

The measurements in the campaign were conducted using the HACH DR/890 instrument, Hanna Instruments HI 8333 Conductivity Meter and a Labinett pH-meter HI 8424. The parameters measured during the measurement campaign using the DR/890 HACH instrument were COD, Phosphate, Nitrate and Ammonia. The DR/890 HACH instrument uses a photometer suitable for colorimetric testing to measure the concentration in the sample after a reaction between the sample and a HACH reaction pillow. The pillow contents react with the sample to give a coloured complex, the darker colour the higher concentration. The instrument is precalibrated and programmed for common colorimetric measurements, appendix 3.

Conductivity was measured with Hanna Instruments HI 8333 Conductivity Meter. The instrument needs to be temperature adjusted as conductivity varies with temperature. The instrument is calibrated with a 0.001 M Potassium chloride (KCl) solution, which should theoretically give a reading of 14.7μS/m at 25°C.

Temperature and pH were measured with a Labinett pH-meter HI 8424. The Labinett pH-meter HI 8424 measures the temperature adjusted pH with an electrode in a 3M KCl + AgCl electrolyte. The electrode have been be calibrated with 2 solutions, pH 4 and 7 before usage.

6.3 Measurement dates

Due to time constraints and a limited number of available samples, the measurement campaign was limited to three weeks, 1^{st} - Nov to 18^{th} - Nov. Sampling dates were chosen to 1^{st}, 4^{th}, 9^{th}, 11^{th}, 15^{th} and 18^{th} of November 1999.

On 1^{st} November samples were taken at the treatment works, i.e. sample points 1 to 3; low inflow to the treatment works. Sampling was done at lunchtime. The weather was fairly good, approximately 25 degrees, sunshine with some clouds.

On 4^{th} November samples were taken in the river, i.e. sample points 4 to 7. The weather was about 25 to 30 degrees and the sun was shining. It had not rained since previous sampling. Sampling was done before lunch, approximately from 10 to 11 am.

The 9th of November samples were taken in the river, sample points 4 to 7. The weather was still warm with 25 to 30 degrees and sunshine. The samples were taken at the same time as previous sampling and there had not been any rain.

11th of November it was between 20 and 25 degrees and cloudy. Samples were taken just before lunch hour in sample points 1 to 3 (KWWTW).

At 15th it was cloudy, it had been thunderstorms and rain in Alice during the night. The day was grey and it was a lot colder than previously sampling dates. Samples were taken at KWWTW. Sampling were done about 9 to 10 am, the inflow to the treatment works was considerably higher than previously sampling dates.

18th of November was the final sampling day with warm weather, approximately 30 degrees Celsius. Samples were taken at all sampling sites (1 to 7) during the morning. The inflow to the treatment works was still high, but had halved compared to the 15th.

6.4 Quality Assurance

All details in a measurement campaign needs to be well prepared in order to minimise errors. There are different kinds of errors that might occur, some of them can be explained by the terminology accuracy and precision. Precision is how well the samples fit together, however this does not automatically give good accuracy. Accuracy is then how close the samples are to the “real” value.

In this measurement campaign the analyses have been made in triplicates, and then average and standard deviation have been calculated. Standard deviation gives a good value of the precision but tell nothing about the accuracy. In order to get good accuracy prescriptions for sampling, cleaning of bottles, analyses procedures etc. have been read and followed.

All bottles for collection of samples was acid washed in 1:1 Hydrochloric acid and then cleaned with deionised water before every sampling. Before sampling the bottles were rinsed 3 times with sample water and then slowly filled.

The deionised water used for cleaning and dilution was replaced at every sampling date if possible. All equipment used was cleaned with 1:1 Hydrochloric acid and rinsed with distilled water before usage. Equipment for handling of samples was treated in the same way before measuring, in order to reduce interference’s created by different handling procedures.

Samples for all measurement points were filtered for all parameters except for pH, conductivity and COD before measurements. At sample point 1-3 (KWWTW) samples were filtered after they had ran with activated carbon in order to reduce the colour of the samples (0,4 mg with 100 ml sample). This was done at sampling dates 11th, 15th and 18th November, at 1st there were no activated carbon available.

Blanks were made for filters in order to measure the contribution from this source, the same have procedure have been done for the activated carbon. Results have been adjusted for these contributors in presented results.

New standards were made for each parameter every new measuring week.

6.5 Potential Interferences

Colour of samples

The samples taken in the wastewater treatment works sample points (1 to 3) had a high initial colour as seen in appendix 2 during all measurements days. To reduce the influence of the colour was activated carbon introduced. The activated carbon reacted with the algae and the sample was then filtered. Pictures of all samples are found in appendix 2.

Deionised water

The quality of the provided deionised water is unknown, however the machine is placed at the department of analytical chemistry, which should guarantee the quality.

Dilution of samples

Some of the samples needed dilution to get in range for measurements. Ammonia and phosphate samples from points 1 to 3 needed 20 to 40 times dilution, which is a potential source of error. Although precision can be evaluated by standard deviation, the accuracy due to incorrect dilution is a source of error that is impossible to interpret.

Measuring techniques

Used instruments might influence results. Used pipet had a maximum volume of 5 ml, with a grading of 0,05 ml. This is a potential source of error, especially when dilution is needed. Unclean vials are another source, however standard deviation can be used to avoid these sources of error.

Standards

Standards were brought from Sweden, which means that they were exposed to temperature variations before arrival. This could change the known concentration in the standard. Inaccurate standard dilutions are another probable interference for varying standard results.

Water Samples

Some of the samples in the Keiskamma River may not be representative for the whole water body since samples were collected from the shore. The influent of the treatment works can not be treated as a representative sample for a longer period of time since it varies throughout the day, week's etc. These samples are treated as momentary values i.e. they vary constantly. Continuously measurement needs to be carried out to get a trend of the variation.

7. Results

In this chapter results are presented in graph form together with a description of the results. In appendix 1 the results are presented in tables with standard deviation. Measurement dates 1st, 4th, 9th, 11th, 15th and 18th of November-1999 are results from this measurement campaign. 2 February, 9 September and 15 December-1998 are results from the consultant's measurement campaign. In some graph's legislation values are shown as a comparison to measured concentrations.

On the right side of the graphs measurement dates are presented.

Consultant's report has used a reference point upstream the merge point of Keiskamma and Gxulu-River. The location of this point is not given but the assumption have been made that this point can be compared with sample point 4, i.e. the reference point used during this measurement campaign, see paragraph 6.1 (page 30). The same assumptions and comparison have been made for measurement point 2, 6 and 7.

7.1 Physical-Chemical Parameters

pH

KWWTW

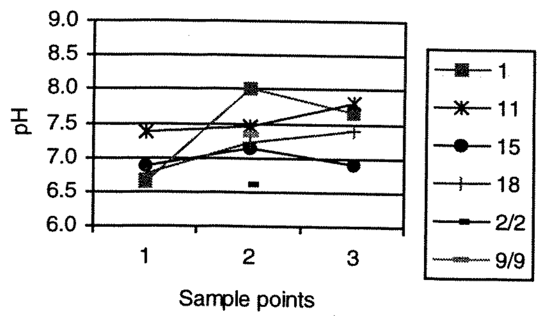

Figure 9: pH results in KWWTW from November 1st, 11th, 15th and 18th and results from the consultant on 2/2 and 9/9

The pH has shown stability throughout the measurement campaign (figure 9). Influent values (average 6.9) are slightly lower than effluent values (average 7.5) and this correlates well with the legislation, which gives 7,5 as a maximum. SBA values are in the same range with effluent values varying from 6,6 to 7,3 (SBA, 1999).

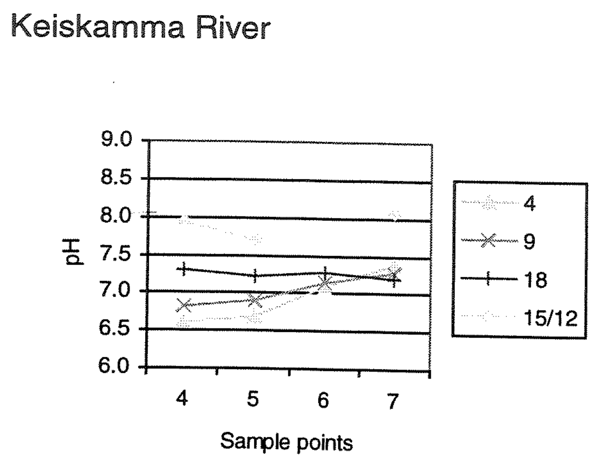

Figure 10: pH levels in the Keiskamma River from 4th, 9th and 18th of November 1999 and a result from the consultant from 15/12/98

pH is increasing downstream Keiskamma River, from an average of 6,9 in the reference point (4) to a maximum downstream KWWTW with a pH of 7,3 (point 7). A comparison with the SBA's values shows on similarities with a maximum pH (8,1) in point 7 (SBA, 1999), as seen in figure 10.

The increase in pH may be explained by a comparison with results obtained at KWWTW. In measurement point 3 the average pH was 7,4 and as this point merges with Keiskamma River between point 6 and 7 the pH might increase slightly in point 7. The greatest increase in pH is however found between point 5 (average 6,9) and 6 (average 7,2).

It should be stated that the pH in Keiskamma River is at present state within limits and does not provide a threat to public health or living aquatic organisms according to legislation.

Conductivity

KWWTW

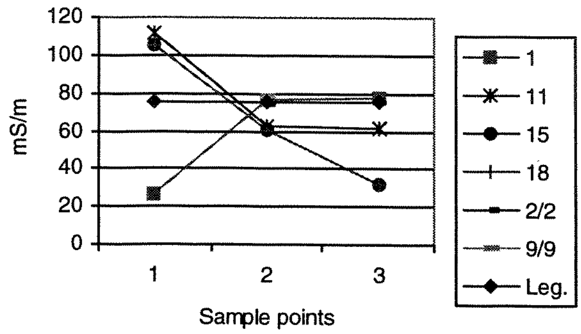

Figure 11: Conductivity levels in KWWTW with a legislative level of 75 (mS/m)

The results shown in figure 11 indicate that the purification of conductivity works satisfactory in the treatment ponds. Levels decrease from an average in point 1 of 107 mS/m to an average of 62 mS/m in the effluent, point 2. Legislation limits is 75 mS/m. Analysis done by SBA shows on an average of 77 mS/m (SBA, 1999), which is slightly higher than legislative limits.

Note: Analysis of conductivity at 991101 is disregarded as not reliable since there were problems with sample point 1 (influent). The reason for these problems is not known, it may be a result of intrusion of fresh water. The sample colour was different from later samples in point 1, see appendix 2.

Keiskamma River

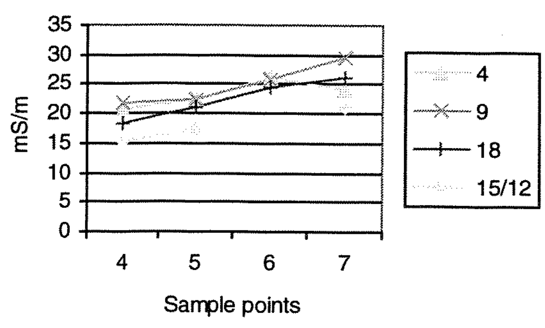

Figure 12: Conductivity results from Keiskamma River (mS/m)

Conductivity concentrations are stable along the watercourse and no increase in concentration can be found in point 7 (figure 12). Concentrations vary from 20 mS/m to 30 mS/m, which correlates with SBA's values (SBA, 1999).

COD

KWWTW

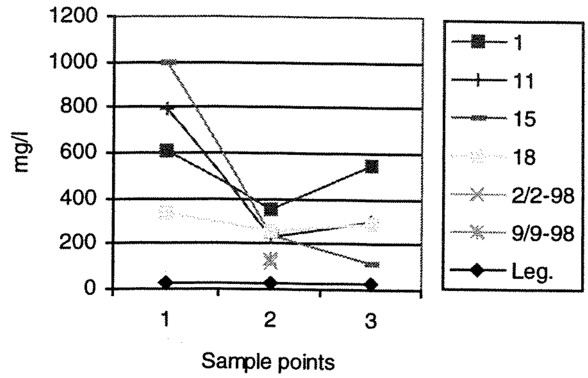

Figure 13: COD results from KWWTW, with an effluent legislation of 30 (mg/l)

The concentration and treatment of oxygen demanding substances is insufficient in the treatment works. Influent concentrations varies from 340 mg/l to over 1000 mg/l, the effluent concentrations are more stable with an average of about 270 mg/l as seen in figure 13. Effluent concentrations are higher than the ones obtained by SBA, average 120 mg/l (SBA, 1999). However all of these values are two times or even higher compared to the current legislation value of 30 mg/l (special standard limits) or 65 mg/l (general standard limits).

Keiskamma River

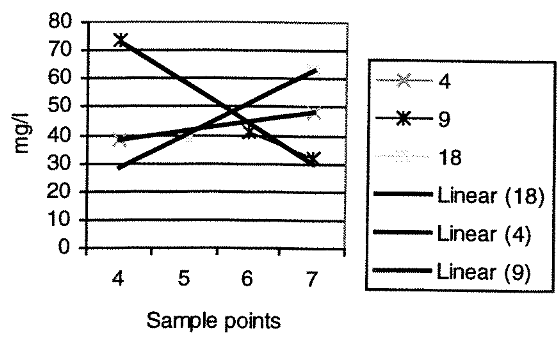

Figure 14: COD results from Keiskamma River (mg/l)

Analysed samples in Keiskamma River are all at concentrations close to detection limits of used HACH equipment (30mg/l). However in point 7 where complete mixing between effluent and the water in Keiskamma River is assumed, concentrations are close to effluent legislation limits (figure 14).

7.2 Chemical parameters (Cations and Anions)

Phosphate (PO_4^{3-}) and Phosphorus (P)

Phosphate is an important parameter, often considered as the limiting nutrient in freshwater systems. Legislative limits are given as Phosphorus in the South African Water ACT and have therefore been recalculated from PO_4^{3-} to P.

KWWTW

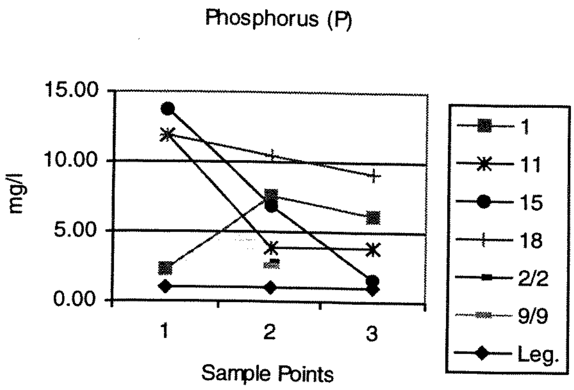

Figure 15: Phosphorous concentration found in the KWWTW on 1st, 11th, 15th and 18th of November, with a legislative effluent level of 1,02 (mg/l)

Concentrations of phosphate vary widely throughout the measurement campaign (figure 15). Concentrations obtained at Nov 1st have been disregarded due to interferences with colour. Samples taken in KWWTW (sample point 1 to 3) after 1st Nov was treated with activated carbon in order to reduce the coloration. Presented figures are recalculated from phosphate to phosphorus using the factor 0,3261 (according to laboratory instructions from HACH, 1987). This has been done to be able to make a comparison with legislation.

Phosphorus concentrations in the effluent vary from 3,4 mg/l to 6,8 mg/l, which can be compared to the SBA average concentration of 2,8 mg/l (SBA, 1999). The legislation for phosphorus is 1,02 mg/l. In the effluent of KWWTW these concentrations are exceeded several times.

Keiskamma River

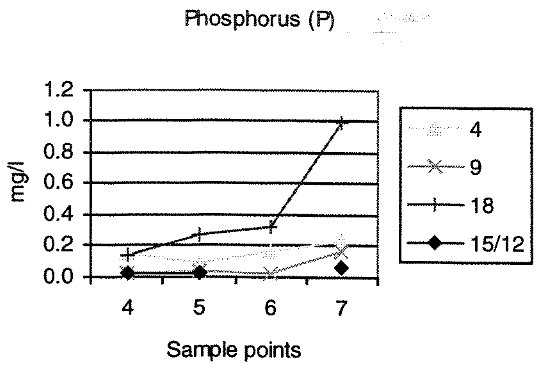

Figure 16: Phosphorous concentrations in Keiskamma River (mg/l)

Phosphorus concentrations are more or less stable from sample point 1 to 6, however a sharp increase in concentration appears between point 6 and 7 (figure 16). The concentration increases 100% to 600% between these 2 points, see appendix 1 for figures. The source of this increase is most likely KWWTW. SBA's analyses show on a lower increase, although the same trend is there (SBA, 1999).

Ammonia (NH_3-N)

Sample date 991101 and point 1 have been mentioned earlier as a problem, this goes for ammonia analyses as well. According to known interference's high colour on samples should not provide any problem (HACH, 1987), however concentrations in point 1 is lower than in the effluent and compared to later analyses and theory this should not be the case.

In point 1-3 activated carbon was used to purify the samples during the rest of the 0measurement campaign. At sample date 18/11/99 the analyses in point 1 to 3 were lost due to dilution problems.

KWWTW

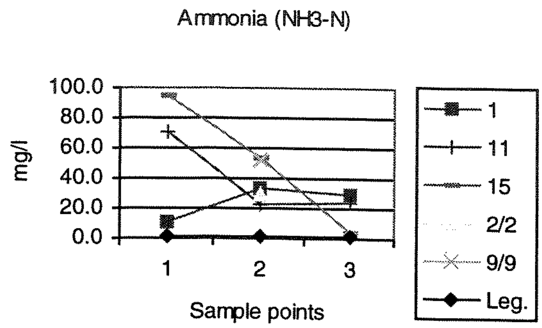

Figure 17: Nitrogen Ammonia concentrations found in KWWTW (mg/l)

Influent values to the treatment works are limited to 2 sampling dates, 11th and 15th of November. Influent concentrations vary on these occasions between 70 mg/l and 95 mg/l. Effluent values from 1st, 11th and 15th vary between 25mg/l to 50mg/l, which correlates with figures obtained from SBA's report (SBA, 1999) and presented in figure 17. Effluent values are very high compared to the legislation, which have a maximum of 1 mg/l.

Keiskamma River

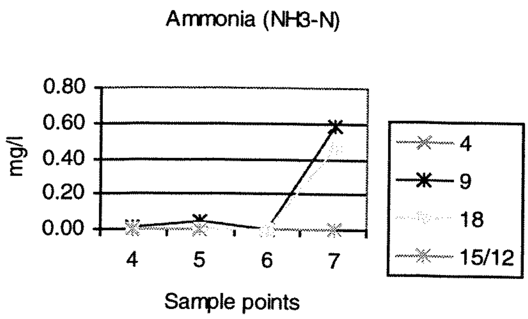

Figure 18: Nitrogen Ammonia results from Keiskamma River (mg/l)

On the 4th November no concentrations of Ammonia were found as seen in figure 18. On sample date 9th and 18th November all values were below detection limit until sample point 7 where peak concentrations were found, from 0 mg/l in point 6 to about 0,5 mg/l in point 7. The high effluent concentrations from KWWTW may be the source to the increase.

Nitrate (NO_3^--N)

Nitrate values have varied throughout the measurement campaign. Influent values have been very low and one possible explanation to this might be interferences with chlorides (Cl^-). Concentration above 100 mg/l causes low values of nitrates and this compared with the conductivity values of 100 mS/m may be a reason for the low concentrations in the influent. Another interference is strong oxidising and reducing substances that interfere at all levels.

KWWTW

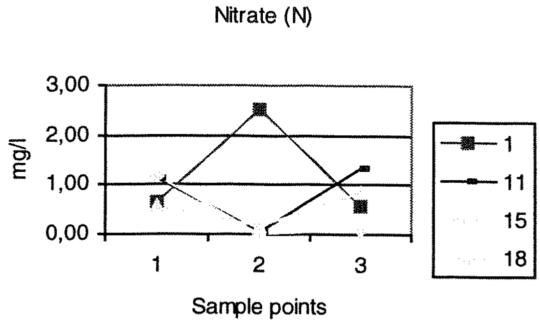

Figure 19: Nitrate concentrations from KWWTW (mg/l)

Influent concentration varies from 0,6 mg/l to 1,2mg/l and effluent values are 0 except for 1st of November when a concentration of 2,5 mg/l was measured (figure 19). These concentrations are low compared to concentrations in regular treatment works.

Keiskamma River

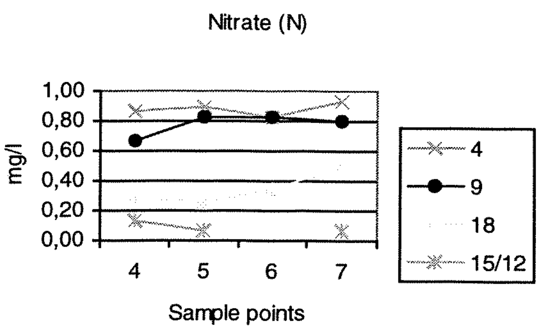

Figure 20: Nitrate results from Keiskamma River (mg/l)

On the 4th and 9th concentrations of nitrate were stable along the watercourse with values varying between 0,7 mg/l to 0,9 mg/l (figure 20). On 18th concentrations are slightly lower (0,25 mg/l to 0,5 mg/l) but rather stable with a small increase between points 6 and 7 (0,35 mg/l to 0,5 mg/l). SBA has measured values of approximately 0,1 mg/l throughout the measurement points (SBA, 1999).

8. Discussion

Measurement results from this campaign show that the environmental impact from KWWTW is considerable on Keiskamma River. Obtained results downstream the treatment works are often higher than upstream. Most trends found in the effluent from the wastewater treatment works are exceeding legislative limits several times.

The pH in the KWWTW is higher in the effluent, a possible explanation to this increase is organic growth in the ponds. pH measurements in the river show almost neutral concentrations (pH 7), with a slight increase downstream. However the pH is well within the legislation levels at all points.

Conductivity levels in the effluent are below legislation limits but evaluated together with SBA's values, give indications of concentrations close to legislative values. The conductivity in the river is stable along the watercourse and no increased concentrations have been measured between sample point 6 and 7.

The influent values of COD varied a lot during the campaign. The effluent on the other hand showed an almost constant value, the wastewater has become a homogenous mixture. The amount chemical oxygen demanding substances found in the effluent from the treatment works are several times higher than the legislation limit. Measurements in the river were close to detection limit of used equipment (30 mg/l). The analyses showed on variations between the sample points, however concentrations above 74 mg/l were not found, which makes interpretations uncertain. The long distance from the wastewater treatment works effluent point to the river could mean that some treatment occurs before the wastewater reaches the river.

A freshwater source, Sandile Dam, is situated downstream the treatment works. Oxygen free water entering the dam may have negative effects on the freshwater quality as well as harm aquatic organisms. However oxygen depletion is seldom a problem in rivers due to rapid movement and mixing with oxygen from the air, but the situation during the dry season with a low flow rate may be a problem.

SBA has not measured COD in Keiskamma River and as a result no comparison could be done.

Although oxygen-demanding substances are the most important polluters of rivers, heavy loading of nutrients can cause harm to the watercourse due to excessive plant growth. Phosphorus and the biological available form phosphate is several times higher than legislation in the river and this may affect the biological composition as well as the oxygen status both along the watercourse and in Sandile Dam.

The samples taken in the wastewater treatment works sample points (1 to 3) had a high initial colour as seen in appendix 2 during all measurements days. The HACH measurement method used for COD, Nitrate, Nitrogen Ammonia and Phosphate measures the colour of the sample at a special wavelength after an addition of chemicals. The chemicals are specially composed by the HACH Company to react with the sample and dye the sample in a colour, which the DR/890 HACH instrument can measure. More colour means a higher concentration of the measured substance. The initial colour of the samples had to be decreased and activated carbon was introduced to decrease the influence that the original colour of the sample had. The colour and reacted carbon was reduced by filtration of the sample before measurement.

The phosphate concentration in the three points at KWWTW showed the same trend during the 11^{th}, 15^{th} and 18^{th}, except in point number 3 the 15^{th} of November. Heavy rain is the probable cause, resulting in a high amount of water from the joining ditch giving a diluted sample. Results were recalculated to phosphorus in order to make a comparison with the legislation, which is 1.02 mg/l. Effluent concentrations are several times higher than this value. The decreased amount of dissolved phosphate in the wastewater indicates that the algae has utilised some of the phosphate or bound to the sediment, but not enough to meet the legislative effluent quality standards.

A clear trend is shown in the river, the samples before the effluent are constant with a noticeable increase in point 7. The same trend is also found in SBA's measurements.

The amounts of ammonia found in the samples from the treatment works in inflow and outflow are exceeding the legislation limits several times, the samples are varying but a decreasing trend from point 1 to 2 can be distinguished. The ammonia is reduced when the ammonia is degraded in both anaerobic and aerobic environments and finally utilised by algae or accumulated in the sediment. The sample from point number 3 is identified as diluted with rainwater from the joining ditch at 15/11/99. Low amounts of ammonia are found in the River in all samples before point number 7 where a rapid increase is shown during two of three sampling dates. This indicates that the treatment works has a too high inflow and cannot break down all ammonia before discharge. The ammonia will pose as an oxygen demand on the receiving river since oxygen is needed in the nitrification process.

Nitrate values found in the treatment works are strange, they do not vary much but if comparing with other treatment works, the values are very low. The values are below the legislation effluent levels in all points, except for sample date 01/11/99 point number 2 (effluent). Since raw sewage contains nitrogen mostly in the ammonia form, which is nitrified to nitrate in the treatment ponds. The low values could be interpreted as the sewage is not getting enough time for aerobic nitrification treatment, due to the high inflow, which is several times higher than the designed. The values from point 2 show a slight decrease from point 1, except from date 01/11/99 when a sharp increase were found. Interferences like chloride and oxygen demanding substances are also possible reasons for the low values.

Nitrate levels are quite stable along the river, which agrees with the SBA report, although they got lower levels.

The relations between the different concentrations of nutrients along the Keiskamma River indicate an almost constant relationship before sampling point 7. In point 7 is a trend with an increase of phosphate and ammonia quite clear, this mean that the Keiskammahoek treatment works is overloaded and can not treat all nitrogen ammonia into nitrate for bio-utilisation in algae. The excess of ammonia and phosphate can cause some oxygen depletion and possible eutrophication in the river downstream the treatment works.

9. Conclusions and Recommendations

Measurement results show that KWWTW cannot handle the amount of wastewater reaching the treatment works. The amount of incoming wastewater is so great that the waste do not get enough time in the ponds to be treated naturally to meet DWAF's effluent standards. The results indicate that the effluent from the treatment works is influencing the Keiskamma River, especially nitrogen ammonia and phosphorous concentrations are increasing rapidly after the effluent form the treatment works. No real other sources of polluters are clearly shown in the results, although no results have been obtained from the S.S. Gida wastewater treatment works. It should be stated that this measurement campaign is to short to draw any substantial conclusions

The amount of oxygen demanding substances are exceeding the legislative level several times, but a clear trend cannot be detected in the river. Possible reasons could be that the oxygen demanding substances in the wastewater is treated on the way form the effluent until it reaches the river, another more possible reason for the low results could be that the concentrations in the river is close to detection limits for the measurement technique.

The amount of ammonia found in the effluent indicates that much of the nitrogen ammonia is not treated. This is probably due to the lack of time for treatment in the ponds, although the majority of the ammonia is treated but concentrations far higher than the legislative levels are not. The phosphorous concentrations in the effluent are also much greater than the DWAF effluent standards, high amounts of both nitrogen ammonia and phosphorous could have oxygen-demanding effect of the river and cause an excessive plant growth.

Since the wastewater treatment works is influencing the Keiskamma River, several actions need to be taken in order to reduce this unnecessary influence. But it should be stated that this measurement campaign is to short to draw any substantial conclusions, therefore the following recommendations are given:

- The measurement campaign should continue in order to evaluate seasonal changes and as a result give a more accurate environmental status of Keiskamma River. This to ensure a sustainable development for both humans and nature.
- The S.S. Gida Hospital and its pump station should continue to be monitored since the pumps can stop working at any time resulting in severe pollution of the river.
- When an effluent can be measured from the treatment works of S.S. Gida a new measurement point should be established here.
- A measurement point needs to be established downstream the refuse dump, this was not done in this campaign due to the dry season.

Stemele Bosch & Associates (SBA, 1999) suggested an activated sludge treatment works should be installed on site were the current treatment works are located to improve the treatment. The activated sludge treatment facility is a more complex treatment method than using treatment ponds or wetlands. It demands a higher degree of maintenance and more skilled personnel. The treatment is excellent for treating oxygen-demanding substances and to some extent nitrogen ammonia. But no real treatment for phosphorous is made unless expensive chemicals are added, which I doubt the municipality can afford.

Treating the effluent from the treatment works in a wetland is an alternative, it is a cheap and simple solution. The only real cost is to buy the land and construct the wetlands. Questions like the owner of the land and soil properties need to be investigated before any decision. The treatment is varying during the year, wetlands work best in summer like conditions. As a bonus could the plants and sometimes the topsoil be harvested and sold as food to the cattle or as a fertiliser. Stemele Bosch & Associates, 1999 ruled out a wetland as an alternative since they believed the land area would be too big. The free grazing cattle in Keiskammahoek might pose a problem since they might eat too much of the reed which might decrease the treatment. The cattle would probably storm a fence around the wetland since they want to eat the fresh plants in the wetland.

Recirculation of nutrients through irrigation was also an alternative discarded by the Stemele Bosch & Associates. There are 7 irrigation units under the Keiskammahoek Irrigation Scheme and the Hillside Irrigation Scheme. Since the effluent from the treatment works not only contains water but also essential plant nutrients. The effluent could be perfect to reduce the usage of fertilisers on the irrigation fields if the wastewater is applied diluted on the fields. The owners of the irrigation fields might even be prepared to pump the effluent to their irrigation scheme and pay a small fee, which would transform the wastewater into a source of income for the municipality. Questions like the bacteriological and heavy metals levels in the effluent must be investigated. It is also planned to connect the S.S. Gida hospital sewer to the Keiskammahoek treatment works, the effluent from the hospital must be measured to detect heavy metals and other pollutants. The ethic must also be considered, in many cultures could a moral problem. Another way would be to spread the effluents over a large land area and let the free grazing cattle graze the fresh grass growing.

I have drawn the conclusion that the best solution to improve the Keiskammahoek wastewater treatment works must be to construct a wetland on the field just after the effluent from the treatment works. It is a simple, cheap method, which do not require skilled personnel and very little maintenance.
The treatment would probably also improve if the municipality could repair the treatment ponds by digging out the collected solids and grit, which has been assimilated on the bottom of the ponds.

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Appendix

Appendix 1 – Results

NOTES: All analyses with given standard deviation has been done in triplicates

Measurement points:

1. Influent KWWTW,
2. Effluent KWWTW,
3. After wetlandarea,
4. Reference point (upstream Keiskamma River, before Gxulu River merge point) ,
5. 150 m downstream the junction point Gxulu- and Keiskamma River,
6. Keiskamma River (upstream effluent point of sewage treatment works),
7. Keiskamma River (downstream effluent point).

Table 1: pH

Sample point	Date (Nov - 1999)						SBA (1998)		
	1	4	9	11	15	18	2/2	9/9	15/12
1	6.6			7.4	6.9	6.8			
2	8.0			7.5	7.2	7.2	6.6	7.3	
3	7.7			7.8	6.9	7.4			
4		6.6	6.8			7.3			7.9
5		6.7	6.9			7.2			7.7
6		7.1	7.1			7.3			
7		7.4	7.3			7.2			8.1

Table 2: Conductivity (mS/m)

Sample point	Date (Nov - 1999)						SBA (1998)		
	1	4	9	11	15	18	2/2	9/9	15/12
Std	14	14	14	13	36	21			
1	27			111	105	105			
2	76			63	61	61	75	79	
3	78			61	31	31			
4		21	22			19			15.2
5		22	23			21			17.5
6		26	26			24			
7		24	30			26			20.9

legislation 75 mS/m
New std at every sampling
15th and 18th strange values on std

Table 3: Chemical Oxygen Demand (COD, mg/l)

Sample point	Date (Nov - 1999) 1	std dev	4	9	std dev	11	std dev	15	std dev	18	std dev	SBA (1998) 2/2	9/9
std	563		557	482		493		545		559	14		
1	605	single				793	38	1001	66	337	23		
2	351	single				230	42	238	32	253	9	115	128
3	548	single				296	11	116	24	290	14		
4			38	74	15						~		
5					~					40	11		
6				41	25						~		
7			48	32	33					63	10		

Legislation 30 mg/l (effluent value)
Detection limit 30 mg/l
New std 1st, 9th and 15th
Analyses has been done on unfiltered samples
On 1th triplicates was not done for unfiltered samples
On 9th 3 analyses were made on std: 1:1 482~500, 1:2 270~250, 1:4 130~125 mg/l

Table 4: Phosphorus (P), (mg/l)

Sample point	Date (Nov - 99) 1	4	9	11	15	18	SBA (1998) 2/2	9/9	15/12
1	2.24			11.89	13.74	3.89			
2	7.54			3.81	6.81	3.42	2.93	2.63	
3	6.15			3.85	1.59	2.97			
4		0.15	0.03			0.05			0.02
5		0.09	0.04			0.09			0.02
6		0.17	0.03			0.11			
7		0.23	0.17			0.32			0.06

Legislation 1,02 mg/l (effluent value)
Conversion factor 0.33
This values have calculated with help of the conversation factor above. Originally values were analysed in PO43-, see table 5.

Table 5: Phosphate (PO4), (mg/l)

Sample point	Date (Nov - 99) 1	std dev	4	std dev	9	std dev	11	std dev	15	std dev	18	std dev	SBA (1998) 2/2	9/9	15/12
Std	1.9		1.5		1.6		1.5		1.9		2.0				
FB	0.6		0.2		0.1						0.12				
ACFB							0.1		0.3		0.13				
1	6.87	0.71					36.47	0.80	42.14	0.40	11.92	0.65			
2	23.13	1.15					11.67	1.56	20.87	0.12	10.48	0.78	8.98	8.06	
3	18.87	2.51					11.80	1.14	4.87	0.90	9.09	0.84			
4			0.46	0.09	0.08	0.05					0.14	0.01			0.02
5			0.29	0.12	0.12	0.02					0.27	0.02			0.02
6			0.53	0.14	0.08	0.03					0.33	0.01			
7			0.70	0.20	0.53	0.07					1.00	0.30			0.06

Detection limit 0.05 mg/l,
New std 1, 9 and 15^{th},
Analyses has been done on filtered samples,
Samples 1-3 have ran with activated carbon (400 mg with 100 ml samplewater) before filtration, except for 1th, when no activated carbon was available.
18th sample 1-3 done in tripplicates, 4-7 in duplicates,
Sample 1-3 have been diluted 20 times at Nov 11, 15 and 18th. On Nov-1th 10 times dilution was used.

Table 6: Ammonia (NH3-N), (mg/l)

Sample point	Date (Nov - 99) 1	std dev	4	9	std dev	11	std dev	15	std dev	18	SBA (1998) 2/2	9/9	15/12
Std	1.05		0.72			1.3		1.0		1.2			
FB	0.09		0.08			0.0		0		0.09			
ACFB										0.12			
1	10.9	0.1				70.4	19.9	94.4	3.4	o.d.			
2	32.7	single				23.3	4.4	53.3	0.6	o.d.	29	52	
3	29.5	single				24.7	0.7	3.7	0.9	o.d.			
4			0.00	0.01	0.00					b.d.			<0.1
5			0.00	0.04	0.02					b.d.			<0.1
6			0.00	0.00	0.00					b.d.			
7			0.00	0.58	0.05					0.46			<0.1

Legislation 1.5 mg/l (effluent value)
Detection limit 0.1 mg/l
New std 1, 9 and 15th
Analyses has been done on filtered samples
Samples 1-3 have ran with activated carbon (400 mg with 100 ml samplewater) before filtration, except for 1th, when no activated carbon was available.
On 1th 10 times and 20 times dilution was used. On 11th, 15th 40 times dilution was used for sample nr 1 and 20 times for sample 2 and 3.
18th measurements in points 1-3 were lost due to dilution problems.

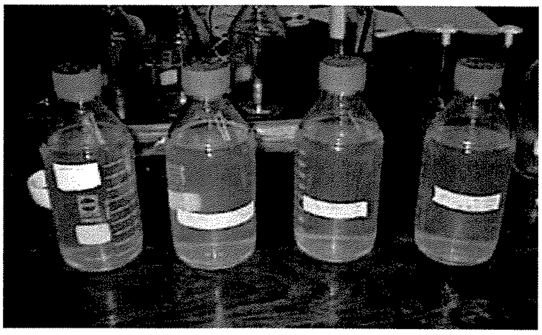
Table 7: Nitrate (NO3-N), (mg/l)

Sample point	Date (Nov - 99) 1	std dev	4	std dev	9	std dev	11	std dev	15	std dev	18	std dev	SBA-98 15/12
Std	1.60		1.90		1.75		1.90				1.97	0.06	
FB	0.10		0.10		0.10		0.00				0	~	
ACFB											0	~	
1	0.63	0.06					1.13	0.12	1.17	0.06	0.57	0.06	
2	2.50	0.26					0.03	0.06	0.00	0.00	0.17	0.06	
3	0.57	0.38					1.33	0.06	0.10	0.10	0.87	0.12	
4			0.87	0.06	0.67	0.06					0.30	0.00	0.14
5			0.90	0.00	0.83	0.06					0.25	0.07	0.07
6			0.83	0.06	0.83	0.06					0.35	0.07	
7			0.93	0.06	0.80	0.00					0.5	0	0.07

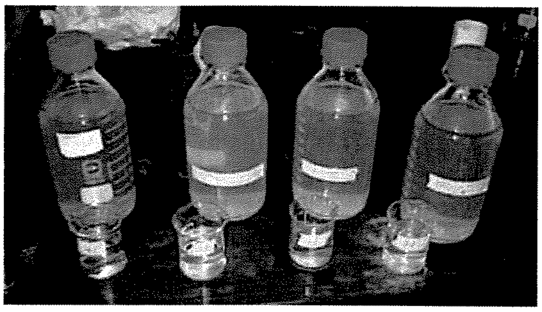
Detection limit 0,2 mg/l
New std 1, 9 and 15th
Analyses has been done on filtered samples
Samples 1-3 have ran with activated carbon (400 mg with 100 ml sample water) before filtration, except for 1th, when no activated carbon was available.
Consult values were calculated in NO3, recalculation was made with the conversion factor 0.225

Appendix 2 – Pictures of samples

Picture 1: Samples from KWWTW 991101. From left to right sample point 1, 2 and 3. Note the coloration of the samples.



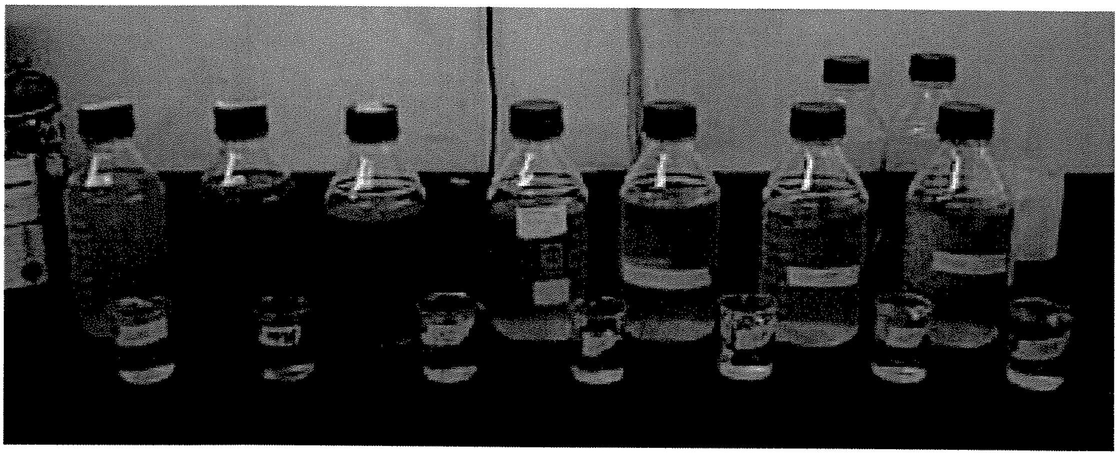
Picture 2: Samples from Keiskamma River 991104. From left to right sample point 4, 5, 6 and 7.



Picture 3: Samples from Keiskamma River 991109. From left to right sample point 4, 5, 6 and 7.

Picture 4: Samples from KWWTW 991111. From left to right sample point 1, 2 and 3. Note the coloration of the samples, in front the filtered samples (treated with activated carbon) can be seen.

Picture 5: Samples from KWWTW 991115. From left to right sample point 1, 2 and 3. Note the coloration of the samples, in front the filtered samples (treated with activated carbon) can be seen.



Picture 6: 991118, samples from all measurement points i.e. point 1 to 7 (from left to right). In front of the glass bottles, beakers with filtrated samples can be seen.
The parameters measured during the measurement campaign using the DR/890 HACH instrument were COD, Phosphate, Nitrate and Ammonia. Conductivity was measured using Hanna Instruments HI 8333 Conductivity Meter. Temperature and pH were measured with pH-meter HI 8424.

Appendix 3 – Measurement Equipment

The parameters measured during the measurement campaign using the DR/890 HACH instrument were COD, Phosphate, Nitrate and Ammonia. Conductivity was measured with Hanna Instruments HI 8333 Conductivity Meter. Temperature and pH were measured with Labinett pH-meter HI 8424.

pH, temperature and conductivity

The Hanna HI 8333 Conductivity Meter measures the conductivity between 4 steel rings in a covering PVC plastic probe. The instrument needs to be temperature adjusted due to the conductivity varies with temperature. The instrument is calibrated with a 0.001 M Potassiumchloride (KCl) solution, which should theoretically give a reading of 14.7µS/m at 25°C.

The Labinett pH-meter HI 8424 measures the temperature adjusted pH with an electrode in a 3M KCl + AgCl electrolyte. The electrode have been be calibrated with 2 solutions, with pH 4 and 7 before usage.

Hach DR/890

The DR/890 HACH instrument uses a photometer suitable for colourimetric testing to measure the concentration in the sample. The instrument is precalibrated and programmed for common colourimetric measurements.

Measurement methods are breifly described below

COD (0 to 1500 mg/L COD)

COD measures the chemical oxygen demand in the sample and is defined as the mg of O_2 consumed per litre of sample under conditions of this procedure. In the HACH procedure, (for High Range 0 to 1 500 mg/L COD), is 2,00 ml of sample added to a COD digestion Reagent vial and heated for two hours. The vial contains potassium dichromate, a strong oxidising agent. Oxidisable organic compounds in the sample react, reducing the dichromate ion ($Cr_2O_7^{2-}$) to green chromic ion (Cr^{3+}).

The instrument is then measuring the amount of Cr^{3+} produced with the help of the green colour of Cr^{3+}. The detection limit for High Range 0 to 1 500 mg/L COD is estimated to 30 mg/L COD. The instrument obtained a standard deviation of ± 16 mg/L COD when the same operator made two vials with 1000 mg/L standard solution.

The COD reagent also contains silver and mercury, silver acts as a catalyst. Mercury is used to complex the chloride interference, which is the main interference up to a specified level, for High Range 0 to 1 500 mg/L COD is the level 2000 mg/L of Cl^-.

Phosphate (0 to 2.5 mg/L PO_4^{3-})

Orthophosphate in the 10 ml samples reacts with the added pillow containing molybdate and an acid, to produce a Phosphomolybdate complex. Ascorbic acid from the pillow then reduces the complex giving an intense molybdenum blue colour if phosphate is present in the sample.

The instrument is then measuring the amount of PO_4^{3-} produced with the help of the blue colour of molybdenum. The detection limit for the procedure is 0.05 mg/L PO_4^{3-}. The instrument obtained a standard deviation of ± 0.05 mg/L PO_4^{3-} when the same operator made two vials with 1.00 mg/L standard solution.

Interference's in the phosphorous reaction procedure that we can determine is turbidity and colour. Large amounts of turbidity and colour can influence due to they may use some of the acid added from the pillows to dissolve suspended particles and a variable desorption of orthophosphate from the particles. (HACH)

Nitrate (0 to 5.0 mg/L NO_3^- - N)

The cadmium metal in the added pillows reduces the nitrate in the sample to nitrite. The nitrite ion reacts with sulfanilic acid to form a diazonium salt, which couples to gentisic acid to form an amber coloured product and then the instrument measures the colour.
The cadmium metal in the added pillows is at concentrations higher than the level where Federal RCRA consider as hazardous. It is not allowed to pour the samples down the drain without collecting the cadmium metal.

The instrument is then measuring the amount of NO_3^- - N produced with the help of the amber colour of the product of the genistic acid and diazonium salt. The detection limit for the procedure is 0.2 mg/L NO_3^- - N. The instrument obtained a standard deviation of ± 0.2 mg/L NO_3^- - N when the same operator made two vials with 3.0 mg/L standard solution. (HACH)

Interference's in the nitrate reaction procedure that we can determine is chloride and in concentrations over 100 mg/L. At high chloride levels can the nitrate measurements be used after a calibration with standards with the same chloride concentration.

Ammonia (0 to 2.5 mg/L NH_3 – N)

Ammonia compounds are combined with chlorine to form monochloramine, which reacts with added salicylate to form 5-aminosalicylate. The 5-aminosalicylate is oxidised in the presence of a sodium nitroprsside catalyst to form a blue coloured compound, indosalicylate. The blue colour is masked by the yellow colour resulting from an excess of reagent giving the sample a green colour.

The intensity of green is directly proportional to the concentration of ammonia in the sample. The detection limit for the procedure is estimated to 0.08 mg/L of NH_3 – N. The instrument obtained a standard deviation of ± 0.02 mg/L NH_3 – N when the same operator made two vials with 1.0 mg/L standard solution.

Interferences in the ammonia reaction are many, nitrate and phosphate are among them, but the levels needed to interference are too high for any concern in our case.