THE ENVIRONMENTAL IMPACT OF NATREF REFINERY STORM WATER ON THE TAAIBOSCH SPRUIT

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This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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[illegible] refinery in South Africa and as such has unique water disposal challenges since it does not have the advantage of marine outlet like many other refineries. Most of its process streams are treated by the Sasol water treatment facility, leaving the concern of water that collects and drains off during rain fall events from the refinery site. Two sampling points were used during this study. Temperature and pH were measured *in situ* while bacterial counts and algal bioassays were performed in VUT laboratory. The area experienced a total of 485 mm of rain during the study period with 75 % thereof during spring and summer, there rest in autumn and winter receiving no rain. The average seasonal pH of the samples remained between 8 and 9.3 and this was found to fall within TWQR as well as being within normal range for natural waters. The temperature changes followed a typical summer/winter pattern, with Taaibosch Spruit showing greater variations from 10.95 °C in winter to 21.4 °C in summer due to its shallow nature. TDS, Nitrates & phosphates were all above the TWQR. Higher HPC & FC counts were observed during spring when rain storms began with Taaibosch Spruit had the higher of the two. As the rainfall continued into summer, the most of the bacterial counts decreased up to the lowest in winter. Higher than expected coliform counts (between 0 and 8 x 10^4) were observed, indicating a possible source of pollution which has to be studied. Chlorophyll *a* values ranged from 2.85 µg/L during spring to100 µg/L in winter indicating the potential for stimulation of the algae and possible algal blooms. The algal bioassays showed inhibition potential of the water during spring, summer and autumn with recovery by the winter. This meant that the storm water from NATREF does have a potential to cause chemical & biological pollution of the Taaibosch Spruit although the actual source of storm water pollution has to be properly studied.

Key words: storm water, pollution, water quality variables, algal bioassays, indicator organisms, water analysis

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INTRODUCTION

1.1 GENERAL INTRODUCTION AND PROBLEM STATEMENT

The study was undertaken at the storm water stream running from The National Petroleum Refinery (NATREF). NATREF was established in 1969 in Sasolburg as the only inland refinery in South Africa (NATREF 2005:1). NATREF has a number of different streams running underground as separate runoff water and effluent sewer systems. This allows for specific treatment processes to be carried out for each stream. The main effluent from the company processes is carried out through the Blowdown sewer system. The water from steam and waste heat boiler that is used in the cleaning out of drums and tubes used in the refinery processes is also returned through the Blowdown system (Naylor Drainage Ltd. 2006:20-23).

The storm water is usually discharged into an ocean outlet for most refineries if the quality is not suitable for recycling (WRC 2005:22). In the case of NATREF however, the water that drains off during rain storm events from the refinery site feeds into the Taaibosch Spruit, an important tributary of the Vaal River. Since this is not specifically treated, it may contribute to the chemical and biological load of the water entering the Vaal River System via the Taaibosch Spruit. The quality of water entering the Vaal River is important since the river serves as the major source of water for the central parts of South Africa (Cloot *et al.* 1992:299-302).

The primary aim of the research was to establish a baseline over a 12 month period, on the acceptability of the storm water runoff on the receiving environment of Taaibosch Spruit.

The specific objectives of the study were to:

- Select suitable sampling points in the system;
- Perform bacterial analysis for indicator and heterotrophic microorganisms

physical and chemical parameters on biological

- Assess the pollution potential of the storm water on the Taaibosch Spruit with the use of an algal bioassay technique and

The secondary aim was to put forward a management plan to address any concern regarding pollution encountered during this study.

LITERATURE REVIEW

2.1 Introduction to storm water

Storm water is the water that is shed as surface runoff whenever the rainfall reaches the ground at a rate higher than it can enter the underlying soils. A number of variables have an influence on the volume and the rate of surface runoff and these include; the intensity and duration of rainfall as well as the type of soil and vegetation covering the area (DWAF 2006a:7). This amount of water is considerable and although it cannot be readily utilized, it still serves as an important resource (Niemczynowicz 1999:2; Burton & Pitt 2002:31) and can be a source of water pollution to receiving water bodies.

The current population growth forces people to concentrate in smaller areas. These people have to make a living which requires transportation and thus large impervious surfaces are developed. This in turn changes the hydrological cycle. Infiltration and groundwater discharge are decreased, alteration of the pattern of the surface causes high peak flows, and large volumes of runoff increases the transport of pollutants from the urban areas, the effects of which are carried downstream as well (Niemczynowicz 1999:3; Burton & Pitt 2002:31). The modern way of doing things makes life easier in the short term whereas the negative implications will be carried over for years to come and even at distances.

2.1.2 Factors associated with storm water runoff

The water discharged from a drainage area may include surface runoff and seepage into the ground. In dry weather, the flow consists of groundwater and surface impoundments, while in wet weather; there is an additional runoff which results directly from precipitation (McGhee 1991:83-86).

(1) Precipitation

n of rainfall together play an important role in om a basin. Rains of low intensity and those that occur during the growing seasons, contribute to a very low runoff.

(2) Solar radiation

Solar radiation affects temperature and in turn has an effect on the evaporation as well as supplying energy to all primary producers.

(3) Local topography and geology

The rate and quantity of runoff are both higher from a steep and impervious surface whilst infiltration is supported by flat pervious surfaces.

(4) Evaporation

Evaporation from an open body of water is higher than that from land. On the land there is shading by plants and a limited amount of water in soil.

(5) Interception

Some part of the rain water is retained on the leaves and does not reach the ground.

(6) Depression storage

This is the water that is kept in low lying areas.

(7) Infiltration

The process is affected by the type of soil, intensity of rainfall, surface condition and vegetation which may affect the porosity.

2.1.3 Storm water pollution

The pollution of rainwater begins in the atmosphere and continues on urban surfaces such as streets and roofs. There the storm water gets mixed with accumulated pollutants from the dry period, wash off from surfaces and contact with building materials. Chemical contamination is speeded up by acidification of rain water through air pollution (Niemczynowicz 1999:6; Csuros1994:269).

The major types of toxic pollutants contained in storm water include; heavy metals, organic and inorganic compounds, gases, anions, acids and alkalis. Organic compounds could originate from domestic sewage (raw or treated), and farm waste (Mason 1996:21). Most of the gh public education and awareness whilst there are those sources of pollutants that are diffuse and originate from watersheds with characteristics that are not fully understood and may vary through time. Such are referred to as non-point sources and their pollution inputs are not constant and therefore pose a challenge from both the regulatory and assessment points of view (Mason 1996:2; Burton & Pitt 2002:4).

The fecal pollution of soil allows the contaminants to enter into a body of water results in a more complex problem than direct input from sewage. The problem has to be monitored taking into account how long the microorganisms survive in soils and possibilities of being washed out by storm water runoff (Van Donsel 1967:1362-1370)

2.1.4 Impacts of storm water pollution

The impact of storm water pollution on receiving water bodies, plants, animals and humans were of interest in this study.

2.1.4.1 Impact on receiving water bodies

The urban areas of South Africa are faced with issues of rapid growth much of which is in the form of informal settlement with poor or non existent sanitation, water supply and refuse removal services. The accumulation of pollutants in such areas is expected to be very high and these could have adverse effects on the overall quality of storm water with a resultant effect on the receiving water bodies. The conditions in formalized, low density and serviced areas will therefore produce storm water of a better if not good quality (Wimberley & Coleman 1992:325; Owusu-Asante & Ndiritu 2009:615).

Urban runoff, storm water included, has been found to have a serious impact on the life of aquatic organisms. The impact is seen to be more severe when the receiving water bodies are small in size and drain from heavily urbanized and

...ce. The major effects are related to long-term ...g in destruction of the habitat, pollution of the sediments and disturbance of the food web (Burton & Pitt 2002:31; Haslam 1992:31). The effects of a pollutant on the microorganisms depend on the dose and period of exposure. A high dose produces acute effects which are rapid, clearly defined, often fatal and irreversible. At the ecosystem level, changes in species diversity will occur with a knock-on effect on the overall balance (Mason 1996:2). The light penetration capacity is reduced by the increase in amount of pollutants which in turn affects the process of photosynthesis. The soils brought in by the storm water suffocate the fish by clogging their gills. The litter that is dragged along by the storm water will break down and release toxic substances which affect the health of birds, plants, and animals living in the waterway (Australian EPA n.d.:1-2).

The quantity and quality of the receiving water also determine the effects different pollutants will have; the quantity is important when one considers the same effluent/pollutant being diluted a thousand times compared to a smaller stream in which the same effluent is only diluted twice, and the quality because of the differences in the chemistry of the water in terms of the pollutants present in the water (Haslam 1992:31).

2.1.4.2 Effect on plants and animals

Natural streams function properly on the basis of a balance between animal and plant life as well as interdependence among the different life forms. Organic substances that enter the stream are metabolized by bacteria into compounds such as nitrates, ammonia, sulphates and carbon dioxide. Plants and algae in turn use these to produce carbohydrates and oxygen. Protozoa and other microscopic animals feed upon the plants and the protozoa are in turn a source of food for fish, crustacea, insects and worms. This natural balance can be disrupted through the introduction of pollutants into the water due to effects they would have on individual species (McGhee 1991:387).

...rough which pathogens are transmitted and can put entire communities at risk, a fact which must be borne in mind when studying water quality (Said *et al.* 2005:115). There are several ways in which health problems can be caused by exposure to storm water. Swimming in areas exposed to storm water discharges, drinking from water supplies affected by storm water discharges and the consumption of fish and shellfish contaminated by storm water discharges, are at the top of the list (Burton & Pitt 2002:85). The pollutants also make the water unsightly which has an effect on recreational activities (US EPA n.d.:1-2).Taking all these aspects into consideration, the impact of the NATREF refinery storm water on the Taaibosch Spruit was evaluated by comparing them to TWQR (DWAF).

2.2.1 Freshwater ecosystems in rivers and streams

Freshwater occupies approximately 3% of the total water on earth (Prescott *et al.* 1999:853). Not only is it essential to life (serves as an important source of drinking water) it is without a doubt a hugely scarce resource, likely to become even worse with the impacts of global warming (Mason 1996:1). Lakes, ponds, springs and rivers are the typical freshwater environments. There are large differences amongst these environments in terms of their physical and chemical characteristics. These in turn have a direct influence on the species composition of each environment (Madigan *et al*. 2003:642).

In general, the populations in lakes and rivers include; algae at 10^3 to 10^4, bacteria at 10^6 to 10^7 and viruses at 10^8 to 10^9 per ml. The response of these organisms to different forms of pollutants could result in the deterioration of water quality. On the whole, freshwater ecosystems are highly sensitive to environmental and anthropogenic stresses. This is demonstrated by the fact the changes that usually take a long time on land are quick to cause population shifts in water (Jones 2001:107-113).

n flow determine the physical and biological ... The discharge of the water depends on rainfall, catchmentsôcharacteristics, area, the slope, animals and most important, human activity in the specific catchments. Water movements may vary from high to low flow around and over submerged objects (Horne & Goldman 1994:356-357). The temperature of most streams is lower in the uplands and becomes slightly warmer in the lower end although they may have 10 ęC daily variations. Rivers however, exhibit smaller temperature variations because of their large volume and heat capacity that act as buffers to the change (Horne & Goldman 1994 :364).

The concentrations of nutrients may vary from very low to extremely high levels of organic matter (Prescott *et al.* 1999:853). Seasonal variations of nutrients are thought to be caused by a combination of factors such as: rainfall, biological recycling, natural fires, soil erosion and retention by the humus layer, depending on the type of nutrient involved (Horne & Goldman1994: 366). Nutrient levels usually increase due to pollution, which results in changes in types of microbial populations. The rate of nutrient turnover also differs from one environment to the other (Prescott *et al.* 1999:853).

2.2.2 Human threats to freshwater resources

The population explosion that is being experienced the world over, places a great deal of pressure on the valuable water resource. This is due to the fact that the same resources are being used for different purposes such as hydropower, waterways, irrigation, drinking water industry and waste water disposal (Jones 2001:110). The following factors are summarized from the State of the Environment Report (DEAT 2005:5-7).

2.2.2.1 Industry and mining

The mining process can result in pH change, increased salinity, metal content and sediment load. The inputs from industries on the other hand, are industry isonous chemicals, nutrients, increased salinity

2.2.2.2 Increased urbanization and deteriorating standards in waste water management

The waste water from many informal settlements in South Africa receives little or no treatment. The available treatment may be inadequate or poorly maintained resulting in uncontrolled leakage or overflow into the natural resources. The high organic and nutrient loads contained in urban runoff contribute to the high microbial loads all of which lead to problems in urban streams and impoundments.

2.2.2.3 Agricultural drainage

The irrigation of agricultural land may result in return flows and seepage containing salts in the form of fertilizers and pesticides or herbicides. The runoff from animal farms such as feedlots and chicken farms further contribute to contamination of water.

2.2.2.4 Land use

Surfaces in urban areas are laid with impervious material such as concrete pavements and tar allowing very little rain water recharge into groundwater and increases the runoff to sewers and storm water drains. The lack of a dilution effect that would usually occur leads to an increase in solute concentrations of the underlying aquifers.

2.2.2.5 Delays in classifying water resources

It is important for quality of water resources to be adequately classified so that proper monitoring and management processes can be implemented. South Africa has gone through an extensive exercise of producing good pieces of legislation which, if properly implemented and monitored, should go a long way towards improving the country's water resources. The issues of lack of capacity nitoring data from which statistical results can be he government as a matter of urgency.

2.3 Water resources in South Africa

South Africa has an annual rainfall of 464 mm which is far below the world average of 860 mm. The greater part of the country receives summer rains with the exception of the Western Cape having a Mediterranean climate with rainfall occurring mainly in winter (Climate features: The rainfall n.d:1). Most of the water is lost to evaporation. All these factors make South Africa a semi-arid country (DWAF 1996a:8). A relatively small amount of rainfall, approximately 8.6% is available as surface water making this one of the lowest conversions in the world. The mean annual runoff of 50 million m^3 a^{-1} is mainly distributed to the Eastern seaboard with the western regions receiving runoffs of around 20% (DEAT1999:3). The runoff that results from rainfall events washes the different types of organic and inorganic substances into the water bodies. The water levels and flows within the rivers are in turn affected by the rain patterns within the different areas of South Africa. In addition to that, water is abstracted from rivers and streams for industrial and domestic water supply, which requires careful regulation and monitoring (DWAF 1996a:8).

The scarce water resources and the variability of hydrological conditions in the country have resulted in the need exceeding the supply for most catchments. The scarcity of water is worsened by continuous introduction of pollutants to both surface and groundwater resources. Common pollutants of South Africa's freshwater environments include industrial waste, domestic and commercial wastewater, agricultural runoff and litter (DEAT 1999:3). Industries in particular, produce a lot of wastes that can have an influence on the pH, colour, nutrients, temperature, salts and mineral content, as well as the turbidity of the water. These factors in turn have an on the organisms living in water and different users (Rand Water Online n.d).

oncern in South Africa

y Status Report (Hohls *et al.* 2002:79) stated that high salt levels represented as high TDS values and fluoride levels in certain areas, are the main water quality problems throughout the country with regards to domestic use. The high TDS in water gives it a salty taste and does not slake thirst and also lowers the aesthetic value of the water as well as making irrigated agriculture in these water management areas (WMAs) more challenging, and limiting crop selection to more salt tolerant crops. The water does not produce any serious health effects in the short term although long term effects could be experienced in sensitive individuals as a result of salt overload. High fluoride levels on the other hand, causes health effects and staining of teeth. Changes in pH were observed at most parts of the country with low pH being recorded at sites such as Klip Spruit (Olifants WMA). The effect if thought to be due to acid mine drainage from the coal mines and mine dumps in the area. The effects of consuming water with low pH include mucous membrane irritation with the noticeable effect being the burning of eyes when the water is used for recreation. Magnesium (Mg), sulphate (SO4), chloride (Cl), sodium (Na) and potassium (K) were also elevated in various parts of the country. South Africa is experiencing disturbing levels of nutrient enrichment at many of its impoundments with the most enriched impoundments often being those that have the greatest concentration of humans in their catchment areas. This is something that requires urgent attention since it is not just about appearance. Eutrophication leads to the frequent occurrence of toxic algal blooms, with the associated deaths of fish and cattle, and the induction of gastro-enteritis in humans.

2.3.2 The water quality situation in Gauteng Province

The southern and northern parts of Gauteng Province have rivers that are fed by different streams and these are affected by mining and industrial activities and urban developments. In the north, there is the Jukskei River which drains water from the densely populated and highly industrialized areas and feeds into the le River in turn drains the water from the recreational spot which serves as a source of water for the Northern Province. The Klip, Riet and Blesbok/Suikebosrand are the three rivers that drain the southern parts of Gauteng Province. These rivers flow different communities before they drain into the Vaal River Barrage Reservoir (Rand Water Online n.d:1). The ecological state of Southern Gauteng Rivers is generally considered to be poor with the exception of the upper Suikerbosrand which is still in a fair overall state (Strydom *et al.* 2006:50). The Vaal River is as a result, having major water quality issues such as, an increase in salinity and other macro ions which have an effect on the use of water. The impact on the water quality of the system by industrial pollution is most significant in the Upper Vaal WMA, where the most concentrated industrial activity is found. The impacts are associated with direct effluent discharges and to surface run-off from industrial complexes (DWAF 2009:242). The total dissolved solids (TDS) and associated components that include sulphates and chlorides have also increased to levels that impact on domestic, industrial and agricultural users. Some areas of the river are experiencing a new water quality problem in the form of microbiological pollution (Rand Water Online n.d).

The formal and informal housing, paving and road networks have sealed the natural surfaces that prevent the rainwater from filtering into the ground in a natural way. It also causes unnaturally high volumes of fast flowing storm water runoff to erode the river channels. This has resulted in more canalized rivers and storm water drains that have replaced the natural wetlands and streams. These in turn transport large volumes of polluted urban runoff to the rivers, causing severe degradation downstream (Strydom *et al.* 2006:50). The information above brings to the fore the need to make a concerted effort to improve the quality of Gauteng rivers from fair to good instead of allowing them to worsen from fair to poor. To achieve this it has become necessary to understand the sources of pollution and to manage the water quality of the receiving water bodies.

Water always contains different substances and it is only in rare instances where it will be in a pure state. People are the judges of the water quality and this is based on a general feeling for what qualifies as good or bad. The decision is mostly based on the appearance, taste and smell and may be misleading (WRC 2001: 5). In scientific terms however, water quality is described by the chemical, physical and biological characteristics of water. These relate to the water being suitable for its intended use; domestic, agriculture, industrial and the maintenance of a healthy ecosystem (Palmer *et al.* 2004:28). Therefore, water of a good quality is of great importance for sustainable economic and human development.

The quality of water is influenced by different types of natural and human factors. Three of the most important natural factors that have a direct bearing on the quality of the water are geological, hydrological and climatic. Adequate water may be available although its use may often be unsuitable for its intended purpose. The natural ecosystem usually adapts to the quality of water, to a certain extent, but any serious changes to the water quality will greatly affect the ecosystem (Bartram & Ballance 1996:9).

Industrial waste water can have an important influence on the water quality in a catchment area with variations from one industry to another due to differing activities. In general, the waste water can contain poisonous or hazardous chemicals, nutrients and can increase salinity and sediments. All these contribute to lowering the quality of water (DEAT 2005:3). Furthermore, the determination of useful water quality objectives should be set in conjunction with the proper definition of purpose(s) and/or control measures otherwise they become useless (Bartram & Ballance 1996:3).

ıter will have the same requirements for some of use having its own demands and impacts on the water quality. Demands in terms of quality and quantity for the different water users will not always agree since the activities of one user may interfere with those of another, such as one user lowering the quality through waste disposal (Bartram & Ballance 1996:9).

2.4.2 Physical quality

Physical quality refers to the system variables such as conductivity, turbidity, pH and temperature. Conductivity is a measure of how electricity is conducted by water which is related to the concentration of total dissolved solids (TDS). The presence of a high TDS may affect different population groups as follows; infants, due to disturbance in salt and water balances, heart patients and individuals with high blood pressure due to high salt concentration, individuals with renal failure and can produce laxative effects when the level of sulphate is high. The removal of this salinity results in higher treatment costs. The extreme levels of pH cause irritation of mucous membranes in humans and animals and the corrosion of pipes and other infrastructure occurs at extremely low pH (WRC 1999:60-61).
Temperature has a direct influence on the solubility of oxygen in water, rate of activities in bacteria, as well as the rate at which gases are transferred to and from water (McGhee 1991:389). The physical factors in general, determine the taste, odour and appearance of the water (WRC 1999:60-61).

2.4.3 Chemical quality

The chemical quality looks at the different types and levels of dissolved substances. Amongst others, the salts, metals and organic substances are measured. Many of these substances are required for the sustenance of ecosystems, but very high doses may become harmful to the users (WRC 2001:5).

eters were of interest in the study for various reasons. The nutrients, nitrogen (nitrate) and phosphorus (phosphate) are regarded as essential for phytoplankton growth and as such they make for good indicators of water quality, hence their inclusion in the study (Karafistan & Arik-Colakoglu 2003:127-143). High nitrate concentrations cause tiredness and failure to thrive and these effects are chronic in nature. Nitrate is difficult to remove from water and due to its stimulatory effects on algae it may lead to eutrophication (WRC 1999:86).

Dissolved oxygen (DO) is one of the most important dissolved gases without which many of the species living in water cannot survive. The bulk of this oxygen comes from the atmosphere which contains approximately 21 % oxygen with algae providing an additional source through their photosynthetic processes although some of it is lost when algae use oxygen as part of their metabolic process at night. Biodegradation of biomass occurs when algae and other organisms die and the process uses up a lot of oxygen. Another factor at play is oxygen solubility in water which is dependent on temperature of the water, partial pressure of oxygen in atmosphere and amount of salt in water (Manahan 2000: 65).

The total dissolved solids (TDS) is used as a general indication of chemical quality of the water (Faust & Aly 1981:2) and the measurement thereof determines the amount of all compounds that are dissolved in the water sample. The measure is also directly proportional to the electrical conductivity since the bulk of these compounds carry an electrical charge and their concentrations have a direct effect on the buffering capacity of the water and therefore the metabolism of the different organisms (DWAF 1996c:108).

Phosphorus on the other hand, is an essential element of DNA, RNA and ATP. In phosphorus limited lakes, the rate of growth of algae, especially in summer, is e of phosphorus loading from the surrounding n 1994: 133 &152). In the initial stages the algal blooms that result from phosphate enrichment will boost photosynthesis which increases the level of dissolved oxygen. When the blooms die however, oxygen is consumed by bacteria during the process of decomposition. This will then results in overall changes in the ecosystem (Behar 1997:1-3).

2.4.4 Microbiological quality

This part specifically identifies the microorganisms such as protozoa, bacteria and viruses. Some of these microorganisms are well known pathogens and may be difficult and costly to detect hence, the common use indicator organisms such as fecal and total coliforms as an indication of pollution and possible risk (WRC 2001:5).

2.4.4.1 Heterotrophic bacteria

The heterotrophic bacteria are those that require organic compounds as a source of both carbon and energy and their occurrence in water is more common than autotrophic bacteria (Manahan 2000:153) they, therefore play a major role in the assimilation and degradation of pollutant organic matter and are suitable indicators of water quality (DWAF 1996b:54-56; Karafistan & Arik-Colakoglu 2003:127-143). Heterotrophic plate count method is aimed at isolating all microorganisms capable of growth on a solid growth medium. Isolation of bacteria of human origin is achieved with incubation at 37 ȩC for 24 hours and those from environmental sources are grown at 22 ȩC (Bartram & Balance 1996:239).

2.4.4.2 Indicator organisms

The presence of coliforms is an indicator of contamination with fecal material which poses a risk to human health (DWAF 1996b:54-56; Karafistan & Arik-Colakoglu 2003:127-143). The principle of using an indicator organism is based on the assumption that other pathogens will also be removed through the nce it is not common practice to check for the omplications and the low levels associated with them (Dawson & Sartory 2000:76). Put in another way, there is a positive correlation between their presence in water (concentration) and potential health risk associated with exposure. The tolerance of indicator organisms to changes in environmental conditions is the same as that of pathogens and they are easier to analyze for, hence their inclusion in water quality analysis (Kinzelman *et al.* 2003:93). For practical purposes, the coliforms are described as; aerobic and facultative anaerobic, Gram negative, non-spore forming, rod shaped bacteria that ferment lactose with gas at 35 ęC in 48 hours (Madigan *et al.* 2003:935).

Total coliforms are used as an indicator of the hygienic quality of the water. They are of major importance in the monitoring of drinking water (DWAF 1996b: 38). Indicators more specific for fecal pollution than total coliforms are fecal coliforms and is applied to different water sources including recreational, waste, raw water supplies and natural water environments (DWAF 1996b:38). The presence of total and fecal coliforms in water is indicated by diarrhoea, and sometimes fever and other secondary complications. The dehydration that results from diarrhoea may be life-threatening especially in infants. The sensitive groups of people include; HIV infected individuals, infants under the age of 2 years and those undergoing chemotherapy. The coliforms may survive the disinfection process within suspended matter (WRC 1999:52). Urban storm water is generally found to have high levels of fecal coliforms that may be well above the quality standard. The primary sources of these bacteria include pet waste, wildlife, unlawful discharges and combined sewer overflows (Minnesota Pollution Control Agency 2008:1-2).

2.4.5 Algae in water

Algae are ecologically important organisms since they serve as primary producers in both marine and freshwater ecosystems. This, they achieve through the process of photosynthesis in which carbon dioxide is fixed and ereby providing the foundation of the food chain stem. This however, should not occur at such an extent to allow for over production of biomass that may lead to consumption of oxygen when it decays, the concept known as eutrophication (Manahan 2000:149). Therefore, the assessment of toxicity on the growth of algae is required in order to protect plants and detect industrial chemicals that may enter a water body

All algae contain chlorophyll a and therefore it can be used to estimate the amount of algae in surface water. It should however be borne in mind that the concentration of chlorophyll a varies between the species and during the lifecycles of a species. Generally, chlorophyll a makes up to 1 or 2 percent of the algal dry weight. For a more accurate estimation, one can count algal cells or colonies because even the species type will be identified (DWAF 1996b:24).

The assessment of water quality has to include members or representatives of the aquatic plant community. Algae are found to be widespread in aquatic environments where they carry out the assimilation of carbon, nitrogen and phosphorus during photosynthesis, a process which also releases oxygen as a by-product into the water and are therefore important for self-purification of surface waters. Thus the examination for the presence of naturally occurring algae and the performance of algal bioassays was important in order to determine the water quality of the storm water samples (DWAF 1996b:39-40).

The algae used in tests are generally sensitive to many substances allowing these types of assays to be commonly used in environmental studies and can be applied in various contexts such as the screening of test chemicals for toxicity or as part of toxicity characterization of chemical substances (Arensberg *et al.* 1995:2103). The method involves the addition of the test material which may be the individual chemical or water sample to a nutrient medium. An inoculum of the specific algae (indicator) is added to the test vessel (bottle or flask) which are

e conditions. The growth of the algae exposed to
:ontrol.

2.4.5.1 Characteristics of indicator algae

The algae, *Selenastrum capricornutum,* has been selected as an indicator of pollution of the water because it is the most commonly used phytoplankton in the assessment of levels of nutrients or toxins in freshwater habitats. This species is highly sensitive to the presence of toxins and their response can give an early warning about the changes in water conditions, however small, before a problem becomes serious (Staveley & Smrchek n.d: 181-202).

2.5 Importance of water analysis

Water quality data is of major importance for pollution control, the assessment of long- term trends and environmental impacts (Bartram & Ballance 1996:5). In the practice of water quality monitoring, the chemistry of the water has become the norm in pollution control. However only a limited range of variables are analyzed and even if the sampling is done regularly (once a month) this aspect of water quality is merely representative and incomplete. Ecotoxicology on the other hand provides a causal link between the chemicals routinely monitored in water and the response of the living organisms to the chemicals. The integration is important because it gives a good foundation towards the development of resource quality objectives (Palmer *et al.* 2004:29-36).

2.6 Summary of the literature review

Storm water is the runoff that forms when the water cannot infiltrate the soil due to dominance of impervious surfaces. The flow and quality of storm water is influenced by a number of factors that have an impact on receiving water bodies, plants and humans. South Africa has a scarcity of water due to rainfall that is lower than the world average. This is worsened by continuous introduction of pollutants to both surface and groundwater resources. Common pollutants of South Africa's freshwater environments include industrial waste, domestic and ltural runoff and litter. The resultant effect of n TDS, salts, microorganisms and nutrients in general, all of which have an influence on the quality of water in South African Rivers. Different variables can be measured to determine the quality status of the water (Rand Water Online n.d). The analysis of storm water in a way that integrates the chemical, physical and biological characteristics, allows for proper understanding of this impact as well as how it can be controlled.

MATERIALS AND METHODS

3.1 The study site

The study site is located a short distance (500 m) outside the NATREF complex in Sasolburg. Sasolburg is situated on the northern boundary of the Free State Province on the southern banks of the Vaal River. The storm water from the NATREF complex drains into a holding weir constructed from concrete channels commonly known as the Paddabaai channels (see figure 1). The Paddabaai channel system undergoes an annual cleaning process during April/ May to remove silt and other detritus which has accumulated during the run off of storm water from its factory with the aid of a front end loader. This operation improves the ability of the channel system to retain solid material thus improving the clarity of the water downstream from it.

This area was chosen as the first sampling point so that the immediate quality of the storm water could be determined. It will be referred to as the Paddabaai channels sampling point (see figure 2).

The storm water then flows a distance of approximately 1.3 km through a shallow stream into the Taaibosch Spruit, the second sampling point (see figure 2). This part of the stream has a lot of medium to large stones and is covered by grass on the banks (see figure 3). This sampling point will be referred to as the Taaibosch Spruit sampling point. A comparison of the two sampling points was done to determine changes to the water and to get information on the quality of the water.

Figure 1: A map showing path followed by the storm water from NATREF complex to the Vaal River and the two sampling points (Google 2010).

3.2 Sample collection.

The study was started in August 2007 and water samples were collected once a month for 12 months from the two sampling points. The samples were transported to the laboratory at Vaal University of Technology in a cooler box.

3.2.1 Sampling point 1: The Paddabaai channels.

A hosepipe technique was used at this site. The hosepipe was flushed with 70 % ethanol to get rid of any contaminants and the excess ethanol rinsed from the pipe with water from the channels. The hose pipe was slowly lowered to a depth of approximately 60 cm by closing the top end of the hosepipe with a thumb to the pipe. The hosepipe was withdrawn and the sterile 1L Scott bottle up to a level of ± 900 ml to allow for shaking and oxygen exchange.

Figure 2: A photo of the Paddabaai channels (Paddabaai sampling point).

3.2.2 Sampling point 2: The Taaibosch Spruit.

The water sample was collected by lowering and holding a sterile 1L Schott bottle into the shallow stream and allowing water to simply flow in up to a level of ±900 ml to allow for shaking and oxygen exchange.

Figure 3: A photo showing sampling point at Taaibosch Spruit during July 2008

3.3 Methods of sample analysis

The storm water samples were analyzed for the following parameters:

3.3.1 Physical parameters

The pH and temperature of the water were measured on site by placing the calibrated meter (HANNA MODEL HI 98128) directly into the stream water. The ambient temperature was also recorded using the same meter. The rainfall for the study period was obtained from South African Weather Services (SAWS). The rainfall figures were used as an indication of the run-off which could have occurred and thus a parameter for the flow of storm water from the factory site.

3.3.2 Chemical analysis

The chemical analyses for the Paddabaai sampling point were carried out on a weekly basis by the NATREF analytical laboratory as a routine task. The following chemicals were measured; TDS, DO, Nitrates and Phosphates. The monthly averages of the chemical parameters were calculated and correlated with the biological variables. The analyses could not be done for Taaibosch Spruit due to the lack of equipment at the time the study was conducted.

ion studies

The aim of the cultivation studies was to isolate and count the different bacterial and fungal populations using R2A for Heterotrophic Plate Counts (HPC) and selective media for specific groups. Ringer's solution was prepared by dissolving one tablet in 500 ml of distilled water, distributed into 9 ml quantities in MacCartney bottles and sterilized. The different media (Table1) were prepared according to the manufacturer's (Biolab) instructions. These materials were prepared a day before sample collection and kept in the refrigerator until use so as to avoid delays in analysis.

The laboratory work began immediately upon the sample reaching the laboratory or within six hours of sample collection. Serial dilutions (ten fold) were performed up to 10^{-5} using sterile Ringers solution as a dilutant. A volume (0,1 ml) of the dilutions was transferred onto the different media using the spread plate method in duplicates. The plates were incubated at the appropriate temperatures and periods after which colonies were counted as indicated in Table 1 below (Nevondo & Cloete 1999:215-220).

Table 1: Media and incubation conditions used in bacterial cultivation

Bacteria studied	**Medium used (Biolab)**	**Incubation temperature (°C)**	**Incubation time (hours)**
Heterotrophic bacteria (Aerobic & Anaerobic)	R2A	37	24
Environmental bacteria	R2A	22	24
Anaerobic bacteria	R2A	37	
Total coliforms	mEndo & Chromocult	37	24
Fecal coliforms	MFC	44.5	24
Vibrio	TCBS	37	24
Pseudomonas	Cetrimide &Pseudomonas agar base	37	24
Clostridium	TSN & Reinforced Clostridial agar	37	24
Enterococci	MEnterococcus	37	24

Algal bioassays were done to determine the effect (inhibition or stimulation) the water samples had on the growth of indicator algae namely; *Selenastrum capricornutum*. The culture of *Selenastrum capricornutum* was transferred into flasks with fresh algal growth medium (culturing medium for Algal ToxKit F^{TM} tests) and placed on a light bench for 72 hours in order for them to reach the exponential phase at the time of use. The influence of algae and bacteria that naturally occur in the water samples was eliminated by removing these organisms through filtration. The samples were first filtered with a glass fibre filter (GFC Whatman) followed by a nitrocellulose membrane filter (0, 45 µm). Water samples were diluted with algal growth medium (AGM) in the 10 x 4 x 1 cm cuvettes (long cells) in duplicate. The active culture of *Selenastrum capricornutum* was then added into the prepared dilutions (see table 2 below). Controls, containing AGM and algae (no water sample), were included with each set of dilutions. The cuvettes were placed on a standard light bench to allow for the growth of the algae with the lids loosely fitted to allow for gas exchange to occur. The absorbance readings were measured every 24 hours from hour 0 to 144 hours at 670 nm using a spectrophotometer (Jenway 6300). The average readings were then calculated and plotted on graphs.

Table 2: Dilutions used for Algal Bioassays

Vol. of Culturing medium for Algal ToxKit F^{TM} tests (ml)	**Volume of sample (ml)**	**Volume of *S.capricornutum culture* (ml) added**	**Final sample dilution (%)**
20	0 (control)	5	0
18	2	5	10
16	4	5	20
14	6	5	30
12	8	5	40
10	10	5	50
8	12	5	60
6	14	5	70
4	16	5	80

Figure 4: Photo of long cells on a light bench.

3.3.3.2.2 Measurement of Chlorophyll *a*

Chlorophyll a measurements were done on the raw water samples to estimate the algal biomass in the water (DWAF 1996a:24). Sample (50 ml) was filtered through a Glass Fibre filter (GF/C Whatman). The filter was then transferred into a McCartney bottle containing 10ml ethanol for the extraction of chlorophyll *a.* Bottles were placed in a water bath at 80 ęC for 20 minutes after which the sample was left overnight in the dark. Extract was added into a 1cm cuvette and absorbance measurements were done at 665 nm and 759 nm.

The following calculation was then used to determine chlorophyll *a*:

$$\mu g Chla / L = [\left(Abs_1 - Abs_2 \times 28.66 Vol\right)_{ETOH}] \, {}^{1}\!/_{Vol_{sample}} \times 1000$$

Where: Abs = $Abs_{665} - Abs_{750}$

Vol_{sample} = volume of filtered sample

Vol_{ETOH} = volume of ethanol used

1000 = conversion of ml to litre

nt microorganisms in combination with algal on potential of the water to be determined at the two different levels namely; primary producers and consumers of the ecosystem in the Taaibosch Spruit. The different variables were compared to Target Water Quality Range (TWQR) guidelines given by DWAF.

3.3.3.3 Statistical calculations

The averages and standard deviations of all the measurements were calculated using Excel 2007 and SPSS packages. The averages were used in the plotting of different graphs. Correlations coefficients were worked out to determine the influence of physical and chemical variables on microbial growth. T-test and ANOVA were used to determine the significant differences between the different variables at the 95 % confidence level.

PRESENTATION OF STUDY FINDINGS

The main aim of the study was to determine the environmental impact of storm water coming from NATREF on the receiving environment of Taaibosch Spruit and eventually the Vaal River. A comparative view of the different seasons for both sampling points was used in the study to determine the changes that may occur in the water to either improve or worsen the quality by the time the water reached Taaibosch Spruit. The seasons were worked out as follows; Spring (1 September to 30 November); Summer (1 December to 28/29 February); Autumn (1 March to 31 May) and Winter (1June to 31 August).

4.1 Physical parameters

4.1.1 Rainfall pattern

The rainfall results (figure 5) were presented in months rather than seasons to show the average obtained over each month as well as to indicate the dry months in the study. During the study period the Sasolburg area received a total of 458 mm for the period August 2007 to July 2008. Highest rainfall of 67.83 ± 23.88 mm was observed during spring, followed by summer with 46.67 ± 23.09 mm. Autumn had a total of 38.17 ± 52.08 mm whilst the winter season experienced no rain at all (SAWS). There was a significant difference between spring and winter rainfall at 95 % level of significance.

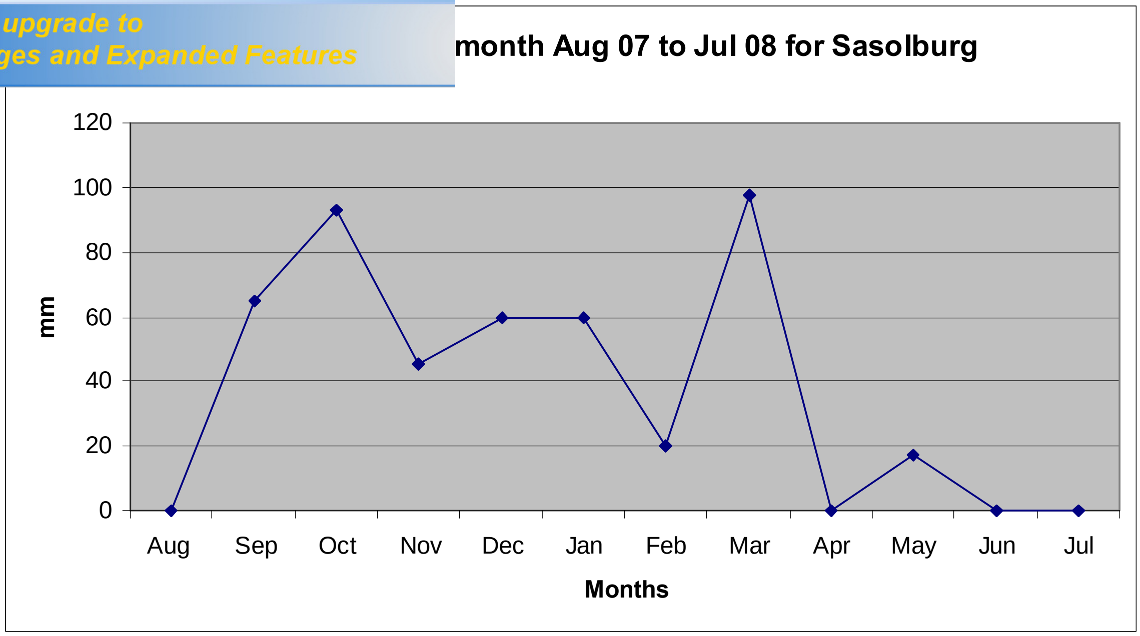

Figure 5: Rainfall data for Sasolburg August 2007 ï July 2008 (SA Weather Services Station 04385884)

4.1.2 Temperature

Temperature is one of the important physical factors that have an influence on the types of microorganisms that occur in the environment because of its direct effect on the functioning of enzymes. Temperature also has an influence on the chemistry of the water. An increase in chemical reactions generally occurs with an increase in temperature and there is less oxygen present at higher temperatures (DWAF 1996c:103-104).

The water and ambient temperatures (see figure 6) followed the same pattern throughout the seasons for both sampling points. Average water temperatures for Paddabaai however, were significantly higher than those at Taaibosch Spruit during autumn and winter. During winter, as the days become shorter and the temperature dropped much more at night, the gap between ambient (20.7 ± 3.11) and water temperatures at Taaibosch Spruit (9.40 ± 1.41) increased. The lower temperatures would be expected to have effect on the microbial activities and loads of the water.

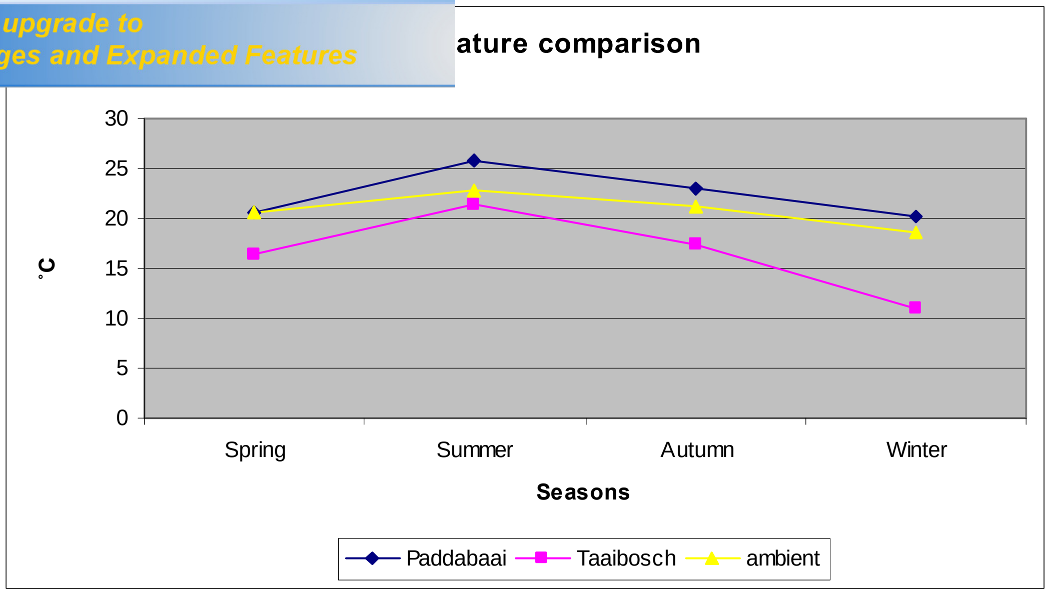

Figure 6: Seasonal temperatures

4.1.3 pH measurements

pH is an important parameter to which different groups of microorganisms have adapted differently (Wiley *et al.* 2008:668). Average pH of storm water was found to be alkaline with levels of 8.5 ± 0.62 and 7.9 ± 1.13 measured at Paddabaai and Taaibosch Spruit respectively (see figure 8) during the study period. pH at Paddabaai sampling point remained above 8 throughout the seasons with a maximum of 8.93 ± 0.04 measured during winter. Statistically significant differences did not occur between Paddabaai and Taaibosch Spruit for all seasons. The water in the Vaal River was also found to have high pH with an average of 8.05 although the upper part of the river was found to be lower at 7.4 (DWAF 2009:146).

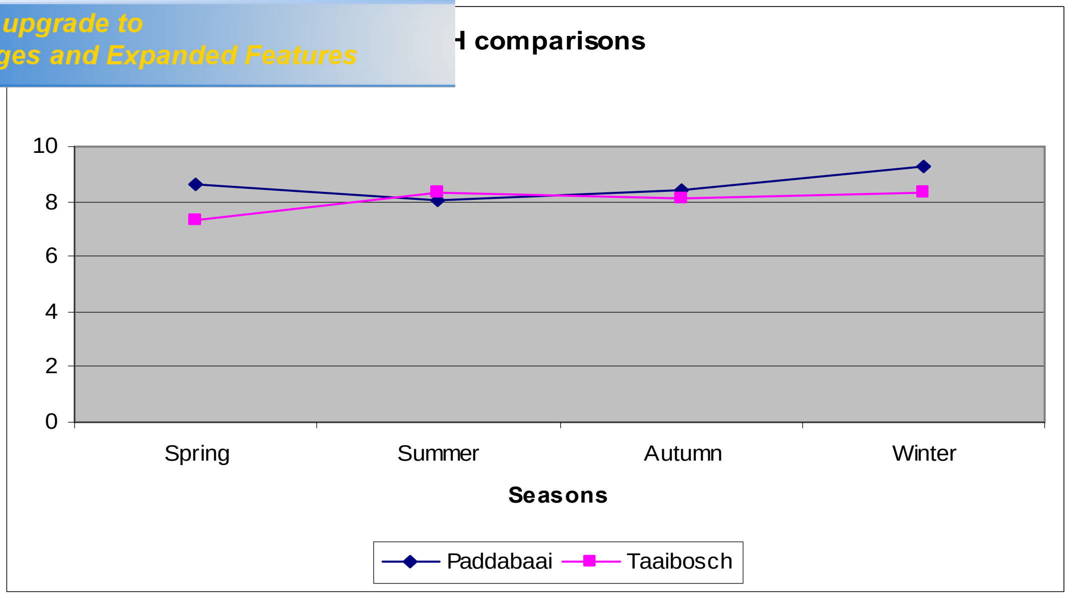

Figure 7: Seasonal pH levels for both sampling points

4.2 The results of chemical analyses

The chemical analyses were only carried out for the Paddabaai sampling point by the NATREF analytical laboratory as a routine task. The same analyses could not be done for Taaibosch Spruit due to the lack of equipment at the time the study was conducted.

4.2.1 Dissolved oxygen (DO)

The average dissolved oxygen (see figure 9) was found to be higher during the summer at 10.9 ± 7.0 mg/L and spring at 9.89 ± 3.4 mg/L than autumn and winter levels. This corresponded with average water temperatures of 25.8 ±3.03 °C and 20.55 ± 2.37 °C for those two seasons. Lower DO averages were obtained during autumn and winter going from 6.22 to 7.8 mg/L at average temperatures of 23 °C and 20 °C. Negative correlation values (95 % confidence) of 0.55 and 0.5 were obtained for summer and autumn respectively and this was in agreement with the fact that the concentration of dissolved oxygen is lower at higher temperatures (DWAF 1996c:53). Water temperatures for spring and winter were both slightly lower resulting in positive correlation values of 0.18 and 1.0 respectively. DO levels of between 5.5 and 5.8 mg/L were measured at

: the level within the Vaal River was found to be ...nge (Rand Water Online).

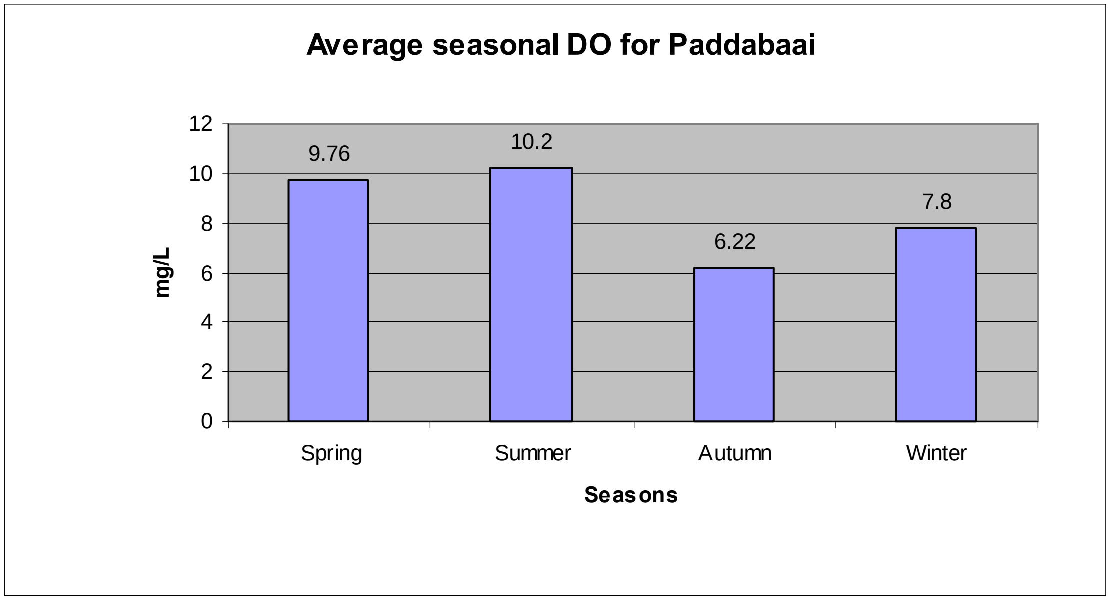

Figure 8: Average seasonal DO for Paddabaai

4.2.4 Total dissolved solids (TDS)

The level of total dissolved solids was seen as an important parameter since it is a measure of the total quantity of compounds dissolved in water including those that can carry an electrical charge and would influence the biology of the sampling points (DWAF 1996c:108-111). The average TDS measurements (see figure 9) showed the highest average measurement of 1038 ± 996 mg/L during summer with the highest value (1281) recorded in January 2008. The lowest average of 311 ± 234 mg/L recorded during spring. The concentrations at Taaibosch Spruit tributary were also found to be fairly high with an average of 299 mg/L.

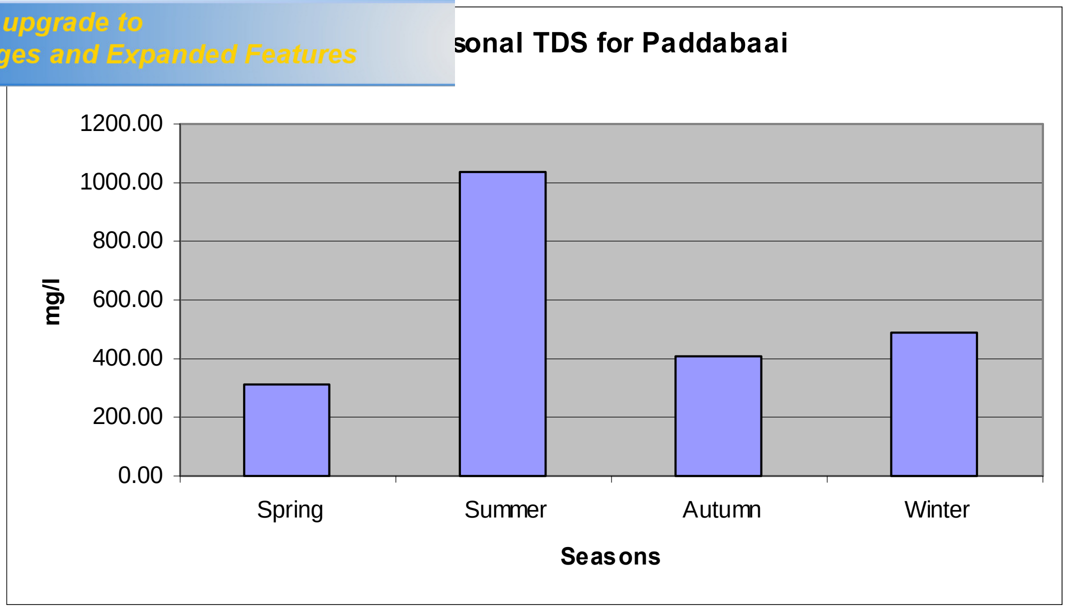

Figure 9: Average seasonal TDS for Paddabaai

4.2.2 Nitrate

Nitrogen and phosphorus were included in the study because they are classified amongst good indicators of the level of pollution in surface waters in South Africa (DEAT 1999:1).The nitrate levels (see figure 10) were generally higher during autumn at an average of 59.7 ± 5.31 mg/L, followed by spring with 44.2 ± 55.89 mg/L, summer at 30.9 ± 8.63 mg/L and winter at 27.4 ± 13.26 mg/L, with an average value of 41 ± 29.2 mg/L for the study period which is higher than expected when compared to the Rand Water guidelines and it would imply that nitrogen was not a growth limiting factor in this study. According to Horne & Goldman (1994:133) ñthe concentrations of nitrogen compounds tend to follow a regular seasonal patternò. These levels were higher than those measured at the Vaal River with a mean of 0.512 mg/L (DWAF 2009: 152).

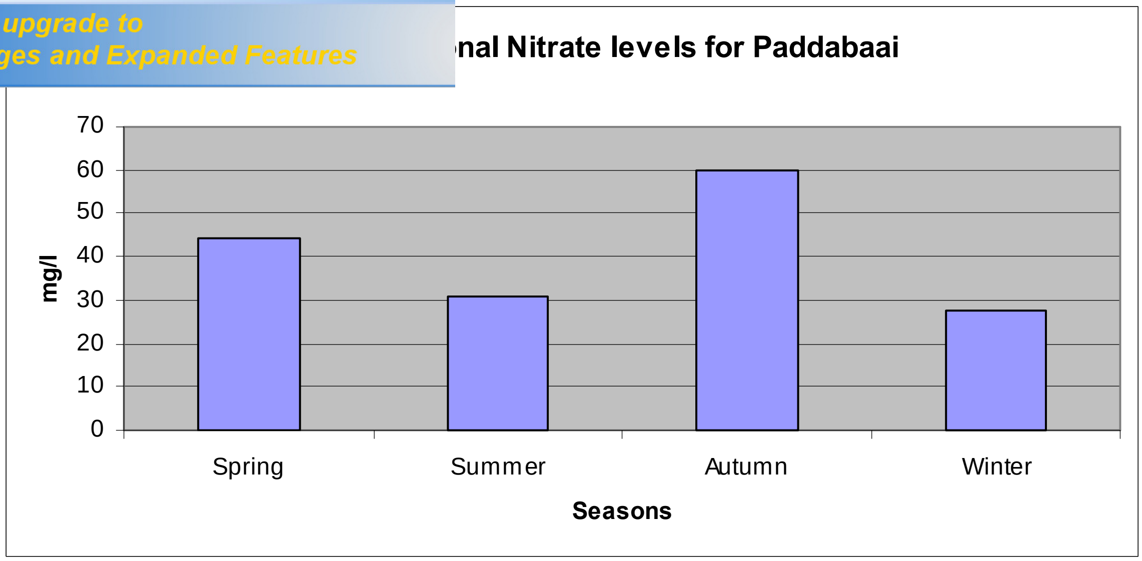

Figure 10: Average seasonal nitrate for Paddabaai

4.2.3 Phosphate measurements

The levels of phosphates (see figure 11) were higher during the summer with an average of 6.6 ± 5.26 mg/L resulting mainly from a level of 12.6 mg/L measured during the month of January 2008. It is normally expected that phosphorus will be higher at warmer temperatures (Horne &Goldman 994:133). Lowest level of 1.8 ± 0.79 mg/L was obtained during spring when the water temperature of 20.9 ± 2.37 ęC was recorded. The summer average phosphate levels were higher than the 5 mg/L recommended for aquatic systems and algal blooms can be expected to occur during that season (DWAF 1996:97). A high average of 0.53 mg/L was measured at Taaibosch Spruit tributary over a 10 year period between 1994 and 2004. This would imply that the storm water is likely to contribute to the high levels if the quality does not change by the time it reached Taaibosch Spruit. The average for Vaal River was 0.05 mg/L for the same 10 year period. Phosphate is therefore referred to as a serious pollutant of the tributary catchment and this is attributable to possible sewage pollution as well as urban and industrial runoff (DWAF 2009:152).

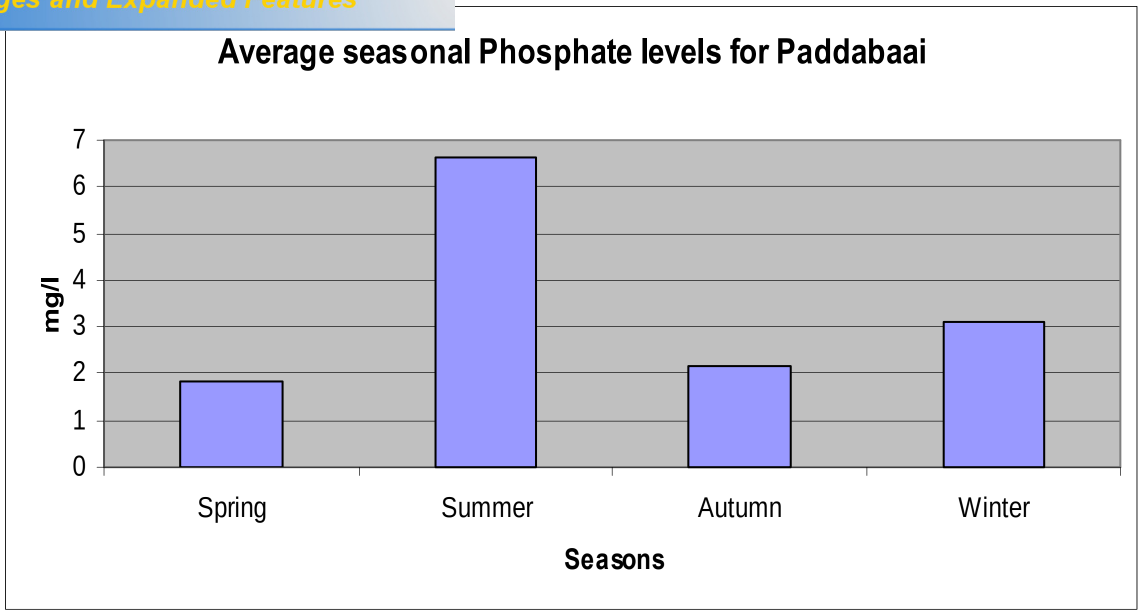

Figure 11: Average seasonal phosphate for Paddabaai

4.3 BACTERIAL COUNTS

The HPC (aerobic and anaerobic), total and fecal coliforms, clostridia and pseudomonads counts were studied to understand the overall quality of the storm water.

4.3.1 Heterotrophic plate counts (Total aerobic and anaerobic counts)

The heterotrophic bacteria that occur in water play a major role in the assimilation and degradation of organic matter and are therefore suitable indicators of quality (DWAF 1996b:54-56 and Karafistan & Arik-Colakoglu 2003:127-143). HPC gave great variations in the monthly counts as observed from the high values for standard deviations with the exception of winter for both sampling points and autumn at Taaibosch Spruit.

4.3.1.1 Aerobic HPC

The aerobic HPC (cfu/ml) for the Paddabaai sampling point were at the highest level of 210 x 10^3 ± 76 during spring followed by summer with 197 x 10^3 ± 223 autumn 120 x 10^3 ± 58.3 and winter 101 x 10^3 ± 83.4 cfu/ml as can be seen in figure 12. Taaibosch Spruit also showed a pattern similar to Paddabaai although

ced. The average for spring was 270 x 10^3 ± 317
12 cfu/ml.

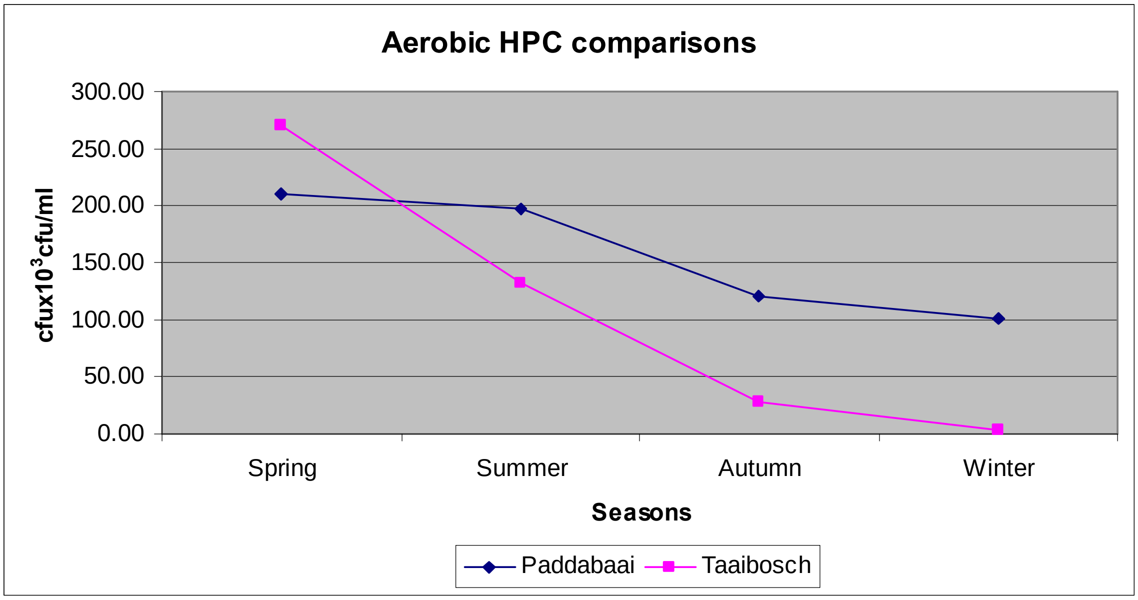

Figure 12: Average seasonal aerobic HPC

4.3.1.2 Anaerobic HPC

The anaerobic HPC also showed a gradual decrease from spring with 90 x 10^3 ± 92.3 cfu/ml to 11 x 10^3 ± 1.41 cfu/ml in winter. were for the same sample gave the highest counts during spring, followed by autumn, summer and almost disappearing in winter. The Taaibosch Spruit samples (figure 13) present a different picture with a gradual decrease from spring to winter for aerobic HPC and the aerobes were consistently higher than anaerobes for both sampling points showing that the system never became anoxic.

The anaerobe counts (figure 13) did not differ much throughout the seasons and the highest count for aerobes were obtained from the Taaibosch sampling point spring sample. The counts from Paddabaai samples however were higher than Taaibosch counts for the rest of the seasons.

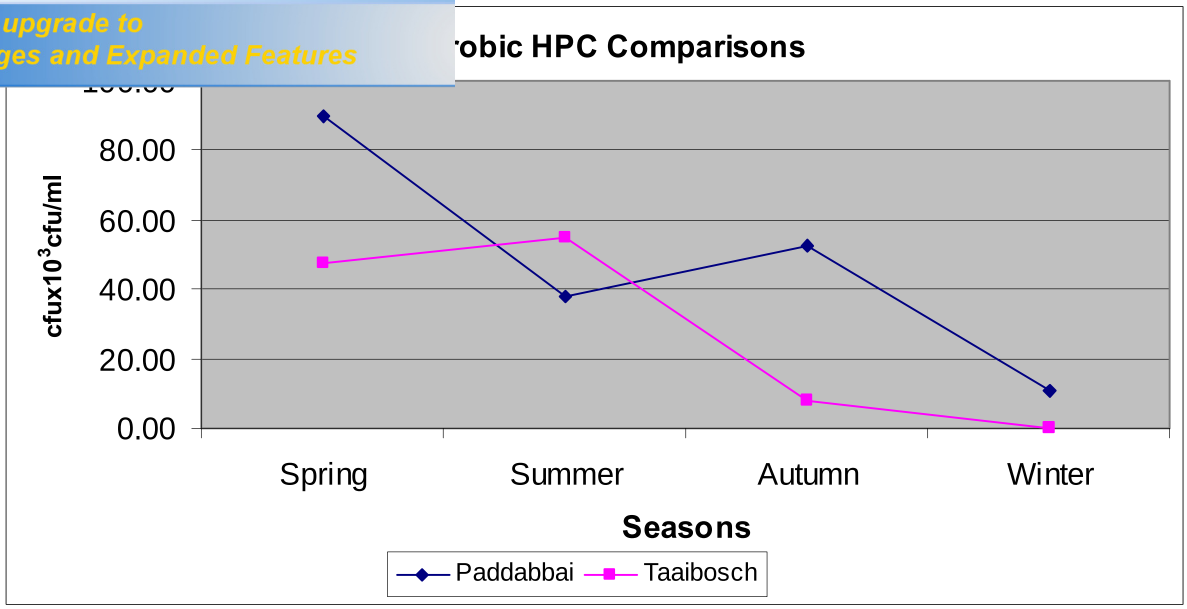

Figure13: Average seasonal anaerobic HPC

4.3.2 Coliforms.

The total and fecal coliforms were selected because they are generally accepted as indicators of fecal pollution of the water (DWAF 1996b: 38).

4.3.2.1 Total Coliforms (TC)

Average TC counts (see figure 14) were generally similar for the Paddabaai samples for all the seasons with no significant differences. The counts varied from 1.5 x 10^3 ± 15874 in summer to 30 x 10^3 ± 37434 cfu/ml in autumn with great intra-seasonal variations being observed. Taaibosch Spruit experienced counts were higher than Paddabaai during spring at 81 x 10^3 ± 33151 cfu/ml. There was however a significant decrease for the other seasons with the lowest of 0.5 x 10^3 cfu/ml in winter.

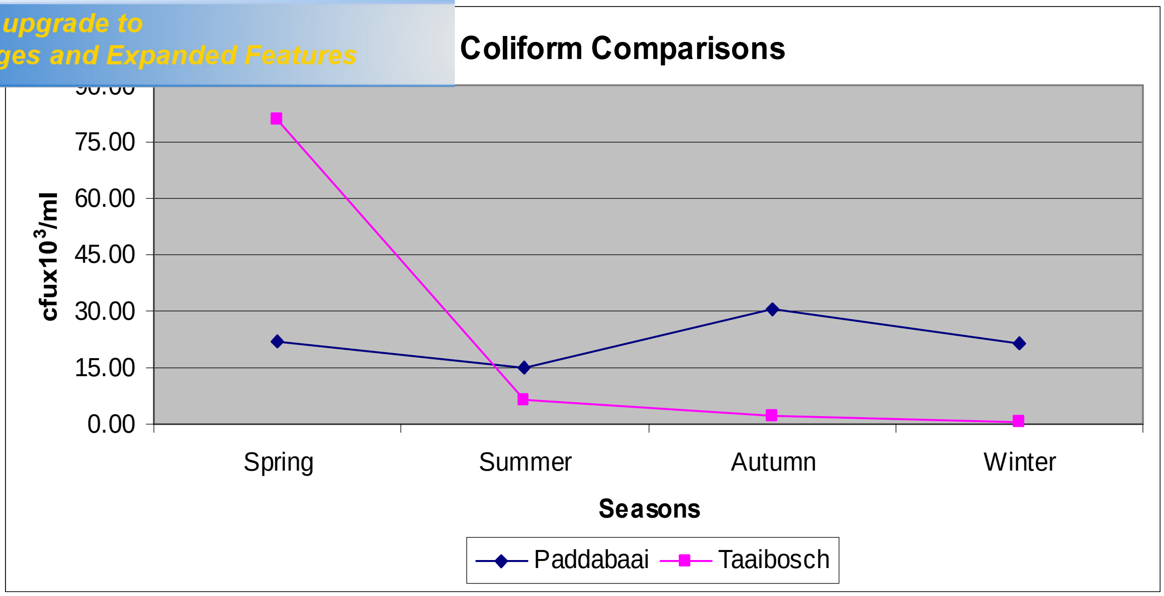

Figure 14: Average seasonal total coliform counts

4.3.2 The fecal coliforms (FC)

Higher FC averages were obtained during spring for both sampling points. Paddabaai spring samples produced an average of 20 x 10^3 ± 17 cfu/ml and the averages from Taaibosch Spruit were 36.6 x 10^3 ± 39.4 cfu/ml. The slight increase from Paddabaai to Taaibosch Spruit though not statistically significant, raises the concern about the source of coliforms between the sampling points in that particular period. The lowest average of 0.67 x 10^3 ± 0.58 cfu/ml for Paddabaai was obtained during winter whilst no growth was observed during summer for Taaibosch Spruit.

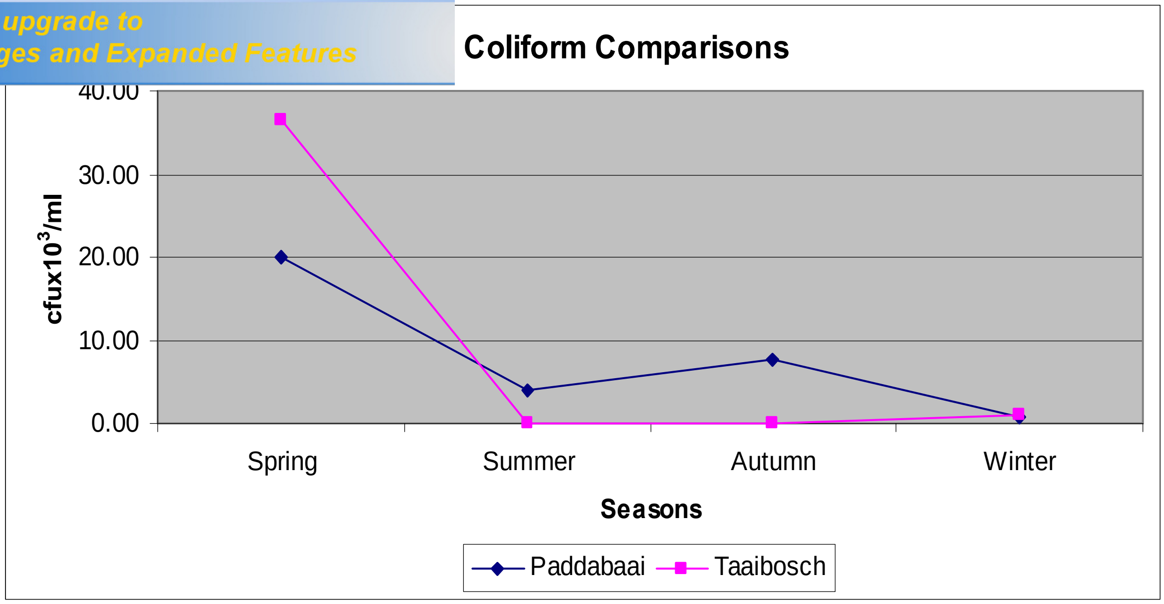

Figure 15: Average seasonal fecal coliform counts

4.3.2.2 Pseudomonads counts

Highest counts at 5.03 x 10^3 cfu/ml were obtained at Paddabaai during autumn with summer having the lowest at 0.47 x 10^3 ± 0.5 cfu/ml. Taaibosch Spruit showed an increase from spring (0.25 x 10^3 ± 0.5 cfu/ml) to summer (2.33 x 10^3 ± 4.04 cfu/ml) followed by a gradual decrease towards autumn and winter.

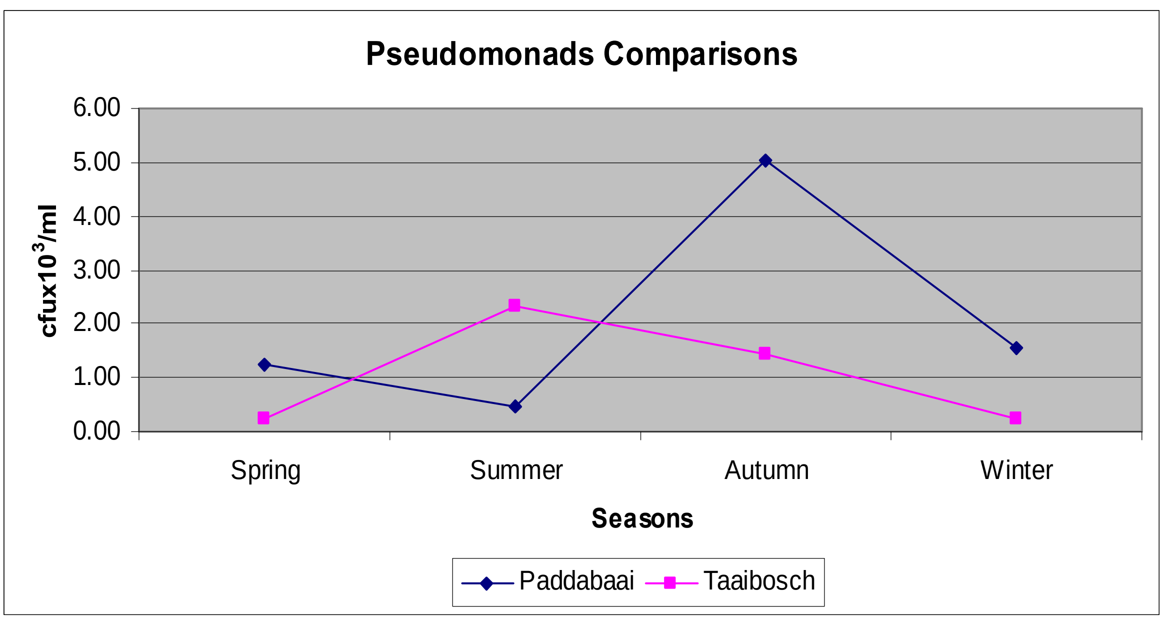

Figure 16: Average seasonal pseudomonad counts

during spring, autumn and winter for the two sampling points. The summer averages were slightly higher at Paddabaai than Taaibosch Spruit whilst a similar pattern with reduction in numbers from autumn to winter was observed at both sampling points.

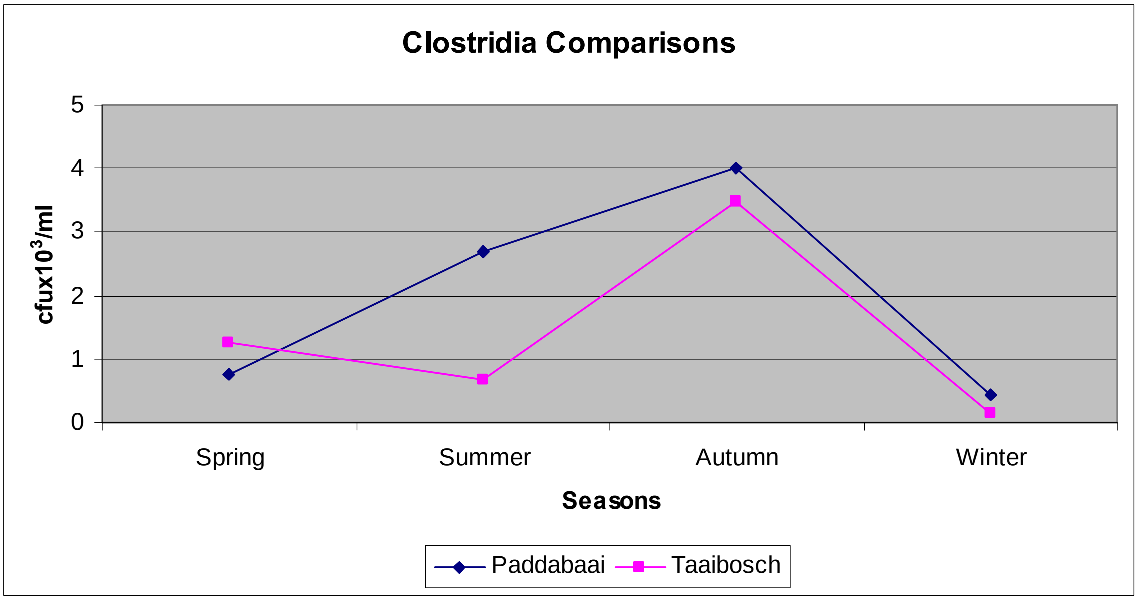

Figure 17: Average seasonal clostridia counts

Summary of bacterial studies

Higher aerobic & anaerobic HPC and TC were obtained during spring at both sampling points with Taaibosch Spruit having the higher of the two. Anaerobic HPC showed highest counts during spring at Paddabaai sampling points whilst Taaibosch Spruit had higher counts during autumn. Taaibosch Spruit had higher counts for TC during spring. The pseudomonads and clostridia showed higher counts during autumn at Paddabaai whilst Taaibosch Spruit had higher psedomonads average counts during summer and clostridia during autumn.

4.4 ALGAL STUDIES

4.4.1 Algal Growth curves

The aim of performing the algal bioassays was to determine the pollution potential (inhibition or stimulation of growth) in the water samples on the growth *capricornutum*. A physiologically active culture of to different concentrations of the water samples and the algal growth medium (culturing medium for Algal ToxKit F^{TM} tests) from 0 percent to 80 % in duplicates (see table 2 under methods). The cuvettes were incubated for 144 hours on a light bench. Absorbance readings of the different mixtures were taken on the spectrophotometer at 670 nm every 24 hours.

Growth curves (Figures 18 -25) were plotted using average absorbance readings against time for each season and sampling points. Growth at different concentrations was compared to the average controls. Concentrations showing growth curves running below the control were regarded as having a potential to inhibit growth and those above controls were regarded as having a stimulation potential. To avoid cluttering the growth curves with too much data, only 0, 20, 40, 60 & 80 % concentrations were used in plotting the graphs. This was possible as it did not detract from the conclusions that can be drawn from the work.

4.4.1.1 Spring (figure 18 & 19)

Stimulation potential was observed at 40 % for the entire incubation period with the rest of the concentrations showing a pattern similar to the control growth curve for the Paddabaai sample. Taaibosch Spruit sample showed initial inhibition at 20 and 40 % concentrations with both increasing gradually after 48 hours. The culture at 80 % concentration reached the stationary phase after 96 hours. Variations were observed from the different growth curves although not statistically significant.

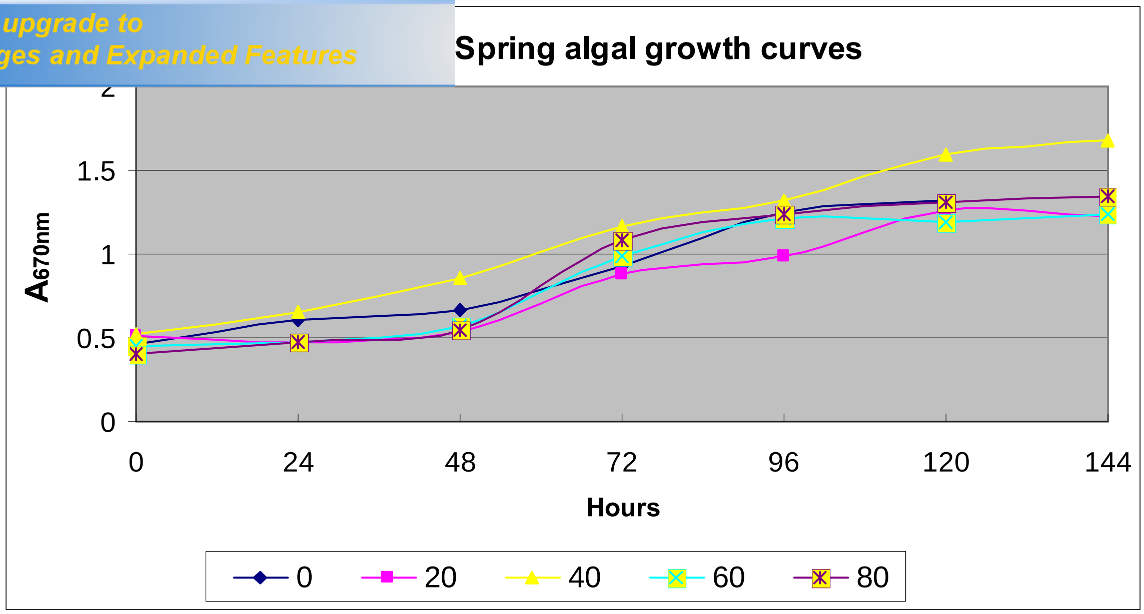

Figure 18: Paddabaai Spring Algal growth curves

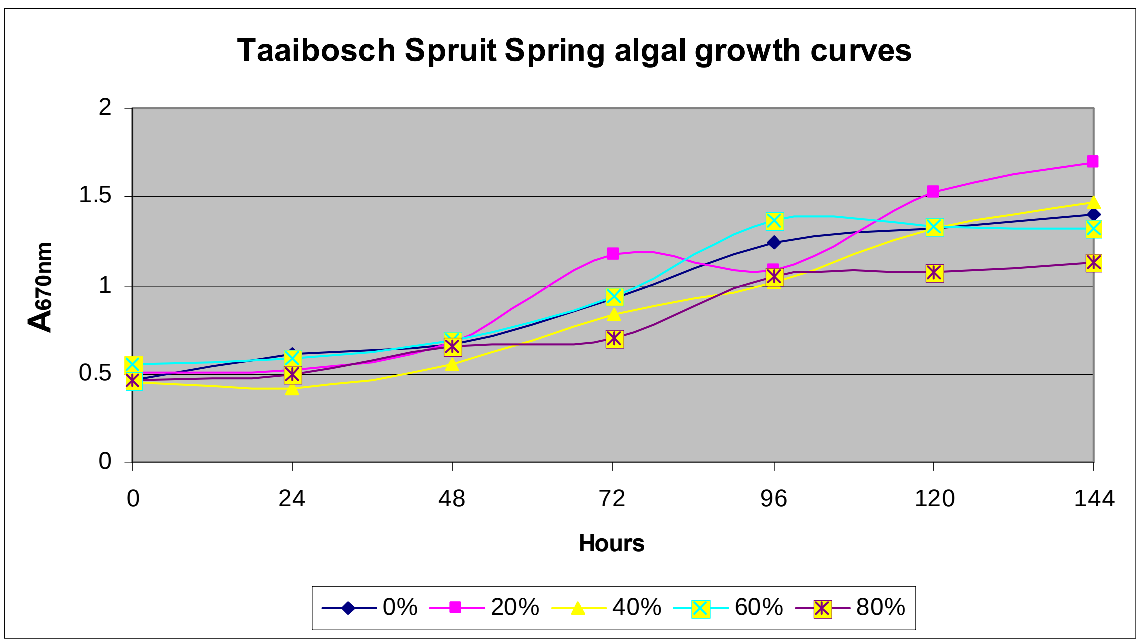

Figure 19: Taaibosch Spruit Spring Algal growth curves

4.4.1.2 Summer (Figures 20 & 21)

Inhibition was observed for the first 72 hours after which stimulation occurred and the culture reached a stationary phase with all the concentration slightly above the control for Paddabaai samples. Taaibosch Spruit samples showed inhibition initially with stimulation occurring after 48 hours and not 72 hours as was

…oition however, continued at 80 % for the entire …npling points. The differences observed in the sample graphs were not statistically significant at 5 % level of significance.

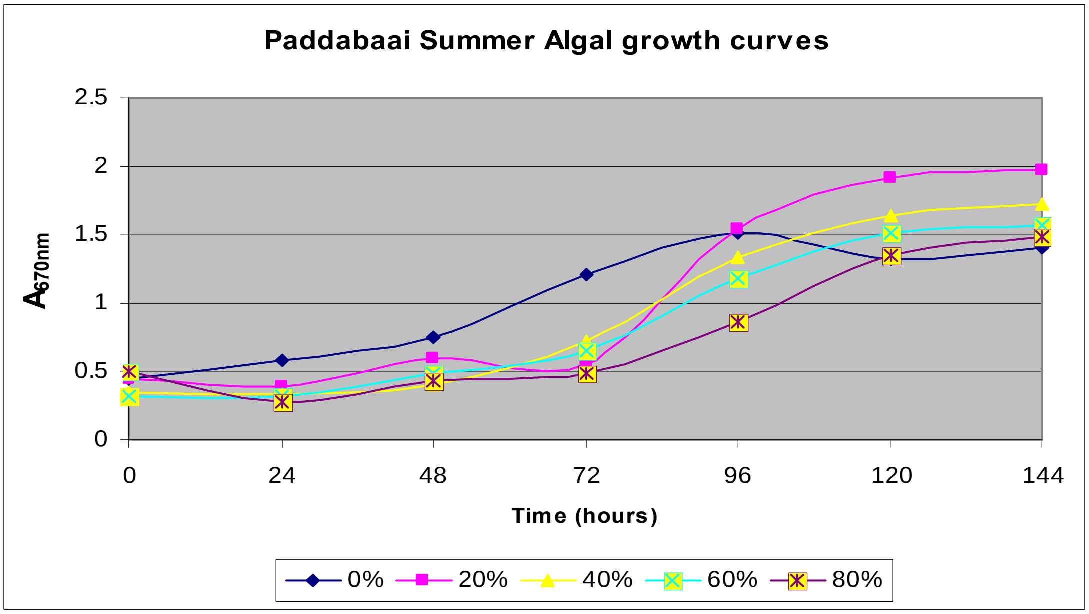

Figure 20: Paddabaai Summer Algal growth curves

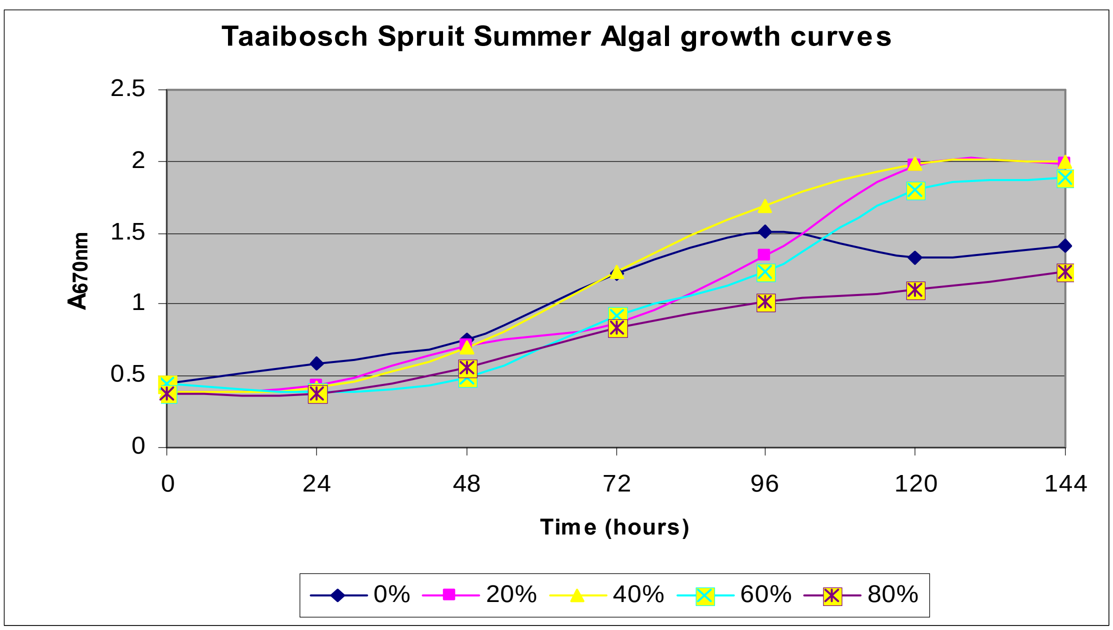

Figure 21: Taaibosch Spruit Summer Algal growth curves

A brief period of stimulation was observed followed by inhibition after 24 hours of incubation for the 20, 60 and 80 % concentrations with Paddabaai samples. The inhibition potential of Paddabaai samples was more evident from first few hours of incubation with the 40 % concentration and this remained unchanged for the whole incubation period, something which also had an effect at 20 %. Slight stimulation/recovery was observed with 60 and 80 % after 96 hours with the curves approaching controls. The inhibition pattern observed with the Paddabaai samples after 24 hours continued at Taaibosch samples with the only difference being that a gradual increase or stimulation occurred with the 80 and not 60 %. The average growth for autumn for Taaibosch is significantly less (5 % level of significance) than the average concentration for autumn for Paddabaai.

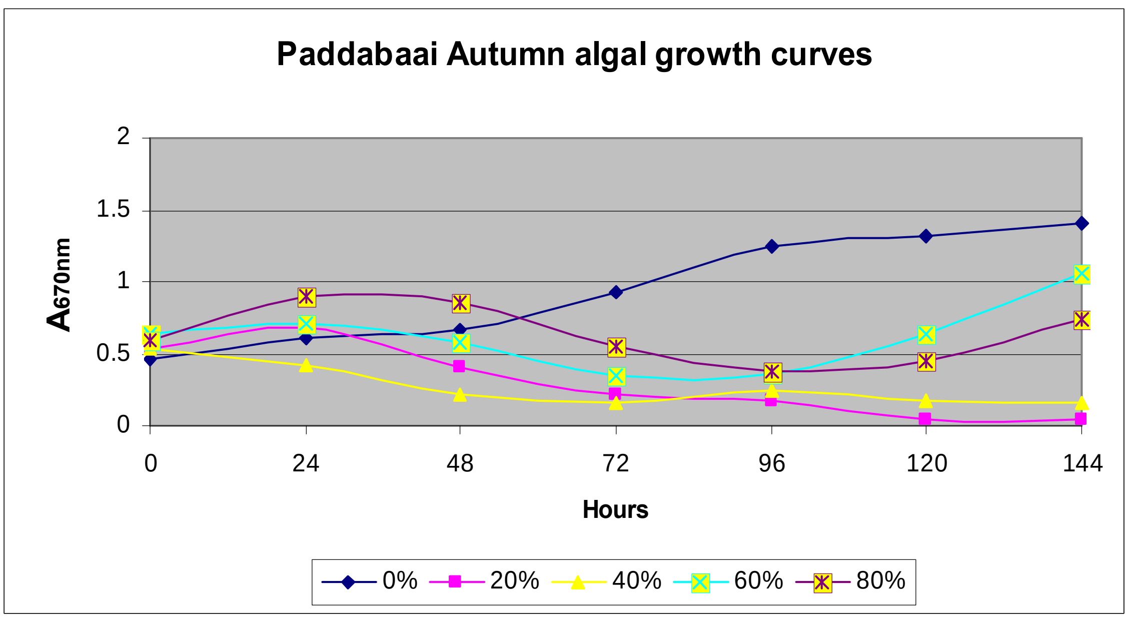

Figure 22: Paddabaai Autumn Algal growth curves

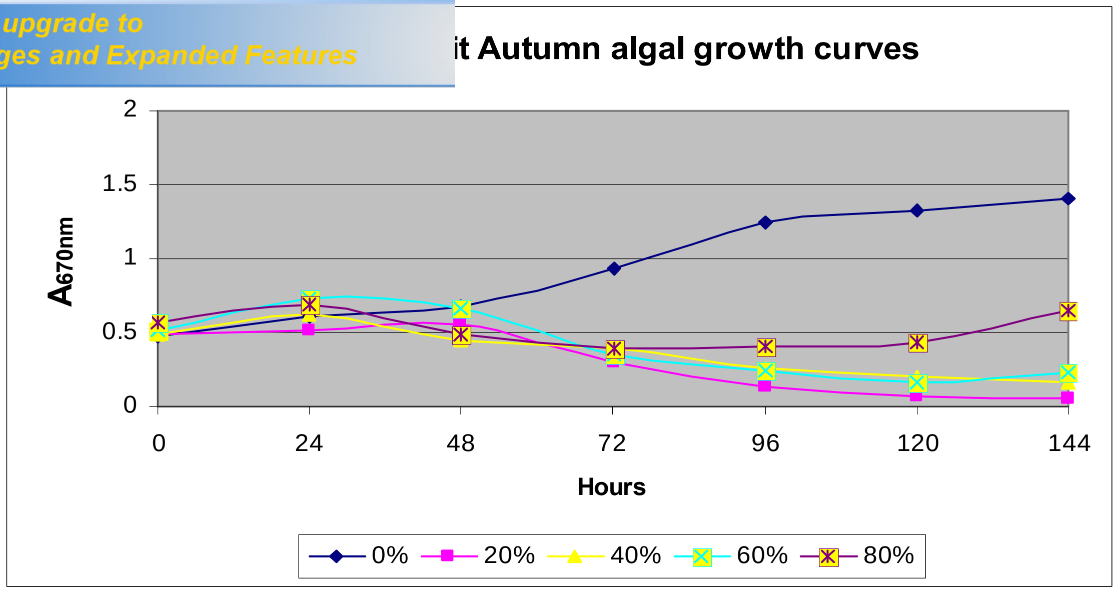

Figure 23: Taaibosch Spruit Autumn Algal growth curves

4.4.1.4 Winter (Figure 24 & 25)

Padaabaai growth curves were much closer to the control with little variations between different concentrations and slight stimulation towards the end of the incubation at 40, 60 and 80 %. Taaibosch Spruit showed initial stimulation at 60 and 80 % for the first 48 hours and again after 120 hours with inhibition in the middle of the incubation period. A steady increase was observed at 40 % for the whole incubation period. The results showed average algal growth for Taaibosch Spruit that was significantly lower than growth with Paddabaai sample dilutions.

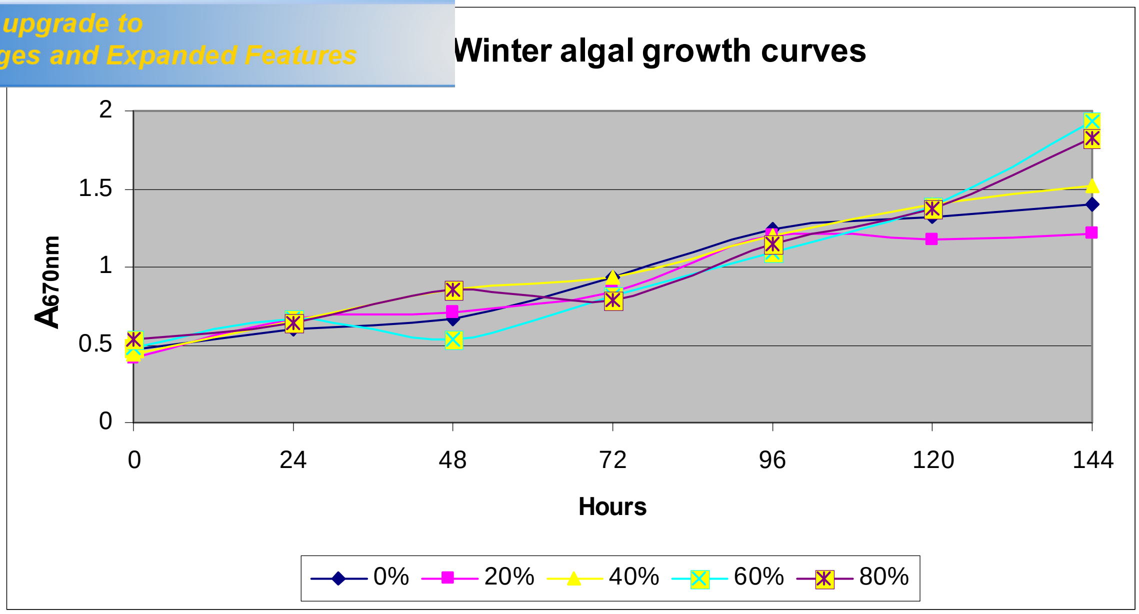

Figure 24: Paddabaai winter algal growth curves

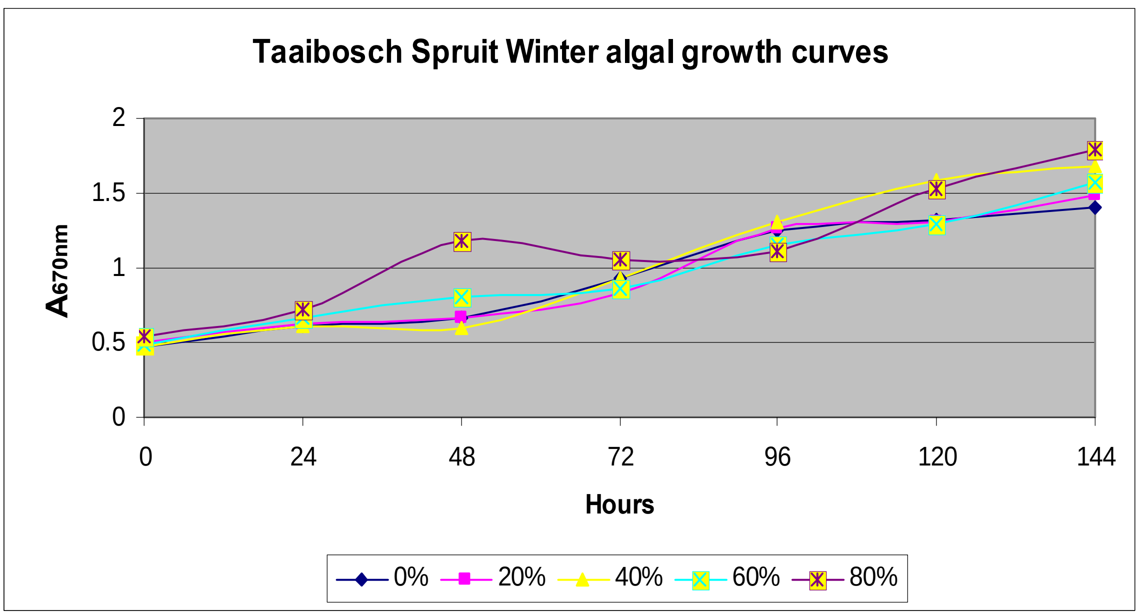

Figure 25: Taaibosch Spruit winter algal growth curves

4.4.1.5 Summary of algal bioassay results

The Paddabaai sample showed stimulation of the algae when the spring samples were diluted to 40 %. The potential to cause inhibition was observed in the initial stages of incubation with 20 and 40 % concentrations of Taaibosch Spruit which changed to stimulation after 48 hours. Samples taken in summer showed ning of the incubation period, a situation which urs Taaibosch Spruit and Paddabaai samples respectively with the exception of the 80 % concentration for both sampling points. No significant differences were obtained between the two sampling points for spring and summer. Autumn samples showed inhibition after 24 hours with some stimulation later on during the incubation period for some of the concentrations e.g. 60 % and 80 % for Paddabaai and 80 % for Taaibosch Spruit with lower concentrations showing constant inhibition throughout. Samples taken during the winter months had initial simulation potential for the 60 and 80 % concentration which stabilized somewhat after 48 hours. The algal growth showed significantly less growth when exposed to Taaibosch Spruit samples than Paddabaai samples during autumn and winter. It would seem that there are changes occurring within the watercourse to result in the effects alternating between inhibition and stimulation of the indicator algae and a proper understanding of such would make for an interesting study in future. The influence of the annual cleaning at the Paddabaai channels would also require a proper study.

4.4.2 Chlorophyll *a* measurements.

Chlorophyll *a* averages for Paddabaai increased steadily from spring at 15.27 ± 6.6 µg/L to autumn with the highest level of 126.05 ± 48.5 µg/L. This was followed by a decrease from autumn to winter. Taaibosch Spruit also experienced the lowest level of 3.8 ± 3.29 µg/L during spring with the highest level of 72.53 ± 56.56 µg/L being measured in summer. The autumn results showed statistically significant differences between Paddabaai and Taaibosch Spruit with Taaibosch Spruit having a lower average.

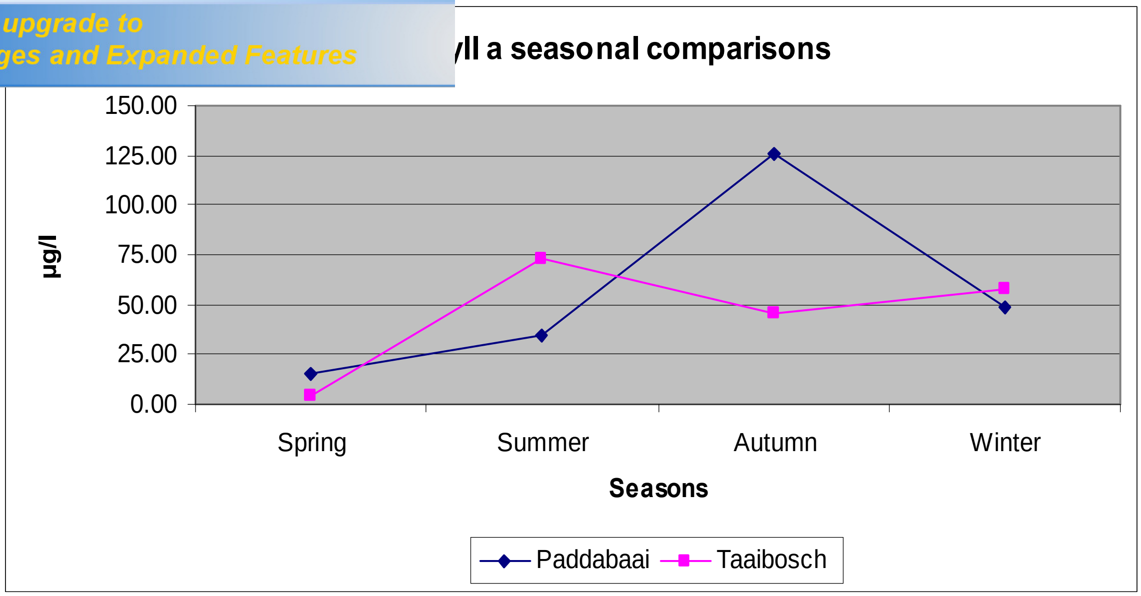

Figure 26: Chlorophyll a seasonal averages

DISCUSSION

5.1 Introduction

This study set out to determine the impact of storm water from the NATREF refinery on the Taaibosch Spruit The study area received a total of 343.5 mm of rain during spring and summer which added up to 75 % of the total 458 mm for the year between August 2007 and July 2008. The average seasonal temperature and the alkaline pH at the Paddabaai sampling point were both always at a higher level than that at Taaibosch Spruit sampling point. TDS averages at Paddabaai sampling point were the highest during the summer whilst the nitrates were higher during autumn and phosphates during summer.

The averages for the aerobic HPC, TC, FC and clostridia were higher at the Taaibosch Spruit during spring. The trend of the average bacterial count declining from either summer or autumn to winter was also observed. The test for potential of the water to either stimulate or inhibit algae showed various degrees of initial inhibition or stimulation followed by the reverse with some concentrations showing outright inhibition. The effect of the water on the algae was not significantly different for the two sampling points during spring and summer. Autumn and winter samples on the other hand, showed less algal growth for Taaibosch Spruit than Paddabaai. The influence of environmental and chemical parameters on bacterial and algal growth was studied through the use of correlation coefficients and comparisons of the measured variables to the DWAF guidelines were presented.

5.2 The influence of physical parameters

5.2.1 Rainfall

The study area received the bulk of the rainfall during spring and summer with spring experiencing the higher of the two. The chemical parameters showed higher averages for phosphates and TDS during summer with higher DO averages being measured during both spring and summer.

erobic and anaerobic HPC and fecal coliforms were higher during spring than other seasons for both sampling points. The runoff during rain storms adds allochthonous material into the water (Hill *et al.* 2006:114-117; Karlavicience *et al*. 2008:1-7) which may have a positive or negative effect on the enzyme activity and microbial growth depending on the type of those materials (Wutor *et al.* 2007:107-110). Correlation studies between rainfall and aerobic HPC for Paddabaai samples produced a positive correlation of 1.0 during summer whereas -0.41 and -0.60 were obtained for spring and autumn respectively. In the case of Taaibosch Spruit a positive correlation of 0.4 was obtained during autumn and negative correlation coefficients were found for spring and summer. There was no correlation between rainfall and winter samples.

The algal bioassays for spring and summer and both sampling points showed initial inhibition followed by stimulation to the point where the growth curves for the different concentrations moved close to the control. The winter (zero rainfall) growth curves however, do not show much inhibition observed from the autumn growth curves. This implies that changes in some other factor(s) in addition to the rainfall may have contributed to these results. It would be interesting to analyses the water at these different times in the study to determine such changes.

Higher chlorophyll *a* was measured during autumn for Paddabaai and summer for Taaibosch Spruit with lowest obtained during spring for both sampling points indicating therefore that rainfall did not have a definite influence on the algal biomass in the water. This was also observed in having both negative and positive correlation factors for the different seasons (see table 3-5 annexure).

he highest level during summer, with spring and autumn having relatively similar temperatures and winter the lowest for both sampling points. The temperature at the Taaibosch Spruit was always lower than at Paddabaai. Higher TDS and phosphates were recorded during summer whilst nitrates were higher during autumn. Temperature is important because of the way in which it influences the chemistry of the water in general. The rate of chemical reactions is expected to increase with an increase in temperature (DWAF 1996c:103-106; Dickens *et al.* 2008: xii). One additional way in which temperature has an influence on the water chemistry is through its direct impact on oxygen. Less oxygen is held by the water at higher temperatures than cool water, thus the saturation may be higher but it may not necessarily contain enough oxygen for the survival of aquatic life (DWAF 1996c:103-106).

None of the bacterial types showed an higher growth during summer as would have been expected especially for Paddabaai (25.26 ęC ± 3.03) since reactions rates are expected to increase at warmer temperatures due to increases in enzyme activity (Wutor *et al.* 2007:107-110). This held true for aerobic HPC obtained from Paddabaai samples since a negative correlation coefficient of 0.22 was found although the other groups of bacteria correlated positively with temperature for the same season. A decrease in water temperatures from autumn to winter on the other hand, was accompanied by a decrease in growth for all bacterial types at both sampling points as the enzymes got denatured leading to a reduction in numbers (Wiley *et al.* 2008:668) and this was supported by positive correlations for those seasons with the exception of autumn FC averages from both sampling points. Furthermore, the toxicity of certain compounds is increased at higher temperatures (DWAF 1996c:103-106) something which had an overriding effect on microbial growth in this study. The toxic effect of chemicals in summer was also observed to a greater extent on the algae with inhibition occurring for the first 72 hours as well as being more pronounced at higher concentrations of the water samples something which did vas the same for naturally occurring algae since rm of chlorophyll a was lower during summer at Paddabaai with an improvement being observed at the Taaibosch Spruit.

5.2.3 pH

The higher average pH level of the storm water showed no major changes throughout the study period (figure 8). According to Wiley *et al.* (2008:668) pH is influenced by factors such as the nature of the inflow and the rate at which carbon dioxide is removed by photosynthetic organisms, the presence of which was indicated by algal biomass determined through chlorophyll a in figure 22. In the absence of this removal, carbon dioxide combines with water to form a weak acid called carbonic acid which would have lowered the pH of the water. The pH is also affected by temperature, the concentration of organic and inorganic ions, and general biological activity. The pH in turn affects the availability and toxicity of components such as trace metals and non-metallic ions such as ammonium, amongst others. Ammonium ions are converted to the highly toxic un-ionized ammonia at pH levels above 8 (DWAF 1996c:87). The rate of change in pH is affected by the buffering capacity in aquatic systems. If the water is poorly buffered, the pH can change rapidly, thereby having severe effects on the aquatic biota which in turn deteriorates the whole water chemistry (DWAF 1996c:87; Karafistan & Arik-Colakoglu 2003:127-143). The target range for water quality for domestic water use on the other hand, is set at between 6 and 9 (DWAF 1996a:131) whilst Paddabaai pH was between 8.65 and 9.2 and Taaibosch Spruit 7.3 to 8.3. The water with that pH is not expected to produce any significant negative effects on health due to dissolved metallic ions or the taste. The different metals with the exception of manganese do not dissolve readily unless there are complexing agents present in the water. The water tastes bitter at pH levels above 9 and would cause severe health effects at pH levels above 11 (DWAF 1996a:131). The pH of the water in the Vaal River was significantly influenced by the chlorophyll concentration in the water because the ing the day increases the pH due to the release WAF 2009:242).

A combination of positive and negative correlation coefficients were obtained for the different groups of bacteria which indicated that pH did not have any significant effects on the growth of bacteria.

5.2.4 The influence of chemical parameters

5.2.4.1 Dissolved oxygen (DO)

The average DO (figure 9) levels were higher during spring and summer at 9.7 ± 3.43 and 10.2 ± 7.00 mg/L respectively with the lowest of 6.2 ± 0.68 mg/L measured in autumn. The target range set in the aquatic ecosystem guidelines is at 80 to 120 percent saturation (DWAF 1996c:56). This brings the DO level to an average of between 8 and 11 mg/L. These measurements are in agreement with the study averages for spring and summer. These levels are suitable for the protection of all life stages of aquatic biota that is adapted to growing in warm and aerobic environments. Dissolved Oxygen values below 40 % saturation are likely to cause toxic effects to aquatic biota (DWAF 1996c:56).

The lower levels of DO obtained during autumn and winter could have been caused by the fact that warmer summer temperatures speed up the rate of photosynthesis and decomposition. Decomposition occurs as the organisms die at the end of their active season; a process which results in oxygen being heavily consumed, hence the lower DO level during autumn and winter. The other variation is caused by rate of in and outflow (DWAF 1996c:56). The storm water runoff delivering oxygen demanding substances to a stream is an effect which may be felt downstream where the actual decomposition occurs resulting in lower DO, a parameter which could not be measured in this study and is seen as an essential part of a future study.

(TDS)

s (figure 9) showed the highest average of 1017 ± 1011 mg/L during summer to the lowest of 405 ± 9.23 mg/L recorded during autumn. According to DWAF (1996a:170), an average of between 0 and 450 mg/L produces a slight salty taste although no negative health effects are observed. An increase in TDS to averages above 1000 mg/L (up to maximum 2000) on the other hand, would have a marked salty taste although still not expected to have any serious health effects in the short term.

There is accumulation of the salts as the water moves downstream because of the continuous addition through natural and anthropogenic sources. There is also very little of the salts that are being removed through precipitation or natural processes. The examples of the types of sources that may contribute to the higher TDS include; urban runoff, domestic and industrial discharges and cultivated areas (DWAF 1996c:108-111). According to Wimberley & Coleman 1993:325-330) the higher TDS levels at a point inflow during rainfall is an indication of pollutant build up on the surface of catchment or a possibility of infiltration into the soil followed by percolation into ground water. The pollutants would be carried out of the catchment as the storms continue and during dry weather flows which would account for the high TDS levels reported in the Vaal River and other South African rivers in general (WRC 2001:36).

The effects of TDS are controlled largely by the constituent inorganic salts of the water. The proportional concentrations of the major ions determine the buffering capacity of the water which in turn has an influence on the metabolism of organisms. The secondary effects on the water chemistry are then observed in the fate of and impact on other chemical components and/or contaminants. The adaptations of individual species, the overall community structure and microbial and ecological processes such as the rates of metabolism and nutrient cycling results are influenced by the resultant changes in TDS measurements (DWAF 1996c:108-111).

served in summer when TDS was at the highest level of 1017 ± 1011 mg/L. Positive correlations were found between TDS and aerobic HPC whereas TC and FC gave negative correlations during summer. Although there were no significant difference in TDS levels, spring showed higher counts for aerobic HPC and FC although the same cannot be said for the counts obtained during autumn and winter when a slight increase in TDS from 405 ± 9.23 to 626 ± 69 mg/L produced the lowest counts in the bacteria. Pseudomonads autumn averages correlated with TDS averages whereas clostridia showed positive correlation coefficients with autumn and winter TDS averages only. This therefore means that a different parameter such as temperature and not necessarily TDS may have had a greater influence on bacterial activities as mentioned earlier in the text. The algal biomass was lower when the TDS was higher showed inhibition of for the first 72 hours and was more pronounced at higher concentrations with the same being observed for algal biomass. In summary, the higher TDS levels were higher than the target set by DWAF and the storm water would thus add to an already high TDS in the Vaal River as reported in a WRC report (1999:36). Chlorophyll *a* was higher during spring when TDS was at lowest level of 405 ± 9.23 mg/L.

5.2.4.3 Nitrates and phosphates

Higher nitrate average of 59.77 ± 5.31 mg/L was measured during autumn with the lowest of 27.53 ± 13.26 mg/L measured during winter. Phosphates were higher during summer with an average of 5.29 ± 6.6 mg/L. The average concentration of nitrates was found to be consistently higher than that for phosphates throughout the study period. According to Horne & Goldman (1994:152), phosphates accumulate in winter and become reduced in spring to less than the averages necessary for phytoplankton growth. The remaining phosphorus compounds that are taken up by algae continue to be recycled in part through the excretion by bacteria over the rest of the year. Phosphorus is also the most common growth limiting factor for phytoplankton because it is trations. A higher amount of the phosphorus is s within and along the watercourse than nitrogen (Horne & Goldman 1994:133).

Inorganic nitrogen is one of the most important elements which is not always available in adequate amounts in rivers and streams and as such may be a limiting factor for plants and algae (Horne & Goldman 1994:133). This is because inorganic nitrogen is rapidly taken up by aquatic plants and converted into proteins and other organic forms of nitrogen in plant cells (DWAF 1996a:81-83). This situation may be worsened by the presence of large amounts of phosphorus such as when pollution causes an increase in phosphorus relative to nitrogen (Horne & Goldman 1994:133), something which did not seem to be an important factor in this study. The averages for nitrate and phosphate in storm water are influenced by a number of factors such as; the time interval between rainfall events, with longer intervals allowing more of the nutrients to be deposited on impervious surfaces before they are washed off by storm water (DWAF 2009:242).

The processes of volatilization, nitrification and denitrification are expected to be higher in summer than winter due to their dependence on temperature. Furthermore the nitrate and phosphate in storm water are influenced by the time interval between rainfall events, with longer intervals allowing more of the nutrients to be deposited on impervious surfaces before they are washed off by storm water (Dillon & Chanton 2005:62-69). Grobler *et al.* (1987:15-22), also reported that resuspension and not chemical release is the dominant method of returning the pollutants to the water column. It may therefore be a worthwhile exercise to study the influence of the sediment in this storm water as a follow up to this study.

In addition to temperature, the overall concentration of inorganic nitrogen present in water is influenced by pH and the availability of oxygen (DWAF 1996c:81-83).

expected from the higher phosphate level of 6.6 g summer (DWAF 1996c:97) was not observed and instead inhibition was the main result obtained from algal bioassays in this study. This implies the presence of an inhibitory compound(s) in the storm water

5.2.4.4 Comparison of chemical results to TWQR (DWAF)

Nitrates averages ranged 27.4 to 59.7 mg/L and according to DWAF (1996c: 84 & 98) water with levels higher than 10 mg/L especially in summer are regarded to be Hypertrophic with high productivity within system and blooms due to blue green algae including those toxic to humans and animals. Furthermore, these concentrations should not be allowed to increase by more than 15 % and the trophic status of the water body should not increase above the current level. Phosphate level of 6.6 ± 5.29 mg/L is summer falls within a 5 to 25 mg/L range classified as having mesotrophic conditions which could result in algal blooms (DWAF 1996c: 84). This therefore, renders the water quality unacceptable and calls for some management process to reduce the two nutrients.

5.3 Bacterial studies

5.3.1 Summary of bacterial studies

Higher aerobic & anaerobic HPC, TC and FC were obtained during spring at both sampling points with Taaibosch Spruit at a higher level than Paddabaai. Anaerobic HPC showed highest counts during spring only at Paddabaai sampling points. Taaibosch Spruit had higher counts for TC at the Taaibosch Spruit whilst FC were higher during spring at both sampling points. This was due to the fact that as the temperature increases from the lowest level during winter to the higher level in spring and summer, so do the rates of chemical reactions along with the general metabolism and the growth of microorganisms (Wiley *et al.* 2008:136). Burton & Pitt (2002:83) showed that when the surface area of a drainage basin is largely paved, the bacterial concentrations are expected to be at the highest level at the beginning of the rainfall and then undergo a decrease as the rainfall events continue. The higher flow of water during storm (rainfall) vash of sediments that are contaminated from secondary pollution and the resultant increase of the microbial load and coliforms in particular (Hill *et al.* 2006: 114-117; Karlavicience *et al.* 2008:1-7).

There are several natural processes in aquatic systems such as sedimentation, adsorption, coagulation and flocculation that may cause the presence of fecal coliforms in water. These may either remove the microorganisms from the water without inactivation or offer them protection against inactivation. The subsequent release through the different processes may be responsible for the apparent increase in numbers of microorganisms (DWAF 1996b:34-36).

The availability of sufficient nutrients and temperature would also play a major role in the multiplication of indicator organisms in general. The bacteria survive for longer periods when temperatures are lower such as winter than in summer, (DWAF 1996b: 34-36; Burton & Pitt 2001:83; OSRAS 2001:165-172) something that does not lead to higher numbers during autumn and winter due to the insignificant discharges during cold weather (Burton & Pitt 2001:38). The survival of microorganisms in sediments is due to their protection against sunlight and other causes of inactivation (DWAF 1996b: 34-36). It is therefore important to consider the inclusion of sediment analysis in the future. The different factors would account for the higher HPC, TC counts at the point of storm water entry namely the Paddabaai sampling points during the high rainfall seasons of spring and summer although the same could not be said for pseudomonads and clostridia. These showed higher counts during autumn at Paddabaai whilst Taaibosch Spruit had higher pseudomonads average counts during summer and clostridia during autumn.

5.3.2 Comparison of bacterial counts to TWQR (DWAF)

HPC averages observed in the study were greater than level of 10^3 associated with higher risk of disease transmission (DWAF 1996:84). The average coliform counts were higher than the 2000/100ml of fecal coliforms in water is associated waterborne diseases, even from the consumption The exposure to microorganisms including pseudomonads through recreational activities results in secondary infections in wounds, exposed tissue, or individuals with reduced resistance (DWAF 1996b: 33). No TWQR were given for pseudomonads and clostridia.

In light of the above information, the water would not be deemed to be acceptable for the Vaal River and this brings to the fore the importance of highlighting the aspects of pollution prevention since the storm water does not undergo any form of treatment. It would also be necessary to determine the source of these bacteria in the storm water since they have a direct impact on the quality of water.

5.4 Algal studies

5.4.1 Algal bioassays (figures 18- 25)

The Paddabaai sample showed stimulation of the algae when the spring samples were diluted to 40 %. The potential to cause inhibition was observed in the initial stages of incubation with 20 and 40 % concentrations of Taaibosch Spruit which changed to stimulation after 48 hours. Samples taken in summer showed inhibition potential at the beginning of the incubation period, a situation which changed after 48 and 72 hours Taaibosch Spruit and Paddabaai samples respectively with the exception of the 80 % concentration for both sampling points. No significant differences were obtained between the two sampling points for spring and summer. Autumn samples showed inhibition after 24 hours with some stimulation later on during the incubation period for some of the concentrations e.g. 60 and 80 % for Paddabaai and 80 % for Taaibosch Spruit with lower concentrations showing constant inhibition throughout. Samples taken during the winter months had initial simulation potential for the 60 and 80 % concentration which stabilized somewhat after 48 hours. The algal growth showed significantly less growth when exposed to Taaibosch Spruit samples than Paddabaai samples during autumn and winter. It would seem that there are watercourse to result in the effects alternating lation of the indicator algae and a proper understanding of such would make for an interesting study in future.

The higher nitrate and phosphate levels did not produce stimulation of the algae as would have been expected. The inhibition is even more pronounced at the Taaibosch Spruit implying that the change in water quality was strongly felt downstream. This effect however, had disappeared by winter indicating therefore, that the annual cleaning of the Paddabaai channels between April and May did to a certain extent improve the quality of the stream. Another possible factor requiring some exploration is the possibility of the stream having undergone a process called self-purification. Self-purification is the potential of the river to dilute or reduce the unwanted effects of the contaminants discharged into the water. This can be viewed as a powerful tool used by the rivers and streams to manage themselves in a sustainable way (Mehrdadi *et al.* 2006:199-204). This inhibition of the algae is a surprising result especially since high levels of nitrates and phosphates were measured during the study. An unidentified chemical compound was probably the cause of the inhibition and this requires more research.

5.4.2 Chlorophyll *a*

Chlorophyll *a* measurements (figure 26) were done as part of algal studies to provide an estimate of the algal biomass present in the water samples. Chlorophyll *a* measurements for Paddabaai increased steadily from spring to autumn with a drop in winter. The Taaibosch Spruit had the highest average chlorophyll *a* measurements during winter followed by summer and then autumn with the lowest being obtained during spring. The higher summer average correlated positively with the higher nitrate and phosphate levels during that season. The immediate effect of the annual cleaning of the Paddabaai channels during April/May has to be properly studied since it is likely to have caused er and the effects only becoming pronounced

5.4.2.1 Comparison of chlorophyll *a* to TWQR

Chlorophyll a averages of 21 (spring) to 93.5) µg/L (autumn) and 2.85 (spring) to 100 (winter) µg/L at were measured at Paddabaai and Taaibosch Spruit respectively. Levels below 15 µg/L would have negligible nuisance conditions as well as no health effects would be observed. Levels above 30 µg/L however such those measured during summer, autumn and winter at both sampling points, would be associated with severe nuisance conditions, algal growth resulting in scums having an effect on the aesthetic of the water and most importantly, the water would have an effect on the health and types of fish (DWAF 1996b:22).

5.4.3 Summary of the discussion

The pattern of rainfall and temperature variations during the different seasons showed direct influence on some of the parameters. Higher bacterial loads (HPC & FC) were higher in spring when the rains started falling and temperatures increasing from winter and decreasing from summer to winter as was stated earlier. The averages of those bacteria were found to be much higher than the levels set by DWAF and would contribute to water borne diseases being transmitted. The findings highlighted the need for extensive monitoring of the storm water and tracking of the source of these bacteria so that they can be controlled. The toxicity of the different parameters was observed during the warmer seasons of spring and summer in terms of inhibition towards the indicator algae especially at higher concentrations, as well as chlorophyll *a* levels when compared to autumn and winter which experienced little to no rain. This meant that dilution resulting from rain storms was not enough to reduce the toxicity of the water to algae even in the presence of higher nitrate and phosphate. pH averages did not show any major /significant changes throughout the study period and was within the levels expected for natural waters (DWAF 2009:141). The Vaal River is said to be experiencing high TDS levels already and the higher rm water are likely to make the situation even

In conclusion, the storm water from the refinery has the potential to cause pollution of the Taaibosch Spruit especially during the spring and summer as well as when the rainfall is not at its highest level. It is difficult however to draw concrete conclusions on what the impact on the Vaal River would be due to the distance between Taaibosch Spruit and the Vaal River, something which can be addressed in a future study.

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The conclusions drawn from the study were presented in line with the different objectives of the study. The primary aim of the study was to determine the impact of refinery storm water on the receiving environment of Taaibosch Spruit with the following as specific objectives:

6.1.1 Select suitable sampling points in the system

The selection of the sampling points was successful since clear differences and/or similarities could clearly be observed between the two points. The Paddabaai sampling point allowed for the determination of the immediate quality of the storm water flowing from the refinery complex since it is a short distance away. The changes that may have occurred to the quality variables were then properly studied at the second sampling point at the Taaibosch Spruit. This does not however provide conclusive evidence on what the quality of the water reaching the Vaal River would be and therefore warrants a study that would have more sampling points to establish that.

6.1.2 Determine the influence of physical and chemical parameters of storm water on biological parameters

6.1.2.1 Rainfall

The rainfall period increased the numbers of bacteria at the Paddabaai sampling point followed by a reduction at the Taaibosch Spruit sampling point demonstrating the ability to dilute the numbers even though the bacterial load was still higher than the levels stated in the TWQR. The effect on the indicator algae, *S. capricornutum,* showed toxicity in the form of inhibition especially at higher concentrations with growth curves moving closer to the control growth curves during winter. Therefore, dilution would not be a solution for the urban storm water studied here.

amples fluctuated in harmony with the seasonal variations as was expected and did not indicate thermal pollution of the water throughout the study period. The changes in temperature along the seasons showed direct influence on the bacterial populations with much higher counts being observed during spring as the water temperatures were gradually increasing from winter to summer. The pH of the samples was within the acceptable limits of the DWAF guidelines as well for natural water bodies and did not seem to have any major influence on microbial activity.

6.1.2.3 Chemical parameters

There was overall inhibition of *S. capricornutum* in spite of the high nitrate and phosphate level at both sampling points. The inhibition was even more pronounced during autumn. The levels of nitrate and phosphates were higher than the TWQR and these would have an effect on the treatment process. Total dissolved solids on the other hand was within a level that may result in negative health effects to sensitive human population groups and is contributing to the already elevated levels of TDS within the Vaal River complex. No clear correlation was observed between the different bacterial populations and total dissolved solids. The changes in the levels of dissolved oxygen was in agreement with the cycles of multiplication of bacteria and algae during spring and summer that are followed by decomposition during autumn and winter when microorganisms are expected to slow down and die off.

6.1.3 Perform bacterial analysis for indicator and heterotrophic microorganisms

Generally, the counts of bacteria were higher during the spring and summer months than the counts obtained during autumn and winter. These levels were higher than the target set for raw water for both HPC and coliforms at both sampling points even when the rainfall was at its highest during spring. This indicated that temperature played a major role as would have been expected.

nents to the bacteria did not seem to be affected in the literature.

6.1.4 Assess the pollution potential of the storm water on the Taaibosch Spruit with the use algal bioassay techniques

The storm water produced an obvious inhibitory effect which increased quite significantly during autumn with observed recovery by the winter time. This therefore highlighted the need to determine the specific compound in the storm water responsible for the inhibitory effect in spite of the presence of high nitrate. The recovery of the system may also have been brought about by the annual cleaning that is carried out just before winter a process which requires proper understanding and exploration.

6.1.6 The secondary aim, to put forward a management plan to address any concern regarding pollution encountered during this study

On the whole, the water was found to be unacceptable and would most likely have a negative impact on the Vaal River. It would be advisable for the Refinery and the municipality to consider the different aspects pertaining to pollution control in order to minimize the source of nutrients and bacteria into the storm water.

6.1.6.1 The results obtained from the rainfall sample suggests the use of dilution Is definitely not a solution to addressing the toxicity problems. Dilution as a solution is also problematic as a long term solution due to the scarcity of water in South Africa.

6.1.6.2 An alternative solution would be to determine the best methods to use for the removal of the actual chemical variable(s) responsible for the toxicity once it has been identified. Different types of membranes can be placed at the entry point of the Paddabaai channels on a trial basis and the results compared although the issue of fouling has to be considered (WRC 1999:36).

ich is currently carried out on an annual basis does seem to improve the quality of the water and may go a long way towards reducing the pollution potential of the water if carried out twice or more a year. An analysis of the water samples just before and after the cleaning process should also form part of the study.

6.1.6.4 The refinery carries out a six monthly monitoring and analysis of the storm water for coliforms and as observed from the study there is a need for more regular analysis and inclusion of more types so that trends can be picked up and properly followed.

6.2 RECOMMENDATIONS

6.2.1 There is a need for more sampling points within the storm water drainage system before the water gets to the refinery so that the source of the coliforms can be properly studied.

6.2.2 It would also be worthwhile to study the sediments as a possible source of bacteria and nutrients as outlined by United Nations Environment Programme (n.d.: 1-3).

6.2.3 There is a need for an investigation into the influence of the possible cleaning of the Paddabaai channels being carried out more than once a year.

6.2.4 A concerted effort and financial investment have to be made towards educating the public on the importance of storm water, the different ways of preventing pollution and the impact of storm water pollution on quality of river water. This is something that the refinery cannot achieve on its own but requires the involvement of the different departments within the municipality.

ARENSBERG, P., HEMMINGSEN, V.H. & NYHOLM, N. 1995. A Miniscale Algal Toxicity Test. *Chemosphere.* 30 (11)*: 2103-2115.*

AUSTRALIAN ENVIRONMENTAL PROTECTION AGENCY. How does pollution affect us? [Online]. Available at: <http://www.epa.nsw.gov.au/ storm water> Accessed: 20/02/2007.

BARTRAM, J. & BALLANCE, R. Editors. 1996. *Water Quality Monitoring. A practical guide to the design and implementation of freshwater quality studies and monitoring programmes*. London: E & FN SPON.

BEHAR, S. 1997. *Testing the Waters: Chemical and Physical Vital Signs of a River*. River Watch Network.

BURTON, G.A. & PITT, R.E. 2002. *Storm water Effects Handbook.* USA.: CRC Press.

CLOOT, A., SCHOOMBIE, S.W., PIETERSE, A.J.H. & ROOS, J.C. 1992. A note on a light-temperature dependent model for algal blooms in the Vaal River. *Water S.A Vol 18(4):299-302.*

CSUROS, M. 1994. Environmental Sampling and Analysis for Technicians. USA. CRC Press.

DAWSON, D.J. & SARTORY, D.P. 2000. Microbiological Safety of Water. *British Medical Bulletin.* 56 (1) 74-83.

DEPARTMENT OF ENVIRONMENTAL AFFAIRS AND TOURISM. 1999. State of Environment Report: Freshwater Systems and Resources. [Online]. Available at: <http://www.deat.gov.za/soer/nsoer/issues/water/state2.htm>. Accessed: 25/03/2009

...ENTAL AFFAIRS AND TOURISM. 2005. State ... uality. [Online]. Available at: <http://soer.deat.gov.za/themes.aspx?m=50#3133>. Accessed: 7/05/2010

DEPARTMENT OF WATER AFFAIRS AND FORESTRY. 1996a. *South African Water Quality Guidelines. Volume 1: Domestic Water Use* (1st Issue). Pretoria. South Africa.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY. 1996b. *South African Water Quality Guidelines. 2nd edition. Volume 2: Recreational Use.* Pretoria: South Africa.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY. 1996c. *South African Water Quality Guidelines. Volume 7: Aquatic Ecosystems.* Pretoria: South Africa.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY. 2006. Storm water Management. Best Practice Guidelines for Water Resources Protection in the South African Mining Industry. Best Practice Guideline G1.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY. 2009. Directorate National Water Resources Planning. Integrated Quality Management Plan for Vaal River System Task 2:Water Quality Status Assessment of Vaal River Sytem. Report No. PRSA C000/00/23051/1.

DICKENS, C., GRAHAM, M., de WINNAAR, G., HODGSON, K., TIBA, F., SEKWELE, R., SIKHAKHANE, S., de MOOR, F., BARBER-JAMES, H. & VAN NIEKERK, K. 2008. The Impacts of high winter flow releases from an impoundment on in-stream ecological processes. *WRC Report* No 1307/1/08.

DILLON, K.S. & CHANTON, J.P. 2005. Nutrient transformations between rainfall and storm water runoff in an urbanized coastal environment: Sarasota Bay, Florida. *American Society of Limnology and Oceanography.* 50(1):62-69.

Chemistry of Natural Waters. USA. Ann-Arbor

GOOGLE 2010. *Digital Globe*. Europe Technologies.

GROBLER, D.S., TOERIEN, D.F. & ROSSOUW J.N. 1987. A review of sediment/water quality interaction with particular reference to the Vaal River system. *Water S.A.* 13(1):15-22.

HILL, D.D., OWENS, W.E. & TCHOUNWOU, P.B. 2006. The Impact of Rainfall on Fecal Coliform Bacteria in Bayou Dorcheat (North Louisiana). *International Journal of Environmental Research & Public Health.* 39(1) March 2006:114-117.

HOHLS, B.C., SILBERBAUER, M.J., KÜHN, A.L., KEMPSTER, P.L. AND VAN GINKEL, C.E. 2002. National Water Resources Quality Status Report: Inorganic Chemical Water Quality of Surface Water Resources in S.A. The Big Picture. Report No: N/0000REQ0801 Final draft.

HORNE, A.J. & GOLDMAN, C.R. 1994. *Limnology* 2nd Edition. USA. Mac Graw Hill.

JONES, J.G. 2001. Freshwater ecosystems - Structure and Response. *Ecotoxicology and Environmental Safety.* 50:107-113.

KARAFISTAN, A. & ARIK-COLAKOGLU, F. 2003. Physical, Chemical and Microbiological water quality of the Manyas Lake, Turkey. *Mitigation and Adaptation Strategies for Global Change.* 10:127-143.

KARLAVICIENCE, V., SVEDIENE, S., MARCIULIONIENE, D.E., RANDERSON, P., RIMIEKA, M. & HOGLAND, W., 2008. The Impact of storm water runoff on a small urban stream. *Journal of Soil Sediments.* pp 3-7.

KINZELMAN, J., NG, C., JACKSON, E., GRADUS, S. & BAGLEY, R. 2003. Enterococci as Indicators of Lake Michigan Recreational Water Quality:

es and Their Impacts on Public Health. *Applied*
p 92-96.

MADIGAN, M.T., MARTINKO, J.M. & PARKER, J. 2003. BrockôBiology of Microorganisms. 10th edition. USA. Prentice Hall.

MANAHAN, S.E. 2000. Environmental Chemistry. 7th Edition. Florida Lewis Publishers.

MASON, C.F. 1996. Biology of freshwater pollution. 3rd Edition. England. Addison Wesley Longman.

McGHEE, T.G. 1991. Water Supply and Sewerage. International Edition. Singapore: Mac-Graw Hill.

MEHRDADI, N., GHOBADI, M., NASRABADI, T. & HOVEIDI, H. 2006. Evaluation of the Quality and Self Purification Potential of Tajan River using QualE Model*. Iran Journal of Environmental Health Science Engineering.* 3(3): 199-204.

MINNESOTA POLLUTION CONTROL AGENCY. 2008. Addressing fecal coliform impairments in a storm water pollution prevention program. Wq-strm07-07:1-2. [Online]. Available at< http://www.pca.state.mn.us>. Accessed: 21/02/2007.

NATREF REFINERY. 2005. [Online]. Available at: <www.total.co.za/Os/ossouthafrica.nsf>. Accessed: 10/02/2009.

NEVONDO, T.S. & CLOETE, T.E. 1999. Bacterial and chemical quality of water supply in the Dertig village settlement. *Water S.A.* 25(2): 215-220.

NIEMCZYNOWICZ, J. 1999. Urban Hydrology and water management ï present and future challenges. *Urban Water:* 1-14.

Keeping the NATREF refinery running smoothly
eering: 20-23

OSRAS. 2001. Additional information on pathogen transport and survival. Rev A. 165-172. [Online]. Available at: <http://www.dig.nsw.gov.au/Files/SepticSafe/OSRAS_165-172.pdf>. Accessed: 12/09/2008.

OWUSU-ASANTE, Y. & NDIRITU, J. The simple modelling method for storm- and grey-water quality management applied to Alexandra settlement. *Water SA Vol 35(5):615-626.*

PALMER, C.G., BEROLD, R.S. & MULLER, W.J. 2004. *Environmental Water Quality in Water Resources Management*. WRC Report No TT217/04. Water Research Commission. Pretoria: South Africa.

PRESCOTT, L.M., HARLEY, J.P., KLEIN, D.A. 1999. Microbiology. 4th Edition. Boston: McGraw Hill.

RAND WATER. [Online] Available at: http://randwater.co.za/CorporateResponsibility/WWE/Pages/WaterPollution.aspx Accessed: 22/07/2011.

ROUX, D.J., JOOSTE, S.H.J. & MACKAY, H.M. 1996. Substance ï specific water quality criteria for the protection of South African freshwater ecosystems: methods for the derivation and initial results for some inorganic toxic substances. *South African Journal of Science.* 92 (April 1996):198-206.

SAID, M.; le ROUX, W.J.; BURKE, L.; SAID, H.; PAULSEN, L.; VENTER, S.N.; POTGIETER, N.; MASOABI, D. & de WET, C.M.E. 2005. Origin, Fate and Clinical relevance of water-borne pathogens present in surface waters. WRC Report No.f:1398/1/05.

he Sasolburg Chamber of Commerce. [Online]. Available at <http://www.sasolburg.net/>. Accessed : 10/02/2009

STAVELEY, J.P. & SMRCHEK, J.C. YEAR. In BLAISE, C. & FERARD, J.F. (Editors). Small Scale Freshwater Toxicity Investigations. Vol 1. 181-202.

STEYNBERG, M.C., HEATH, R. & VILJOEN, F.C. 1996. *Raw Water Quality* Guidelines for Rand Water. Version 1.

STRYDOM, W.F., HILL, L. & ELOFF, E. (Editors) 2006. *The achievements of the River Health Programme 1994- 2004: A national perspective on the ecological health of selected South African rivers.* Pretoria: South Africa.

UNITED NATIONS ENVIRONMENT PROGRAMME. s.a. *Planning and management of lakes and reservoirs: an integrated approach to eutrophication*. [Online] Available at <http:www.unep.or.jp/ietc/publications/techpublications/techpub-11/1-2-1.asp>

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY. 2006. Performance of Storm water Retention Ponds and Constructed Wetlands in Reducing Microbial Concentration. Washington DC. EPA/600/R-06/102: SEP2006. [Online]. Available at: <http://www.epa.gov/nrmrl/pubs/600r06102.pdf>. Accessed: 12/09/2008.

VAN DONSEL, D.J.; GELDFREICH, E.E. & CLARKE, N.A. 1967. Seasonal variations in survival of indicator bacteria and their contribution to storm-water pollution. *Applied Microbiology* :1362-1370.

VAN VUUREN, L. 2008. Eutrophication. *The Water Wheel*. September/October: 14-17.

SION. 1999. Quality of Domestic water supplies. VRC Report No: TT101/98

WATER RESEARCH COMMISSION. 2001. Quality of Domestic Water Supplies. Volume 1. Assessment Guide. 3rd print. Report No: TT101/98

WATER RESEARCH COMMISSION. 2005. Water and Wastewater Management in the Oil Refining and Re-refining Industry. Report No: TT180/05

WILEY, J.M., SHERWOOD, L.M. & WOOLVERTON, C.J. 2008. Prescott, Harley, and Klein's Microbiology. International Edition. New York: McGraw Hill.

WIMBERLEY, F.R. & COLEMAN, T.J. 1993. The effect of different urban development types on storm water runoff quality: A comparison between two Johannesburg catchments. *Water S.A. Volume 19(4):325-330.*

WUTOR, V.C., TOGO, C.A. & PLETSCHKE, B.I. 2007. Comparison of the direct enzyme assay method with the membrane filtration technique in the qualification and monitoring of microbial indicator organisms- seasonal variations in the activities of coliforms and *E. coli*, temperature and pH. *Water S.A.* Volume 33(1):107-110.

Table 3: Aerobic HPC & environmental factors correlations

	Rainfall		water temp		pH	
Seasons	Paddabaai	Taiibosch	Paddabaai	Taaibosch	Paddabaai	Taaibosch
Spring	-0.41566	-0.34	0.90	0.86	-0.55	-1.00
Summer	1	-0.63	-0.22	0.59	-0.99	0.29
Autumn	-0.60112	0.41	0.82	0.71	0.10	-0.67
Winter	0	0	1	1	-1	1

Table 4: Total coliforms & environmental factors correlations

	rainfall		water temp		pH	
Seasons	Paddabaai	Taiibosch	Paddabaai	Taaibosch	Paddabaai	Taaibosch
Spring	-0.33	-0.71	0.25	0.34	-0.60	-0.97
Summer	-0.87	-0.07	0.06	0.12	-0.99	0.43
Autumn	-0.96	0.92	0.69	-0.70	0.30	-0.75
Winter	1.00	-1.00	-1.00	1.00	1.00	1.00

Table 5: Fecal coliforms & environmental factors correlations

	rainfall		water temp		pH	
Seasons	Paddabaai	Taiibosch	Paddabaai	Taaibosch	Paddabaai	
Spring	0.45	-0.96	0.73	0.75	0.34	-0.97
Summer	-0.64		0.99		-0.03	
Autumn	0.42	-0.81	-0.83	-0.27	0.89	0.95
Winter	0.43	-0.50	1.00	1.00	#DIV/0!	1.00