A WATER RESOURCE QUALITY ASSESSMENT CASE STUDY INVOLVING A PACKAGE PLANT IN MOGALE CITY.

By

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submitted in accordance with the requirements for the degree of

MASTER OF SCIENCE

in the subject

ENVIRONMENTAL SCIENCE

at the

UNIVERSITY OF SOUTH AFRICA

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November 2011

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DECLARATION

I, Karin de Bruyn, declare that this dissertation entitled: "A water resource quality assessment case study involving a package plant in Mogale City" is my own work, and has not been submitted before for any degree or examination and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

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K de Bruyn DATE

ACKNOWLEDGEMENTS

I would like to thank the following people of Mogale City Council for their valuable input and much needed assistance with this research project:

- Mr. Rinus Bouwer who is the Manager of Parks in Mogale City.
- Mr. Stephan Du Toit who is the Mogale City Environmental Protection Specialist.

I would also like to thank Ms Retha Britz who is the Laboratory Manager and Scientific Services Specialist at Mogale City for her input, guidance, assistance, patience and understanding. Ms Retha Britz and the laboratory staff has been an indispensable part of this research project.

I would like to give a sincere thanks to the owners, managers, board members and operating personnel of the research site for their patience, assistance and sharing of their knowledge, without whom, this study would not have been possible.

Then, sincere thanks to Ms Merle Werbeloff for providing the statistical analysis of the data and Ms Gina Walsh, Mr. Marco Alexandre and Mr. Michiel Jonker the freshwater consultants from Ecotone for assisting with the habitat assessment.

I would like to give a special thanks to my Supervisor Prof. Hendrick for all his help, understanding and guidance without whom, this research project would not have been possible. I've learned a great deal from you, not only in research but also in life and appreciate you taking the time and effort to make this possible for me.

I would like to thank my Co-Supervisors: Prof. JB Dewar and Ms. ME Brand, for your valuable input, guidance, understanding and patience. You helped make this research project possible and I appreciate all the hard work and effort you have put into this project. I am honored to have had such a great and skilled team working with me on this research study.

Finally, I would like to thank my family for their support and especially my husband for braving the elements with me during my field work. Thank you for your patience, time and understanding. I would also like to thank my dear friend Ms Liza Theron, you have helped kept me sane throughout this project.

ABSTRACT

Inadequately treated wastewater effluent is harmful to the receiving aquatic environment. Water-borne chemicals and microbial pathogens pose a health risk to anyone living downstream from sewage treatment facilities. This study assessed the effluent from a package plant with a design capacity of 48kℓ/24 hours, servicing 12 household units and a restaurant in Mogale City. Over a 12 month period, fortnightly water samples were collected from ten selected sites including two boreholes, a river and two dams. Standard parameters including physical (pH, EC, temperature, DO and SS), chemical (nutrient concentration) and biological (bacterial counts) were analysed using handheld meters, standard membrane filter techniques and colorimetric methods. One borehole was affected by pathogen and nitrate runoff from an adjacent poultry farm. If regularly monitored, the package plant effectively removed microbes (most samples contained 0 cfu/100mℓ) but above limit COD, ammonia and phosphate was released in the effluent (with maximum values of 322 mg/ℓ, 42.52 mg/ℓ and 7.18 mg/ℓ, respectively). Generally, river and dam water at the site was of good quality.

Key Words: ammonia, aquatic environment, biological parameters, chemical parameters, nitrate, package plant, pathogens, phosphate, physical parameters, wastewater effluent

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GLOSSARY

(Definitions/terms provided in this glossary are contextualized/phrased in terms of this research project. This glossary was prepared from various sources which are listed in the reference list).

Acid: any substance that acts as a proton donor. Substances with a pH less than 7.

Activated sludge systems: a system/treatment process that involves aerobic secondary treatment, sludge/settled solids contains active populations of microorganisms that break down organic matter.

Aeration: introduction of air/oxygen into a system or substance for example with the use of blowers.

Aerobic: having oxygen/air present. Some microorganisms require oxygen to live/grow.

Ammonia: an alkaline compound of nitrogen and hydrogen (NH_3) that can cause environmental problems such as eutrophication when discharged in excess amounts into water bodies.

Anaerobic: when there is no oxygen/air present. Some microorganisms are able to live/grow in an oxygen free environment.

Anecdotal research: research consisting of second hand evidence/personal views/answers to questionnaires of owners, operating personnel and suppliers, rather than experience, knowledge or scientific investigation.

Bacteria: prokaryotic, single celled organisms, lacking nucleus and are able to cause disease.

Biochemical oxygen demand (BOD): a measure of the amount of oxygen required to decompose organic material in a unit volume of water.

Carcinogen: cancer causing agent.

Case study: type of research in which specific detailed data are gathered over a specific period of time about, in this case, package plant effluent quality, system efficiency, management and monitoring, for the purpose of learning more about package plants, which is a relatively new and poorly understood subject.

Chemical analysis: analysis/testing of/for chemicals in water/waste water/effluent samples.

Chemical oxygen demand (COD): the amount of oxygen that is required to completely oxidize the organic matter in a water/waste water sample.

Chlorination: the use of chlorine to disinfect water/waste water.

Cholera: a disease caused by *Vibrio* bacteria, spread through polluted water containing faeces, causing diarrhea and vomiting.

Coagulation: dosing of chemicals followed by rapid mixing to destabilise suspended particles to allow aggregation.

Coliforms: gram negative, lactose fermenting enteric, rod shaped bacteria such as *Escherichia coli*, used as indicator species/organisms of faecal pollution.

Coliphages: these are viruses that infect bacteria/organisms such as *Escherichia coli*.

Comparative analysis: type of analysis which focus on similarities and differences between data e.g. comparing sample results with existing results, comparing study with previous literature and case studies, comparing types of systems etc.

Concentration of coliforms: amount of coliform bacteria present in samples.

Conductivity: measures ability of water to conduct electric current and is directly related to total dissolved solids/ions in water/waste water.

Cryptosporidium: protozoan parasite in the intestines of vertebrates causing diarrhea.

Denitrification: formation of gaseous nitrogen from nitrate or nitrite by microorganisms.

Dissolved oxygen (DO): oxygen in a gaseous form that is dissolved in water, it is important for all aquatic organisms to breathe as well as for certain microorganisms that require oxygen to live.

Domestic waste water: consists of 90% waste water by volume that arises from domestic and commercial activities and premises and may contain sewage. Also includes household waste from washing, bathing and toilets.

Dysentery: infectious disease, inflammation of lower bowels, cause diarrhea.

Ecosystem: a self sustaining and functional system of organisms in their natural community/environment.

Effluent: human excreta, domestic sludge, domestic waste water, grey water or waste water resulting from commercial use and that are discharged after treatment processes.

***Escherichia coli*:** is a bacterium that produces toxins causing diarrhea. Transmission occurs through faecally contaminated food and water. Is also used as indicator organisms of faecal pollution.

Eutrophication: increase in concentration of elements required for life. Increased nutrient loads may lead to population explosion of algae and bacteria that form a dense, opaque layer preventing light penetration through water. Bacteria beneath surface die and decompose, leading to reduced levels of dissolved oxygen in the water and aquatic organism deaths.

Faeces/excreta: these are biological waste products from the digestive tract and urine.

Filter/Filtration: a process by which water/wastewater is allowed to slowly filter through a substance such as sand, rocks or plastic growth media contained in a specific container so as to remove small remaining particles or organisms.

Floatation: a process whereby the flocs are removed from the waste water surface.

Flocculation: waste water is agitated or mixed to promote formation of aggregated or larger particles called flocs**.**

Giardia: flagellate protozoan in intestines of mammals causing diarrhea.

Grab samples: this is a single sample of water/effluent, grabbed/taken at random, at a specific time and a specific place over a specific/short period of time.

Indicator species: species/organisms used to indicate a specific condition/state for example coliform bacteria are used to indicate the presence and degree of faecal pollution in water.

Microbial analysis: analysis/testing of/for microorganisms such as bacteria in samples.

Monitoring: regular collection of water data such as water quality so as to provide a record of the water body's response over time.

Nitrates: a salt or ester of nitric acid (NO_3), can have an impact on the environment by causing eutrophication when discharged in excess amounts into water resources.

Nitrites: a salt or ester of nitrous acid (NO_2), can have an impact on the environment by causing eutrophication when discharged in excess amounts into water resources.

Nitrogen: element in group 15 in periodic table, has atomic number of 7. Noted in various oxidation states but is usually in a gaseous form, can have an impact on the environment by causing eutrophication when discharged in excess amounts into water resources.

Nutrients: a growth-supporting substance. A limiting nutrient that has an influence on plant growth. These can also be seen as environmental pollutants such as phosphates, nitrates, nitrites and ammonia.

Orthophosphate: a salt or ester of phosphoric acid ($O\text{-}PO_4$), can have an impact on the environment by causing eutrophication when discharged in excess amounts into water resources.

Organic matter: contains carbon, decomposing material that originates from living organisms, plant/animal.

Overall water quality of site: this includes the chemical, physical and biological characteristics and indicates the level of purity/safety of all the water resources at the site. It indicates the value of usefulness/suitability for intended use of the river, dams and borehole water at the research site.

Package plant: small on-site waste water treatment facility, above or below ground, pre-engineered/fabricated with a design capacity less than 2 000 m^3/day.

Parasite: organisms that live on tissues of other living organisms/host from which they derive their nutrients.

Pathogens: microorganisms capable of causing disease in other organisms.

pH: measure of how alkaline or acidic a solution is on a scale from 0 – 14. The number 7 being neutral, less than 7 being acidic and higher than 7 being alkaline.

Phosphates/Phosphorus: element in periodic table in group 15 with atomic number of 15, usually in solid form. Can have an impact on the environment by causing eutrophication when discharged in excess amounts into water resources.

Physical parameters: quality variables tested to determine quality of samples, includes: temperature, electrical conductivity, pH, dissolved oxygen (DO) and suspended solids.

Point sources: pollution sources such as pipes, accidental spills. Are readily identified and stationary, easy to recognize and control.

Primary treatment: physical removal of organic matter, usually first step in treatment processes.

Qualitative research: this type of research uses inductive reasoning, includes various realities/personal views or meanings from different individuals, assumptions, analysis done by describing, explaining and interpreting personal opinions and observations. This type of research involves qualities or attributes that cannot be expressed as quantities. Data collection is usually done through questionnaires.

Quantitative research: this type of research uses objective realities/objects/parameters that can be measured, deductive reasoning and statistics and predetermined methods (aims, hypothesis and research questions). It involves numeric data (numbers or measurements) that can be predicted, confirmed, validated and tested. Data collection is done through taking of samples and physical testing/measuring of specific parameters.

Secondary treatment: aerobic biological treatment with micro-organisms, removes organic matter and nutrients, usually second step in treatment processes.

Sediment/sedimentation: the settling out of solid particles from a liquid such as water/waste water.

Settling: waste water remains stagnant to allow larger particles to settle uot of suspension to bottom of tank.

Sewage effluent: liquid discharge from sewage treatment plants after going through a series of treatment processes.

Surface water: water on surface of earth e.g. streams, rivers, dams etc.

Suspended solids: solid material/molecules in a liquid or water that does not dissolve in water and can be captured on a filter.

Tertiary treatment: disinfection process to produce high quality effluent, usually third step in treatment processes and is used to destroy disease causing bacteria.

Turbidity: measure of light scattering ability of water, indicates concentration of suspended matter.

Typhoid: systemic infection caused by *Salmonella*, cause fever, weakness, abdominal pain.

Urbanization: condition of being urbanized, a social process whereby cities grow and societies become more urban.

Virus: microscopic particles of protein and nucleic acid, unable to replicate or adapt outside of living host and able to cause diseases.

Waste water: liquid waste produced by human activities.

Waste water treatment systems: these are specifically designed plants/structures/systems build to treat raw sewage/waste water through primary, secondary and tertiary treatment processes.

Waterborne disease: disease causing pathogens that are transmitted via a water source and cause infections in the human body.

Water quality: this includes the chemical, physical and biological characteristics and indicates the level of purity/safety of water. It indicates the value of usefulness/suitability for intended use of water.

Water quality variables/parameters: these are individual constituents of a given sample of water/effluent such as temperature, pH etc, that can vary in concentration/magnitude and thus have an effect on the water/effluent quality.

Water resources: water reserves, such as groundwater, surface water or borehole water that can be used for daily activities or to sustain life.

ABBREVIATIONS

BOD	Biochemical Oxygen Demand
Cl^-	Chloride
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
DWA	Department of Water Affairs
EC	Electron conductivity
IHAS	Invertebrate Habitat Assessment System
IHI	Index of Habitat Integrity
N	Normal
N	Nitrogen
NaCl	Sodium chloride
NH_3	Ammonia
NO_2	Nitrites
NO_3	Nitrates
O_2	Oxygen
P	Phosphorus
SABS	South African Bureau of Standards
SASS5	South African Scoring System
SO_4^{2-}	Sulfate
SS	Suspended Solids
THM	Trihalomethanes
UNISA	University of South Africa
WHO	World Health Organization

Chapter One

1. Introduction

In South Africa, water is a scarce and valued resource that requires protection and conservation. The impact of climate change is considerable and 65% of South Africa receives an average annual rainfall of less than 500mm/a. Thus, drought is a big concern and freshwater resources are under severe pressure. In addition, the demand for water has increased dramatically over the years as a result of an increasing population and urbanisation (Walmsley *et al.*, 1999).

South Africa's existing water resources available for use consists of 77% surface water, 9% groundwater and 14% re-use of return flows. Seventy four percent of South Africa's rural communities depend entirely on groundwater (The United Nations World Water Development Report 2, 2006). Groundwater or boreholes are a source of water for approximately 1.5 billion people globally, especially in rural areas (Harvey, 2004). Previously, groundwater did not receive much attention and was considered an unimportant water resource but with increasing water demand, decreasing available river flows and increasing surface water pollution, groundwater has become the most feasible option for water supply (Department of Water Affairs and Forestry, 2004).

There are widespread problems associated with the quantity and quality of water in South Africa and these are compounded by the loss of almost half of the natural wetlands. The term water quality is used to describe the chemical (phosphates and nutrients), physical (temperature, pH, conductivity) and biological (bacteria, viruses and parasites) components of water. Changes in water quality are used as indicators to establish the degree of pollution. Unmanaged human activities can cause deterioration of surface and groundwater quality (State of the Environment Report for Mogale City Local Municipality, 2003).

Waste water is a global problem that has become a very important issue but is also a difficult environmental problem to solve (Rudel *et al.*, 1998; Gasparikova *et al.*, 2005). Many of South Africa's water resources have become polluted due to effluent discharge, sewage effluents and mine and agricultural activities (Walmsley *et al.*, 1999). The term effluent is described by the Water Services Act of 1997 as human excreta, domestic sludge, domestic waste water, grey water or waste water resulting from commercial or industrial use[1]. Domestic waste water is defined as consisting of 90% of waste water by volume that arises from domestic and commercial activities and premises and may include sewage, household waste from bathing, washing and toilets[2]. Water quality guidelines as defined by the Department of Water Affairs and

[1] www.dwaf.gov.za/Documents/Notices/Water%20Services%20Act/SEC9DREG_20_April_2001.pdf

[2] www.dwa.gov.za/Projects/WARMS/Registration/R000218/updatedwasterelatedwateruseregistration

Forestry and the Water Research Commission (1995), consists of information provided for water quality constituents and include quality criteria and target ranges that is used to assess the fitness of water for its intended use as well as treatment options. Requirements for treatment of domestic sewage effluents must adhere to either the General or the Special standards. General limits are used unless wastewater is being discharged into sensitive areas such as dolomite or protected areas. In these cases the special limits apply (Government Gazette, 1984).

Many communities depend on surface water for their daily activities. These sources are often contaminated due to untreated or inadequately treated waste water effluents entering these surface waters and thus affecting the quality of the rivers/streams (Freese and Nozaic, 2004; Damafakir *et al.*, 2009) by contributing to oxygen demand, nutrient loading and algal blooms (eutrophication) as well as water-borne diseases (Morrison *et al.*, 2001). This can lead to the increased occurrence of disease amongst communities such as gastrointestinal and other diarrhoeal diseases which, in developing countries, could be life threatening (Igbinosa and Okoh, 2009; Omar and Barnard, 2010).

Treatment of waste water is a very important process in the overall management of the country's water resources, as is the measuring of the amount of pollutants that will be present in the discharged effluent and eventually end up in rivers and streams. Thus, the influence of the treatment process will determine the potential hazard associated with the effluent to the water resources, environment and human health (Lester, 1983). It is these concerns that highlight the need for catchment assessment and management programmes that are essential for managing water resources, not only for environmental sustainability but also for social and economic benefits[3].

A number of developing countries have inadequate waste disposal systems, lack of infrastructure and capacity, and, together with a rapid increase in population, there is an increased demand for not only water resources but also proper disposal of domestic waste (Mahomed *et al.*, 2008; Damafakir *et al.*, 2009). A solution to this demand has been the development of package plants. Package plants were introduced to meet the ever increasing demands and needs of rural or small, isolated communities, residential areas and holiday and recreational sites. These systems are usually complete, pre-assembled structures and can be under- or above ground. They are also known as alternative on-site treatment facilities or pre-engineered sewage treatment plants, and have increased in number over the last few years due to its apparent efficiency, low cost and ease of operation (Goronszy, 1979; Department of Water Affairs, Department of Health, Water Research Commission, 2002a).

There are various types of package plants in operation in South Africa, including: activated sludge, submerged bio-contactors, rotating bio- contactors, trickling filter plants, anaerobic

[3] www.panda.org/about_our_earth/about_freshwater/rivers/irbm/cases/southafrica_river_case_study_cfm

systems, pond systems and constructed wetlands. They operate by using a series of treatment processes that are very similar to those used in conventional large scale treatment plants (Department of Water Affairs, Department of Health, Water Research Commission, 2002a; Damafakir *et al.*, 2009). Typical treatment processes in a sewage treatment plant consists of primary, secondary and tertiary treatment. Primary treatment makes use of physical processes where the organic matter is removed via settling, floatation, skimming, coagulation and flocculation with the use of rakes, grit chambers, sedimentation and clarification. Secondary treatment involves aerobic treatment where organic matter and nutrients are removed through the metabolic action of microorganisms. It also involves the use of activated sludge, trickling filters and stabilisation ponds for removal of phosphates and nitrogen through denitrification and nitrification. Tertiary treatment is the advanced treatment process that include disinfection (removal of bacteria) and sand filtration for the removal of nutrients, dissolved and or suspended solids, organics and metals (Dettrick and Gallagher, 2002; Department of Water Affairs, Department of Health, Water Research Commission, 2002a; Kistemann *et al.*, 2008).

Package plants have various advantages due to the fact that they are easily assembled, low in cost and easy to operate, but there have been problems associated with these self contained, small scale units. These result mainly from variable load conditions that may result from increases in activity during certain times of the day. Often, there is also a lack of skilled supervision, monitoring, maintenance and operating personnel (Goronszy, 1979). These problems could pose serious threats to the environment and human health if effluent of a poor quality is released into the water resources (Voortman and Reddy, 1997; Dettrick and Gallagher, 2002; Department of Water Affairs, Department of Health, Water Research Commission, 2002a).

As indicated, South Africa's water resources are very important and are relied upon by many people for their daily activities as well as for irrigation purposes. It is, therefore, clear that assessment, planning and management of South Africa's water resources are vital to ensure a sustainable resource and reduce damaging impacts on these natural systems (Department of Water Affairs and Forestry, 2008). It is, thus, crucial that maintenance, control and monitoring of package plants be sufficient, so as not to add to the situation regarding poor quality effluent release into waterways. Inadequately treated effluents may be a source of pathogens, nitrogen, phosphate and metals, and can, thus, deteriorate water resource quality and cause ecological and health problems in surrounding communities.

A literature review was done on package plants (globally, in parts of Africa and South Africa) to gather information and knowledge on the efficiency, quality of effluent produced and problems associated with these small on-site waste water treatment facilities. Treatment facilities have difficulty keeping up with the ever increasing demand for treatment of domestic waste/sewage (Nyamangara *et al.*, 2008). Discharge of harmful substances/pollutants that may be present in inadequately treated sewage effluent can cause damage to the structure and natural functioning of the environment and its ecosystems (Slabbert and Venter, 1999). According to Morrison *et al.* (2001), sewage effluent that is discharged into the environment, is a major source of water pollution and this problem only increases with small, simple and sometimes not efficient working waste water treatment systems.

The following diagram illustrates the different aspects which the literature review for this research study entails:

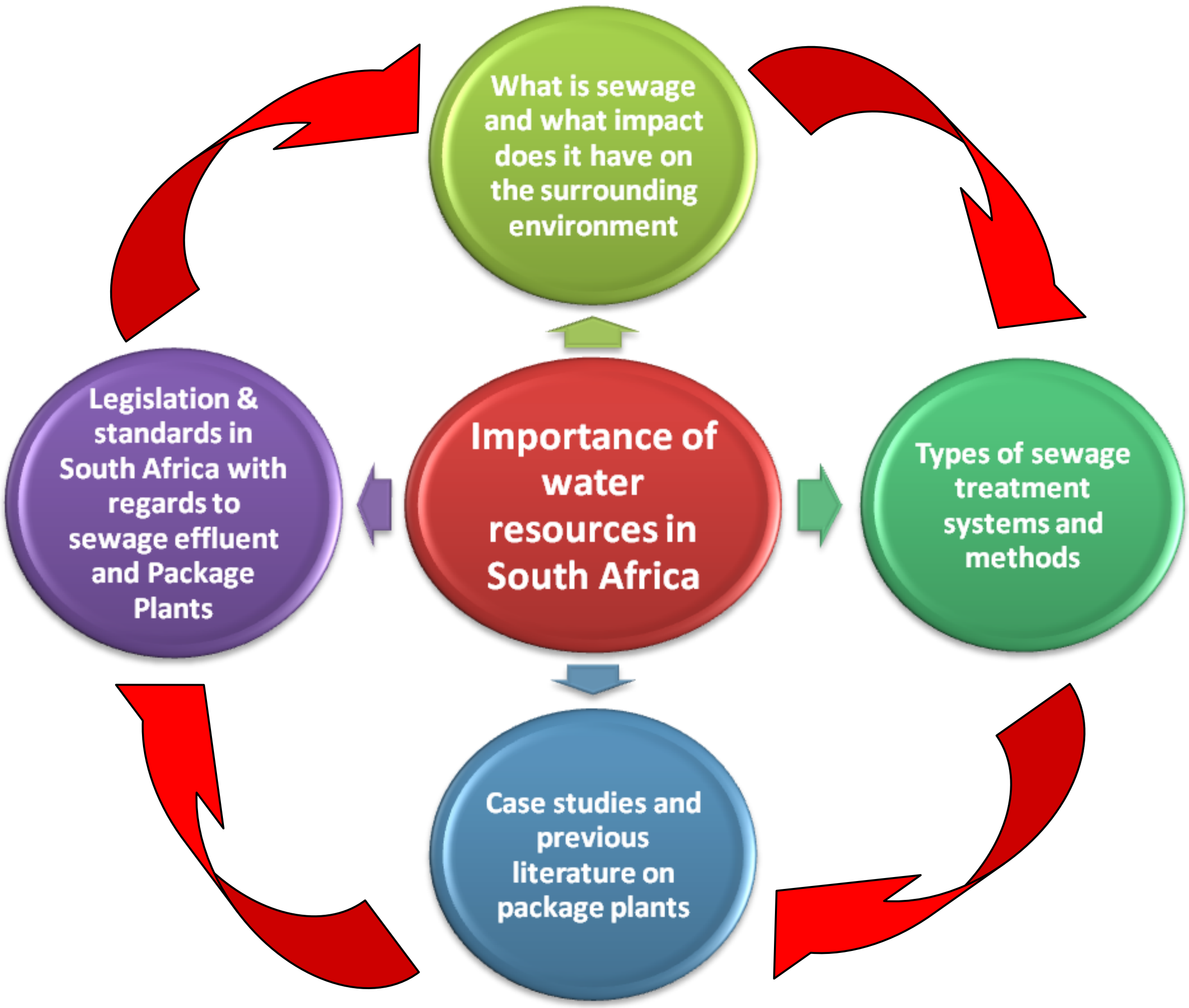

Figure 1.1: Diagram illustrating the contents of the literature review

Chapter Two

2. Literature Review

2.1Management of Water Resources

"High quality water is more than the dream of the conservationist, more than a political slogan, high quality water, in the right quantity at the right place at the right time, is essential to health, recreation and economic growth. Of all our planet's activities, geological movements and decay of biota and even the disruptive propensities of certain species, no force is greater than the hydrologic cycle".

Richard Bangs and Christian Kallen, 1985

Due to developments in South Africa, deterioration of the quality of the water resources has occurred. Through monitoring programmes information is gathered on the status of all rivers as well as the impact of human activities on these aquatic ecosystems (Nomquphu *et al.*, 2007). Information gained from water quality assessment studies can be used to develop management programmes that in turn can be used to achieve and maintain acceptable water quality of all the water resources. This can only be achieved by continuously assessing all quality parameters (physical, chemical and biological) over long periods of time to account for temporal/seasonal variations as was done with this research project which stretched over a period of one year[4].

According to Nomquphu (2005), previous monitoring programmes in South Africa primarily focused on quantity rather than quality of aquatic ecosystems. That lead to the Department of Water Affairs and Forestry recognising the need for water quality monitoring programmes and has established the following:

- National Chemical Monitoring Programme
- National Aquatic Ecosystem Monitoring Programme
- National Microbial Monitoring Programme
- National Eutrophication Programme
- National Toxicity Monitoring Programme and National Radioactivity Monitoring Programme (Nomquphu, 2005).

The Department of Water Affairs and Forestry (1998) recommends that "knowledge of water quality and protection of water resources can only be accomplished through a comprehensive

[4] http://www.smallreservoirs.org/full/toolkit/docs/III%2005%20Water%20Quality%20Assessment_MLA.pdf

and standardized monitoring programme". Monitoring should be an essential part of impact assessment studies and management programmes with regards to waste water treatment facilities so as to determine the impact of these facilities on the surrounding aquatic environment. Management of groundwater together with surface water forms part of a complete water quality resource management programme (Department of Water Affairs and Forestry, 1998). These programmes aim to ensure environmental, social and economic sustainability as well as help protect the country's aquatic ecosystems (Department of Water Affairs and Forestry, 2003).

An earlier report of the Department of Water Affairs and Forestry and Water Research Commission (1995) indicated that water quality management policies and practices were based upon the belief that because water is limited, effluent has to be returned back into the natural water ways or re-used and therefore changes in water quality will occur. Management also focuses on quality of receiving waters rather than effluent quality from a specific source due to the fact that waste discharges sometimes have little or no effect on water uses. Water quality management thus involves: setting of water quality objectives, impact assessments of effluent discharges into receiving water and effluent discharge permits.

South Africa's demand for water will outstrip its supply by 2025 (Oberholster *et al.*, 2008). Thus management of water quality is important. With the industrial and domestic sewage effluent discharges increasing there is a demand for water toxicity testing. By identifying the need to manage and monitor South African water resources, the focus was placed on the country's legislation to ensure quantity as well as quality monitoring programmes. The following chapter will look at the types of water related legislation and standards in South Africa with the focus on waste water discharge (Nomquphu, 2005; Oberholster *et al.*, 2008).

2.1.1 Assessment and monitoring of water resources

Drinking water is extracted from surface water such as dams, rivers and groundwater sources such as boreholes. Due to the fact that different human activities along the entire reach of the catchment will influence the overall resource as well as ultimately the quality of the country's drinking water, it is obvious that water extraction sites as well as the entire river catchment should be assessed and monitored (Department of Water Affairs and Forestry, Department of Health, Water Research Commission, 2002b).

Pollution of rivers and streams affects the health of communities relying on the river as a source of water, but also affects communities (economically and aesthetically) living next to the river (Department of Water Affairs and Forestry, Department of Health, Water Research Commission, 2002b). Globally, millions of people die each year from treatable water borne diseases and with increasing water pollution and aquatic ecosystem destruction, sustainable water management and assessment must be undertaken. Water related diseases such as diarrhoea, cholera, dysentery, hepatitis and Schistosomiasis are common in South Africa (The United Nations World Water Development Report, 2006).

Water pollution and other human activities are threatening the quantity and quality of our rivers, streams and groundwater and it has become clear that there is an increasing need to assess and monitor water quality. According to Bartram and Ballance (1996), monitoring can be defined as the process of sampling, measuring and recording of various water characteristics. They also state that there are three types of monitoring:

- Long term monitoring with measurements and observations to define status and trends
- Short term intensive monitoring for a specific purpose
- Continuous monitoring used for quality management

Water quality assessment and monitoring is a means of establishing the health of rivers, streams and groundwater/boreholes and providing information on the quality and the ecological state of that specific aquatic environment, affects of contaminants, human activities and waste water treatment discharge on the ecosystem and to provide knowledge used to establish management programmes[5] (Bartram and Ballance, 1996).

It can thus be concluded that a complete assessment of the health of an aquatic ecosystem requires not only chemical, biological and physical analysis but habitat assessment as well, all of which was achieved with this research study (Bartram and Ballance, 1996). Previous quality assessments of rivers was done by periodic sampling and analysis was done on the physical and chemical parameters only and thus did not provide a complete assessment of aquatic ecosystem health (Oberholster *et al.*, 2008).

Freshwater ecosystems are constantly under threat globally due to the fact that rivers and streams act as final recipient of wastes and, thus, pollution is always of concern. The health of rivers can be determined through biomonitoring which involves the process of determining the condition or health of the fish, vegetation and macro-invertebrate populations (Dickens and Graham, 2002). These processes of data collection are known as SASS (South African Scoring System), IHI (Index of Habitat Integrity), VEGRAI (Riparian Vegetation Response Assessment Index), FRAI (Fish Response Assessment Index) and diatoms (Mogale City Local Municipality State of the Environment Report, 2003).

FRAI – this type of biomonitoring assessment is based on the environmental intolerances and preferences of fish populations and their responses to any change within the river system (Kleynhans, 2007).

[5] www.internationalwaterinstitute.org/forms/water_quality_manual_part1

Diatoms – they are used as biomonitoring tool to assess or determine changes in water quality and the state of health of the aquatic ecosystem, thus, in turn the river/stream's ability to support life. Diatoms can be used to assess short and long term changes within an ecosystem due to the fact that they remain in one place for long periods of time and "reflect on ecological memory of water quality" (Walsh and Wepener, 2009). Changes in water characteristics will decrease certain species and increase others thus changing species composition and biodiversity (Harding *et al.,* 2005; Walsh and Wepener, 2009).

These methods help to determine the ecostatus/health of a river and should thus form part of any river health monitoring programme. An ecostatus assessment is based on drivers, such as physical and chemical changes, and in turn biological responses of fish, invertebrates and vegetation and provides information on the causes of change and the system's ability to support flora and fauna. Determining the ecostatus of a river supports data gathered from physical, chemical and biological analysis to provide an overall picture of the condition of the aquatic ecosystem receiving waste water effluent (Kleynhans *et al.*, 2005; Kleynhans and Louw, 2007).

2.1.2 Rationale for this research

Over the years, water resources have deteriorated rapidly with increasing effluent discharge and lack of water resource management with regards to sewage treatment works (Oberholster and Ashton, 2008). In a study done by Paterson and Nursall (1975), on the effects of domestic and industrial effluent on a large turbulent river, it was found that waste water from sewage treatment facilities did, indeed, have an impact on a river catchment in Canada. There were increased levels of phosphorous and nitrogen with various naturally occurring aquatic biota being completely eradicated.

According to a study done by Avery (1970) on the effects of domestic sewage on aquatic insects and salmonids of the East Gallatin River, treated sewage effluent proved to be a major pollutant in a river in Montana where sodium chloride, phosphorous, nitrogen, dissolved oxygen and BOD levels were influenced. The study also showed a reduction in insect and fish populations in the sections of the river below the effluent discharge site. Likewise, South Africa's freshwater resources are under pressure due to population growth and increased pollution. If this trend of water use and waste discharge continues, this country's water resources will not be sustainable (Oberholster and Ashton, 2008).

According to Igbinosa and Okoh (2009), water quality data on fresh water in South Africa are scarce. There is also very little information available on the extent of water pollution in this country. Various surface and groundwater problems, however, are identified such as salinisation, nitrate and fluoride pollution. Salinity or total dissolved inorganic compounds is a result of effluent discharges from waste water treatment plants, surface runoff, irrigation practices etc. Excess amounts of nitrate and nutrients in these waste waters leads to eutrophication, algal growth and overall deterioration of water sources and structure and function of aquatic ecosystems. Other water quality components of concern in South Africa's river catchments include microbial quality, sedimentation and silt, acidification, trace elements, oxygen consumption compounds and thermal pollution (National State of the Environment Report – South Africa, 1999; Wakelin *et al.*, 2008).

The package plant studied for this research project discharges its treated effluent directly into a river that forms part of a larger catchment. It was thus decided to include a water resource assessment at the research site so as to determine not only the quality of the package plant effluent, but also the impacts of the discharged effluent on the surrounding aquatic ecosystem. Sewage contains various substances that are harmful to the environment and human health. Treatment of sewage is thus essential and can be accomplished through various methods to ensure that these harmful substances do not enter the receiving water resources. Treatment methods and technology has changed over the years in an effort to improve effluent quality so as to cause minimal to zero impact to aquatic ecosystems and community health.

2.2 Domestic Sewage

Waste water consists of raw domestic sewage (Omar and Barnard, 2010). Raw sewage or human waste consists mainly of water but also includes substances such as solid organic matter, faeces, liquid matter (urine), carbon, nitrogen, phosphorous, sulphur, hydrogen, fats, carbohydrates, enzymes, proteins, trace elements/heavy metals, sand, debris, pathogens and bacteria (Schölzel and Bower, 1999). An example of a typical composition of raw sewage is listed in Table 2.1.

Table 2.1: The composition of raw sewage[6].

Suspended Solids	250 – 400mg/ℓ
Ammonia	25 – 50mg/ℓ
Total Phosphorous	15 – 25mg/ℓ
Chloride	60 – 100mg/ℓ
Fats	100 – 200mg/ℓ
Faecal Coliforms	2 – 30 x 10^6 /100mℓ

[6] www.ewisa.co.za/misc/DomWWater/default.htm

2.2.1 The importance of sewage treatment

Inadequately treated sewage effluent does not only pose a health risk to humans, but also has an impact on the environment by affecting Dissolved Oxygen (DO) levels and causing increased nutrient loads and algal blooms due to high levels of phosphorous and nitrates (Igbinosa and Okoh, 2009). Other ecological impacts include: changes in flow patterns, reduction in species diversity, increase in invasive pest species that choke the ecosystem, high levels of ammonia is also toxic to aquatic life. Thus, discharging of these effluents can cause overall deterioration of the receiving aquatic environments and limit the utilisation of these water resources and in turn affecting the quality of living for the communities depending on water.

Polluted water resources also have other social impacts such as closure of beaches/water bodies and reduction in ecotourism. Economic impacts are also a result of sewage effluent pollution: increased costs due to increased maintenance and monitoring of water resources and reduction in property values[7]. Thus, treatment of sewage is important to preserve human and environmental health (Schölzel and Bower, 1999).

2.2.2 Types of treatment processes

Conventional treatment of sewage is defined by Schölzel and Bower (1999) as a process of solids separation, pollutant stabilisation/degradation and the removal of toxic/dangerous substances. Treatment consists of various stages which include: preliminary treatment, primary treatment, secondary and tertiary treatment.

- Preliminary treatment – this is the first step in the treatment process and involves the removal of debris and large solid material. This is usually done by screening and grit removal. As the raw sewage enters the treatment plant it is passed through a series of screens to remove large floating material. From there it enters a grit chamber/tank and this removes sand and small stones (Schölzel and Bower, 1999; Botkin and Keller, 2005). From here it goes to the sedimentation tank and primary treatment begins.

- Primary treatment – this second step involves removal of organic solids through settlement/sedimentation (course and heavy particles settle first due to gravity) as well as removal of oils and fats (these float on the liquid part and are removed through skimming).

- Secondary treatment – during this step there is biological reduction of organic matter that settles out to form sludge. By applying the natural activity of bacteria, the organic matter is broken down through anaerobic and aerobic processes. This can be done through various different processes such as the activated sludge processes, trickling filters,

[7] http://seawaste.uwc.ac.za/archive/MikeLuger.pdf

rotation bio-discs, extended aeration, stabilisation ponds and reed beds. During the anaerobic processes (which occurs in the absence of oxygen) bacteria breaks down the organic matter and produce CO_2 and methane. During aerobic processes bacteria requires oxygen (that is provided by aeration) to feed on/break down the organic matter and also produces CO_2 and sludge (sedimentation and particles at the bottom of the tank).

- Tertiary treatment – this process/step involves nitrification (occurs in the presence of oxygen), denitrification (occurs in the absence of oxygen), filtration and disinfection. Nitrification and denitrification are responsible for removal of nutrients such as ammonia, nitrates and phosphates. The liquid waste then goes through a filtration process to remove any remaining small suspended particles in the effluent. Bacteria, viruses and protozoa that are suspended in the liquid portion are then removed through disinfection (with the use of chlorine and ultra-violet light).

It can be seen from the above that treatment of sewage involves various processes and stages. The higher the treatment efficiency, and the more processes/steps that are applied, the better the effluent quality will be (Schölzel and Bower, 1999).

2.2.3 The history of sewage

Over the years advances in technologies has strived to improve sewage treatment and disposal and has undergone many changes, improvements as well as challenges. According to Schladweiler (2001) global efforts by various countries to treat and dispose of sewage began at a very early stage:

3200BCE – Scotland showed first signs of drainage systems with lavatory-like plumbing and outlet drains.

4000 – 2500BCE – Iraq had storm water drain systems, cesspools under houses and drainage pipes.

3000 – 100BCE – Isle of Crete had terracotta piped drainage systems and channels.

2000 – 500BCE – Egypt used copper pipes and toilets with beds of sand to contain the waste.

300BCE – 500CE – Greece used lead and bronze pipes and sewer systems that delivered the waste water to basins.

800BCE – 300CE – Rome had complex drainage systems and waste water sewers beneath the city that delivered the waste to the river.

During the dark ages however, sanitation went back to the basics with night soil programs and only in the 1800’s did a central waste water system open in Berlin.

1830 – Sewers were constructed after a cholera epidemic.

1850 – Combined sewers were build that discharged into rivers.

According to Stanbridge (1977) in Britain there were rapid population growth and urbanisation. Waste was taken to specific sites and dumped. Surface water sewers were opened to receive waste water. However, because the sewers were not designed for this purpose there was a deadly gas build up.

1852 – Improvements were made to sewers which lead to partially separated and ultimately complete separate sewer and waste water systems.

1853 – Preliminary treatment was introduced with removal of solids with wooden plank screens.

1855 – Tanks with gravel filters were used for solids removal.

1859 – Britain started with chemical treatment. Bleach was used for disinfection and deodorizing of waste water.

1864 – Rotating screens were introduced.

1885 – Concrete was used for the first time to construct sewers and in California, waste went first to a sewage reservoir and then into the ocean. Great concern increased over water pollution, human health and environmental impacts and it was decided that sewage had to be treated first (Schladweiler, 2001).

1885 – 1887 – Filters were used that consisted of charcoal, gravel, straw, sand and stone, polarite and magnetite and permanganate and hypochlorite was used for disinfection (Stanbridge, 1977).

1887 – An experimental sewage farm was developed were sewage was taken and discarded and then used as fertiliser. However, there were increased concerns about health risks and controversies about the advantages and disadvantages of the farm. The farm was eventually declared as a failure and the Sydney Health Board recommended that the sewage should not be used for irrigation but rather treated by intermittent downward filtration using irrigation beds/sand (Beder, 1993).

1891 – Georg Stayton proposed that chemical precipitation with lime should be used in conjunction with filters in a two stage process. Stage one: chemical precipitation in settling tanks. Stage two: artificial filters should be used instead of sand.

1898 – The Sydney Water Board began experiments with filters and tanks, from there the septic tank treatment concept.

1899 – The first Sydney Sewage Works was completed.

1902 – Precipitation tanks were replaced with septic tanks/anaerobic tanks because lime treatment became too expensive. Effluent was again passed through sand filter beds and pumped into the ocean (Beder, 1993).

1939 – The first treatment works was opened in Britain and used pre-aeration before settlement (Stanbridge, 1977).

According to Schladweiler (2001) various treatment methods were implemented over the years from 1880 - 1930:

- Intermittent filtration – sewage applied to sand beds
- Chemical precipitation – adding lime and iron sulphate to form flocks which settled out leaving clear liquid.
- Septic tanks – sedimentation of solids and digestion by bacteria.
- Imhoff tanks – that consisted of two chambers in which settling of solids and digestion occurred.
- Separate sludge digestion – consists of separate tanks, one for settling and one for digestion.
- Contact beds – which were the forerunner of the trickling filter, tanks were filled with stones, coke or coarse material.
- In 1908 trickling filters were used – sewage was distributed through spray nozzles over coarse bed of stones.
- In 1915 activated sludge systems were used – where settlement and aeration occurred.
- Rocks, grit chambers and screens – for removal of large solids, oil and grease.

In 1920 sludge was disposed of by first drying it and then it was sold as fertiliser. Disinfection methods (chlorine) was used in the early 1900's, hypochlorite in 1909 and then liquid chlorine. In 1875 none of the U.S cities treated sewage. In 1900 only two U.S cities started with sewage treatment. By 1926 approximately 20 U.S cities were treating sewage (Schladweiler, 2001).

According to Beder (1993), the origins of the modern concepts of primary and secondary treatment arose from the Sydney Commission proposing that treatment should have two stages:

- Removal of solids
- Biological decomposition of organic matter.

Various options for treatment were considered and a conclusion was drawn that septic tanks, sedimentation and chemical precipitation are all suitable treatment methods. A decision could not however be made on which method was the best option and thus a recommended minimum was presented for effluent quality standards. This standard is referred to as the 20:30 standard:

BOD<20mg/ℓ and SS<30mg/ℓ as achieved by whatever process (Beder, 1993).

It is clear from the above history that sewage treatment and disposal started very early and has come a long way. Various methods were experimented with and improved. Treatment and disposal of sewage was not only a concern internationally. South Africa also joined in the race to effectively and safely treat sewage.

2.2.4 The South African sewage history

According to Osborn (1988) in 1897 the City of Johannesburg made use of the bucket system. Buckets full of sewage were collected and taken to the Waterfall farm to be dumped. From 1898 to 1919 septic tanks were used. This early technology was introduced to South Africa by the British military. The effluent from these tanks were treated in contact beds and used for irrigation. The first operational sewage works was established in 1904 in Bloemfontein and consisted of septic tanks, five primary filters and five secondary filters. This was known as SA's first double filtration system. In 1905 the first municipal scheme commenced at Wynberg. There sewage passed through fixed screens as well as rotary screens propelled by water wheels. From there it went through a grit removal process and to filter beds with rotating sprinklers.

1908 – The first separate sludge digestion and Travis sedimentation tanks were used in Johannesburg.

1909 – Permission was given to discharge purified effluent directly into rivers/streams.

1910 – Mr M Lundie was the first chemist appointed in SA and introduced the concept of mesophilic anaerobic sludge digestion. In this process the pH of the sludge is adjusted with the addition of lime.

1921 – The first Imhoff tanks were installed in Cape Town.

1922 – The first conventional activated sludge plant was installed at Boksburg Hospital.

1928 – The biological filtration system was introduced.

1930 – Slow sand filters were used in Johannesburg and was considered the earliest form of tertiary treatment.

1956 – The National Water Act was introduced which prohibited the use of settled sewage for irrigation purposes.

1960 – During this time the pond system started to receive attention.

1973 – The KwaMashu Works in Durban used mechanical raked rotating bar screens.

1983 – The Darvill Works in Pietermaritzburg used stone traps for grit removal and incineration of grit was done at the Cape Flats Works.

It was found that aerobic digestion was first practised at the Klipfontein Sewage Works. Removal of fats from sewage was introduced at the Johannesburg Klipspruit Works. This was done through suspending a sack in a manhole underneath the scum removing pipes. The fat that was trapped in the sack was then used to manufacture other products such as soaps, creams and cosmetics (Osborn, 1988).

The first recorded use of chemicals was at Zonderwater Prisoner of War Camp where lime and alum was added. With the early sewage works there was however complaints from the surrounding residents about odour. Remedial action was taken to deodorise, reduce noise and to make the sewage works more aesthetically acceptable (Osborn, 1988).

The history of sewage treatment and disposal started out very basic and has evolved into a process that consists of primary, secondary and tertiary treatment technologies as well as a variety of system types.

2.2.5 Types of sewage treatment systems

2.2.5.1 Conventional large scale systems

Waste water consists of domestic sewage, industrial effluent and surface runoff[8]. At the large scale conventional treatment plants the waste water passes through various treatment stages to be purified as can be seen from Figure 2.1.

[8] http://www.sawater.com.au/SAWater/Education

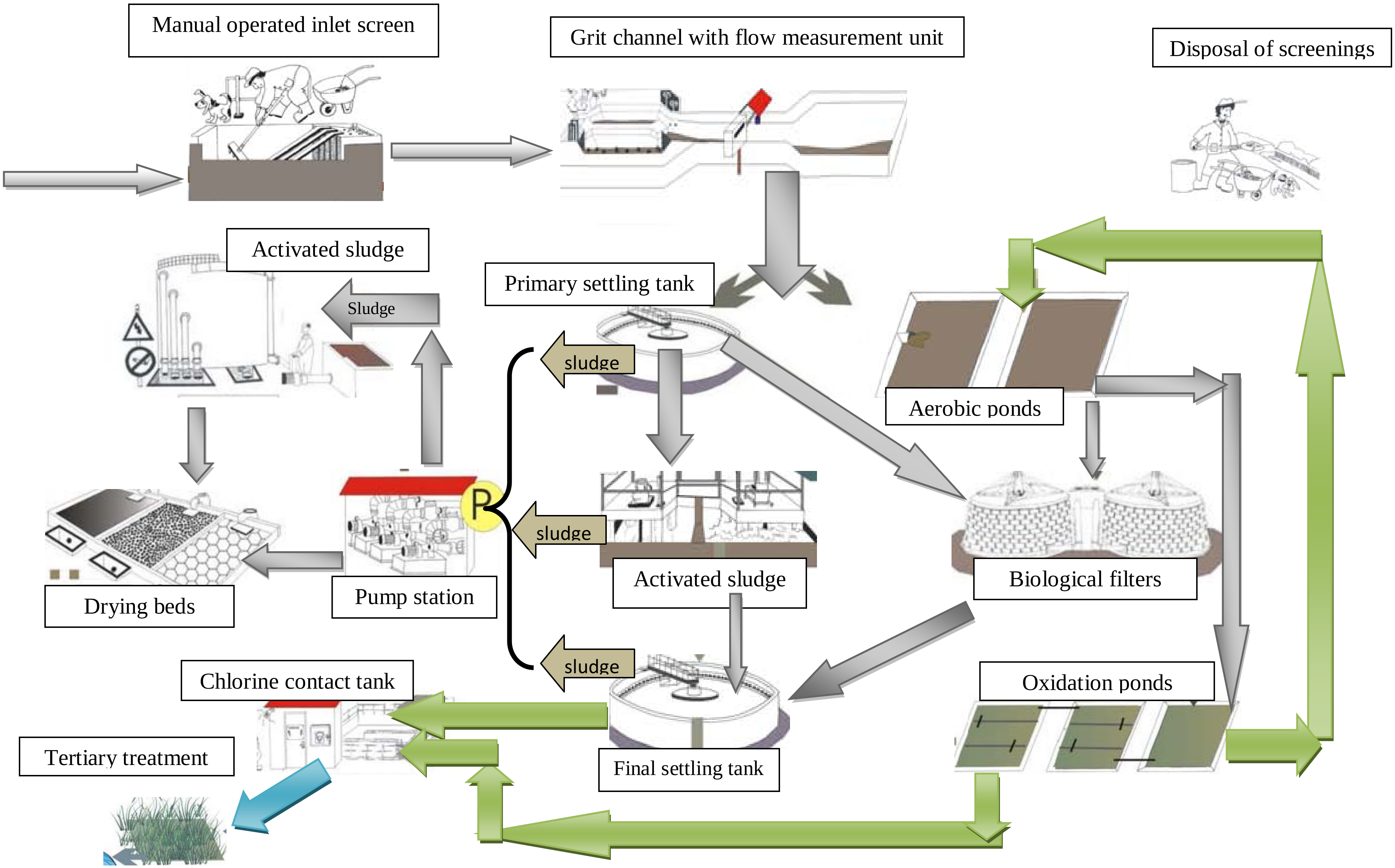

Figure 2.1Various stages used in large scale conventional treatment systems (Department of Water Affairs and Forestry, 2002).

1) Preliminary treatment

During this first stage screens, as in Figure 2.2, are used to remove large solids and grit. Silt is also removed in grit channels[9] as can be seen in Figure 2.3.

Figure 2.2: Manual operated inlet screen used to remove large solids and grit (Department of Water Affairs and Forestry, 2002).

Figure 2.3 Grit channels used to remove silt (Department of Water Affairs and Forestry, 2002).

[9] http://www.ewisa.co.za/misc/DomWWater/default.htm; http://www.sawater.com.au/SAWater/Education

2) Primary treatment

Waste is passed through a sedimentation/settling tank, as can be seen in Figure 2.4, to remove organic solids through settling.

Figure 2.4 Settling or sedimentation tank where organic solids settle out of solution[10]

3) Secondary treatment

At this stage dissolved and suspended organic material is broken down by naturally occurring microorganisms and is called the activated sludge process[11] (Fig. 2.5).

Figure 2.5: The activated sludge process where suspended organic material is broken down by microorganisms (Department of Water Affairs and Forestry, 2002).

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[10] http://www.ci.camarillo.ca.us/main.aspx?q=6083&p=10047

[11] http://www.ewisa.co.za/misc/DomWWater/default.htm; http://www.sawater.com.au/SAWater/Education

From there it passes to biological filtration tanks (Fig. 2.6) to oxidize carbon and ammonia nitrogen and aeration tanks (Fig. 2.7) where oxygen is provided to mix and promote microorganism growth.

Figure 2.6: Biological filtration tank where oxidation of carbon and ammonia takes place (Department of Water Affairs and Forestry, 2002).

Figure 2.7: Aeration tanks where oxygen is introduced to promote microorganism growth (Department of Water Affairs and Forestry, 2002).

The waste water then enters the clarifier tanks where the biomass settles out and forms sludge. The sludge is then pumped to the anaerobic digesters for further treatment. The clarified liquid goes for tertiary treatment[12].

[12] http://www.ewisa.co.za/misc/DomWWater/default.htm; http://www.sawater.com.au/SAWater/Education

4) Tertiary treatment

Waste water is disinfected to reduce disease causing pathogens. Disinfection is done through the use of chlorine, ultraviolet ponds and micro-filtration and biological detention ponds[13] as can be seen from Figures 2.8 and 2.9:

Figure 2.8: Chlorine contact tank used for disinfection of waste water (Department of Water Affairs and Forestry, 2002).

Figure 2.9: Ultraviolet and detention ponds also used for disinfection of waste water (Department of Water Affairs and Forestry, 2002).

[13] http://www.ewisa.co.za/misc/DomWWater/default.htm; http://www.sawater.com.au/SAWater/Education

5) Sludge treatment

Sludge treatment is done with the help of anaerobic microorganisms in sludge digester tanks as can be seen from Figure 2.10. The liquid portion is pumped back into the aeration tanks for further treatment and the final effluent is discharged into rivers or the ocean. The solids remaining are dried in drying beds (Fig. 2.11) and used as fertilizer[14].

Figure 2.10: Anaerobic sludge digester tank that makes use of anaerobic microorganisms to break down the sludge (Department of Water Affairs and Forestry, 2002).

Figure 2.11: Sludge drying bed where the remaining solids are dried (Department of Water Affairs and Forestry, 2002).

[14] http://www.ewisa.co.za/misc/DomWWater/default.htm; http://www.sawater.com.au/SAWater/Education

2.2.5.2 Small scale systems (Package plants)

Many people are not able to connect to large conventional municipal sewage systems due to lack of infrastructure and development, poor soil structure, geology or high water tables. With increasing rural and suburban development more people have become interested in small waste water treatment works. There are various differences between small and large scale treatment systems such as quality and quantity. Small systems have low investment and maintenance costs, they operate quietly, have reduced odours, simple operation, long durability and effluent can be discharged into streams (Hanna *et al.*, 1995; Gasparikova *et al.*, 2005).

In the past small communities used low technology approaches to treat waste water which included only septic tanks, stabilization ponds and filtration and often these methods did not comply with the required standards. However, in recent years, package plants have increased in number and made some improvements with new technologies. The difference between large scale conventional treatment works and package plants are the fact that package plants are on-site systems with a discharge less than 2000m^3/day, they can be build/installed at low cost, can be used to treat waste of small communities, are easy to transport and install (Hulsman and Swartz, 1993; Gaydon *et al.*, 2007).

There are three groups/technologies used for package plants:

- Those that uses anaerobic processes
- Those that uses aerobic processes
- Those that make use of both anaerobic and aerobic processes.

These systems consists of septic tanks, stabilization ponds, biological filtration, emergent hydrophyte systems, artificially aerated ponds, trickling filters, rotating biological contactors and activated sludge systems. A comparison between these three groups/technologies is shown in Table 2.2.

Table 2.2: Comparisons between various package plant systems (Hanna *et al.*, 1995; Gasparikova *et al.*, 2005; Ra *et al.*, 2007; Odjadjare *et al.*, 2010).

Anaerobic systems	**Aerobic systems**	**Combined anaerobic and aerobic systems**	**Activated sludge**
Low energy consumption	High energy consumption	Low energy consumption	

Table 2.2: Comparisons between various package plant systems continued

Anaerobic systems	**Aerobic systems**	**Combined anaerobic and aerobic systems**	**Activated sludge**
Simple construction	Complex construction with poor operation and maintenance failures	Complex construction	Needs skilled construction, operation and requires monitoring and maintenance
Low sludge production	High sludge production	Low sludge production with short detention time	
Minimal nutrient removal	Very good nutrient removal but inconsistent and overall poor effluent quality	High nutrient removal with biogas production	High removal (95% BOD, 90% SS) and good effluent quality but ineffective in removal of *Listeria*

There are three technologies available for use in South Africa and include:

- Activated sludge systems with extended aeration or sequencing batch reactors.
- Submerged biological contactors.
- Rotating biological contactors (Gaydon *et al.*, 2007).

The **activated sludge systems** usually consists of a septic tank, aeration tank, clarifier tank and a disinfection tank as can be seen from Figure 2.12 (Laas and Botha, 2004; Damafakir *et al.*, 2009).

With the **submerged biological contactor system** (Fig. 2.13), plastic media are used that acts as substrate for microorganism growth. This system consists of a septic tank, biological contactor tank with media and air blowers, cone shaped clarifier tank and a disinfection tank (Laas and Botha, 2004; Damafakir *et al.*, 2009).

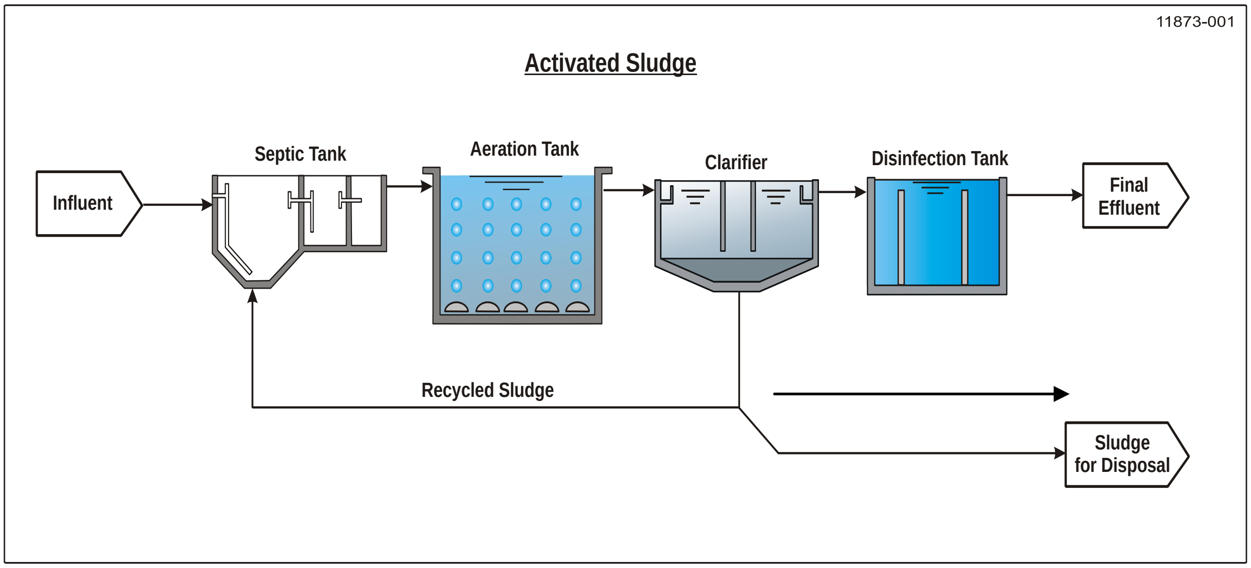

Figure 2.12: Activated sludge system (Damafakir *et al.*, 2009).

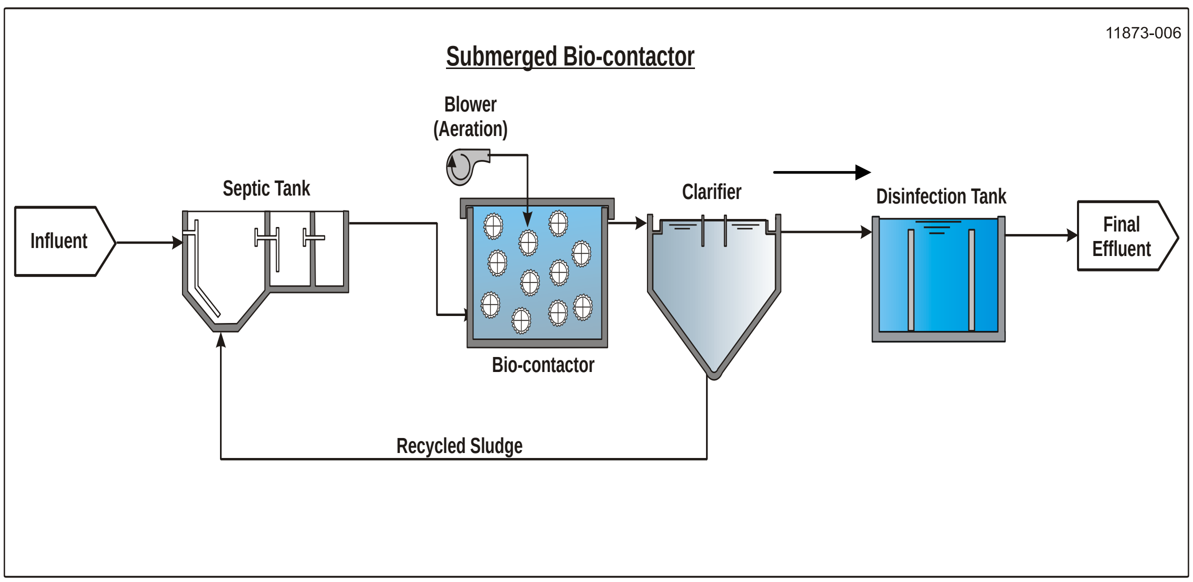

Figure 2.13: Submerged biological contactor system (Damafakir *et al.*, 2009).

The **rotating biological contactor system** consists of a series of rotating discs placed on a horizontal shaft (Fig. 2.14). This provides the aeration and approximately 40% of the disc area must be submerged in the waste water. The system also contains a humus tank where the solids and liquids are separated through sedimentation and is then passed to the disinfection tank (Laas and Botha, 2004; Damafakir *et al.*, 2009).

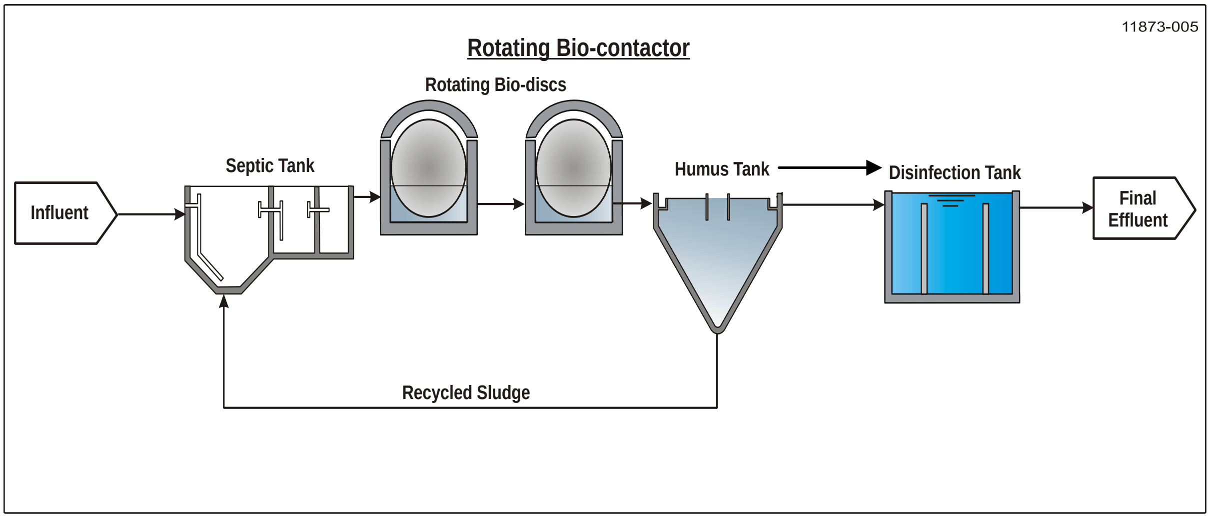

Figure 2.14: Rotating biological contactor system (Damafakir *et al.*, 2009).

2.2.6 Problems with package plants.

Although package plants are low cost and simple to operate alternatives to sewage treatment, there are problems associated with these treatment systems. The most common problems encountered include: bad odour, poor effluent quality, poor design and construction, system failures, lack of maintenance and skilled operators, lack of proper monitoring, technical and management problems and variable influent loads also cause problems. Some systems show non-compliance with removal of COD, NH_3, pH, *E. coli* and suspended solids.

Problems associated with pH occur due to excessive aeration which in turn leads to increased nitrification and thus a drop in pH levels. COD levels are increased with the use of soaps, detergents and fats. A specific amount of oxygen is also required to convert NH_3 to nitrates. Any changes in temperature, pH or chemicals will lead to an increase in NH_4.

Problems with bacteria are due to inadequate disinfection and insufficient contact time with chlorine. High concentrations of suspended solids will also prevent chlorine from making adequate contact with the bacteria and too much NH_3 reacts with the chlorine causing insufficient disinfection (Hanna *et al.*, 1995; Laas and Botha, 2004; Gaydon *et al.*, 2007; Damafakir *et al.*, 2009; Momba *et al.*, 2009a).

These problems can be reduced with a few solutions such as:

- designing of package plants to treat the volume load of the area they serve, thus proper designing of complete systems

- training and education to ensure skilled operation and maintenance
- the use of effective flow equalization measures
- ensure efficient screening of waste water and installation of fat traps
- installation of warning alarms for system failures
- the use of sand filters to improve effluent quality
- improve and ensure efficient aeration
- increasing de-sludge/cleaning frequencies and maintenance
- insure efficient sludge retention times
- perform frequent, detailed sampling and analysis of effluent (Gaydon *et al.*, 2007).

Various claims have been made by distributors/manufacturers with regards to package plant treatment systems. However, the following can be said: **the effluent produced is not clean water but a potential pollutant and these systems do require maintenance and repair[15]**.

It can thus be concluded that proper maintenance and skilled operation is required to sustain a well functioning package plant. All of these factors should be considered when choosing the type of package plant as well as cost, electrical supply and backup and topography. All these will have an impact on the proper function and operation of a package plant (Schölzel and Bower, 1999).

2.2.7 The submerged biological contactor system

The package plant that was chosen for this research project is based on the same principal as a submerged biological contactor system. According to the suppliers these systems:

- were first launched in 1996
- typically consists of septic tanks, submerged bio reactor with AWW MARK 2 fixed growth media and aeration, clarifier tank to extract excess solids and disinfection with chlorine
- are easy to install and operate
- are very cost effective

[15] http://extension.missouri.edu/publications/DisplayPub.aspx?P=WQ403

- comply with requirement standards
- are odourless and silent
- can be used for small communities, villages and towns
- provide for reuse of effluent that can be used for irrigation and subsistence agriculture.

According to the Department of Water Affairs and Forestry[16], these domestic sewage treatment plants are:

- Small and compact, simple to install and run
- Versatile and highly efficient
- Capable of rendering toxic domestic waste clean, clear and 100% reusable
- Exceeds minimum international discharge standards as well as the Department of Water Affairs discharge limits
- Minimizes the need for chemicals
- Is a 100% odourless, almost silent AND pathogen free
- Can be re-circulated into irrigation systems, swimming pools, water features or used for flushing
- Can cope with any capacity of domestic waste water
- Does not require continuous supervision or maintenance – requires very little human input and technical knowledge, the only human input is occasional top up of chlorine for disinfection
- Its economical saving water and power

They also state that "submerged biological contactor systems renders dangerous domestic waste completely safe for discharge into natural waterways" and that "communities that take possession of these treatment plants are taught how to maintain their plants, how to properly utilise their plants, and basic personal hygiene"[17].

[16] www.dwaf.gov.za

[17] www.dwaf.gov.za

The system chosen for this research project (Fig. 2.15) is based approximately on the same concept as the submerged biological contactor system shown in Figure 2.14.

Figure 2.15: The domestic sewage treatment system at the research site

The system consists of 12 tanks altogether above ground, as well as two underground septic tanks, thus a total of 14 tanks (Fig. 2.16).

2.17).

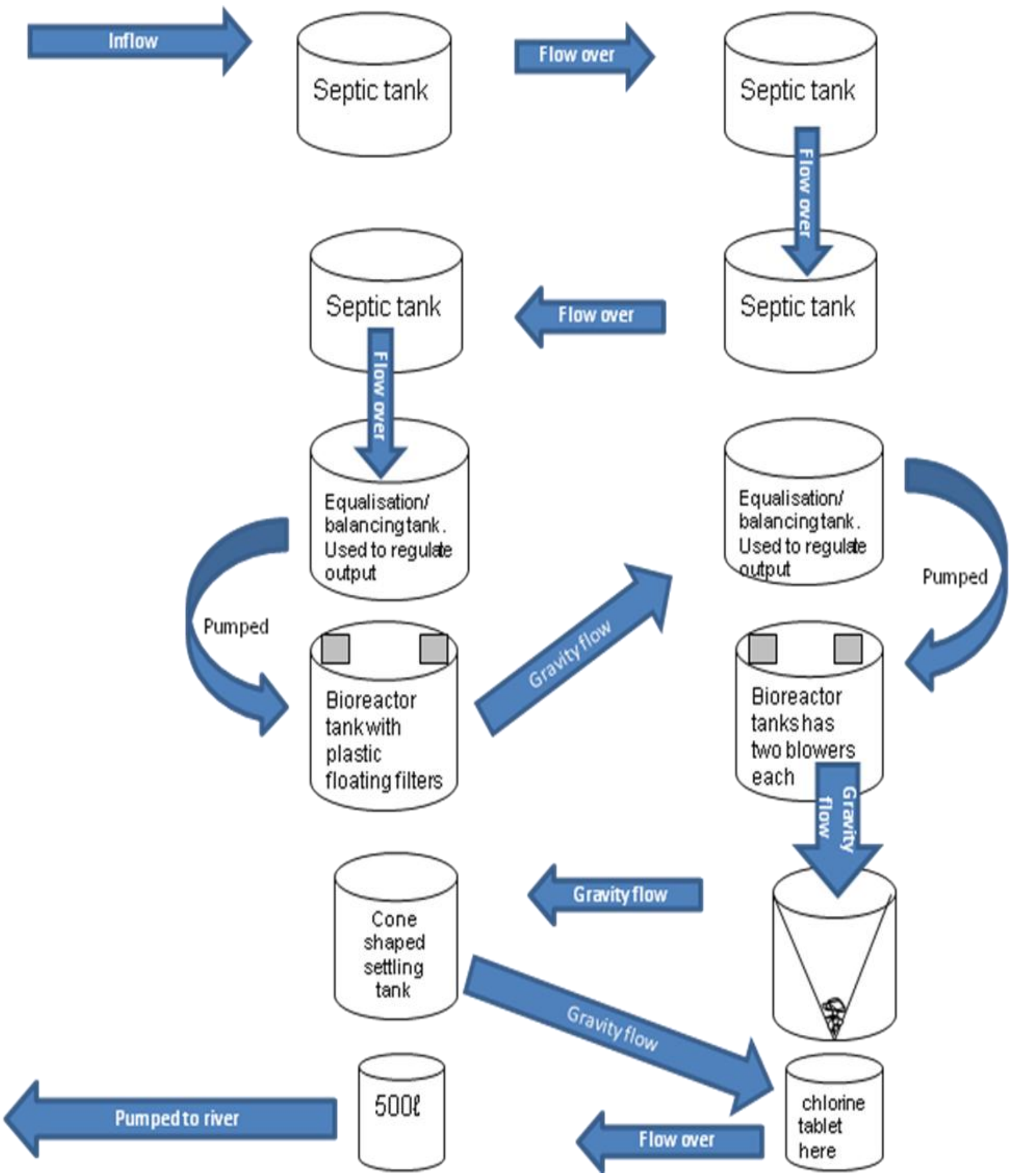

Figure 2:16: Diagram of selected package plant for research project.

The first four tanks are the septic tanks, from there the wastewater flows over to the equalisation tank and then it is pumped to the bioreactor tank that contains the plastic floating filters (Fig. 2.17).

Figure 2.17: Plastic filter media randomly packed in bioreactor tanks

The waste water then gravitates to another equalisation tank and is again pumped to yet another bioreactor tank. These bioreactor tanks both have two sets of blowers that are responsible for pumping air into the bottom of the bio-tanks. The sewage then goes to the clarifier tanks (there are two) which are cone shaped. The solids then settle out in the bottom of the cone and are then pumped back into the system.

The remaining liquid/effluent then goes to the disinfection tanks (also two of them) where it is treated with Brilliant Stabilised Chlorine Tablets with the active ingredient: Trichloroisocyanuric Acid 990g/kg. The entire system takes up land space of approximately 14.6m x 6.6m. It takes 28 days for the waste water to pass through the complete system and the effluent output is ±1000 litres per hour (personal communication: Plant operator[18], August 27, 2010).

2.2.7.1 Fat traps

The specific package plant described and studied for this research project also includes a fat trap (Fig. 2.18).

[18] Due to confidentiality agreement the name of the source could not be disclosed.

Figure 2.18: The underground fat trap used to remove fat from the kitchen waste water

Waste water that originates from the research site's kitchen area firstly goes through the fat trap before it reaches the treatment plant. Waste water from kitchens contains organic matter, fat, oil and grease. These oils and greases may have an influence on the waste water treatment plant by affecting aerobic and anaerobic processes (activated sludge systems), lead to high levels of BOD, clog pipes and cause an overall decrease in the system's efficiency and that is why removal of these substances prior to entering the package plant is essential (Kommalapati and Johnson, 2001; Brown, 2003). The liquid originating from the kitchens passes through these traps, usually consisting of various compartments. During retention time, the fat/oil/grease gets separated from the liquid portion and floats on the surface. There it accumulates and is then skimmed or pumped off, thus letting only the remaining liquid/waste water pass through to the waste water treatment plant (Brown, 2003). An illustration of a fat trap is shown in Figure 2.19.

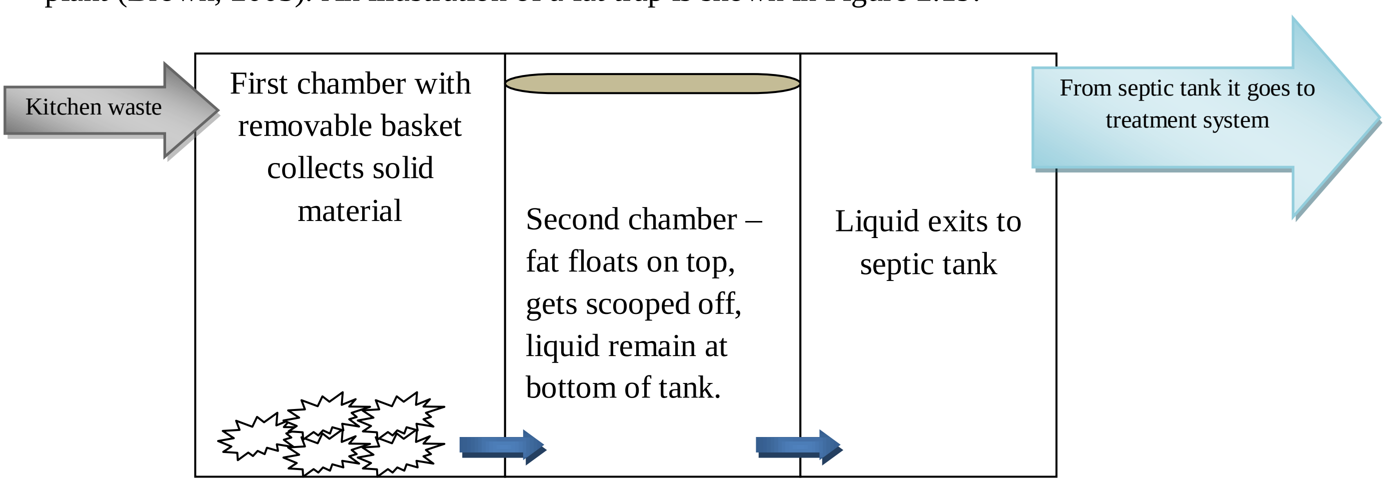

Figure 2.19: An illustration of a fat trap.

2.2.8 Summary

This section described what is meant by domestic sewage or waste water. It also highlighted the importance of treating these wastes as well as the treatment processes involved and showed the history of sewage and the advances that was made in treatment processes both internationally and in South Africa. Difference between conventional large scale treatment systems and package plants were mentioned as well as distinguishing between various types of technologies available, and although package plants are said to have advantages, a brief overview of common problems associated with these small on-site treatment systems was given. Lastly the submerged biological contactor system that was specifically chosen for this research was described. The concept of package plants is considered to be relatively new. Various studies have been done on the types, functions and efficiencies of small waste water treatment systems/package plants.

2.3 Research on Sewage Effluent and Package Plants

2.3.1 Global research on sewage effluents

In a study done by Kreissl and Cohen (1973), on the treatment capabilities of package plants in Ohio U.S.A, it was found that the overall effluent quality was of good standard. Tests involved COD, colour, odour, turbidity and coliform removal, all of which remained low and below acceptable standards. It was concluded in this study that “no conclusions can be drawn from this study concerning long term maintenance and operational difficulties”.

According to a study done by Hays (1976), on the potential for parasite disease transmission through sewage plant effluents, it was found that due to the weight of the parasite cysts, they tend to end up in the effluents and none of the treatment processes can guarantee complete removal of all the parasites.

This was confirmed by a study done by Paul *et al.* (1995), on the occurrence of faecal indicator bacteria in surface waters. It was found through sample taking and analysis that there was slight contamination of the rivers/streams in which effluents were being discharged.

However, a few years later Heistad *et al.* (2006) found that with the treatment of domestic waste with a small waste water treatment system, *E. coli* and coliphages concentrations in the effluent were below the acceptable standards. Nutrients and organic matter were also removed efficiently and it was thus concluded that discharging of the effluent will not have any significant impact on the environment.

Kistemann *et al.* (2008) compared various sewage treatment plants and their microbial removal efficiencies and found that smaller plants/package plants, with a capacity of 308-321m^3, had the lowest removal efficiency and their effluents were of poor quality, in particular with regards to the removal of *Giardia* cysts.

Wakelin *et al.* (2008) did an assessment study on the effect of a wastewater treatment plant's effluent on the ecology of bacterial communities in a freshwater stream. The study showed a strong cause-and-effect relationship between poor quality effluent discharges and high bacteria counts in the stream.

According to a study that was conducted by Ra *et al.* (2007), the biological toxicity of a wastewater treatment plant's effluent was evaluated using *Daphnia* and *Selenastrum* species. The study revealed that even though the effluents did comply with the recommended standards, they still showed biological toxicity to these species. It was concluded that different types of treatment processes have an effect on the toxicity levels.

The various studies all show different conclusions with regards to system efficiencies. However, the majority of studies show that there are problems with the operation, function and efficiencies of wastewater treatment plants (Hays, 1976; Paul *et al.*, 1995; Kistemann *et al.*, 2008; Wakelin *et al.*, 2008). Clearly the type of system, type of treatment process and proper operation and management of theses treatment plants have an effect on the quality of the effluent that will be produced.

2.3.2 Research in other parts of Africa

Haarhoff and Van Der Merwe (1996), studied waste water reclamation in Windhoek and found that acceptable effluent quality can be achieved if proper maintenance of the package plant (operations and equipment) and regular monitoring of the system functions and effluent quality is done.

The need for sufficient maintenance and operation was demonstrated in a study done by Nhapi and Tirivarombo (2004), on sewage discharges and sewage treatment efficiencies in Zimbabwe. It was found that high levels of nutrients such as nitrogen and phosphorous were present in samples taken from the Marimba River in which treated sewage was discharged. It was thus concluded that the treatment works were not operating sufficiently.

It is clear that efficiency of treatment plants plays a crucial role as demonstrated by yet another study done by Sajidu *et al.* (2007), on water quality and waste water treatment plant efficiencies. This study found that these plants do not entirely remove all heavy metals in effluents and that these pollutants enter the rivers via effluent discharge.

Various water assessment studies have been done in Ghana to determine the quality of the rivers. In a study done by Karikari and Ansa-Asare (2006), a water quality assessment was conducted in the Densu basin. The study showed that human domestic effluent, animal and agricultural activities are the main source of pollution and the cause of high levels of nutrients and poor microbiological quality.

According to studies done by Karikari *et al.* (2006) and Abdul–Razak *et al.* (2009) independently, on the assessment of water quality of both the Angaw River and the Oti River in Ghana, it was found that the physical and chemical parameters and microbiological quality was poor and above the accepted recommended standards. The studies concluded that the poor quality was due to human and animal waste entering the rivers as well as improper management of waste effluents discharged into the rivers.

It is thus clear from the above assessment studies that human activities and waste effluents have an impact on the overall water quality of the rivers and that constant, proper monitoring and management is required to ensure good quality water resources.

2.3.3 Research in South Africa

According to a study on package plants for small communities (Hulsman and Swartz, 1993), it was found that the activated sludge system provided effluent of good quality that conformed to the South African water quality standards.

However, Momba *et al.* (2009a) conducted a survey study of small wastewater treatment plants in seven South African provinces, by gathering information on system design, equipment, treatment methods and performance. It was determined that only 70% of these plants comply with the recommended standards and that problems mainly occurred with poor management and knowledge of the system operation as well as lack of water quality monitoring.

Gaydon *et al.* (2007), evaluated the sewage treatment of package plants for rural, peri-urban and community use in KwaZulu Natal. The study aimed to gain knowledge about sewage package plant technologies, identify suppliers and test the package plant performance. The study concluded that there are various challenges occurring with package plants such as poor design, maintenance, effluent quality and lack of legislation.

Clearly not all treatment/purification processes are efficient as was demonstrated by a study done on the prevalence of *Giardia* cysts and *Cryptosporidium* oocysts. It was found by Kfir *et al.* (1995) that these parasites are not completely removed during purification steps of sewage effluent thus, they end up in surface waters when being discharged and pose a health risk to communities using these surface waters for their daily activities. This study also found that incidence of Giardiasis and Cryptosporidiosis has been increasing and is one of the main causes of waterborne diseases causing diarrhoea.

A study done by Momba *et al.* (2009b) investigated the survival of certain viruses in treated sewage effluent. The study showed that even though disinfection with chlorine was applied, certain viruses were still present in the treated effluent which posed a health risk to the surrounding communities. They recommended alternative approaches to disinfection and proper management of the treatment plants.

Inadequately treated effluent does not only pose a health risk to humans but also to the environment. In a study done by Slabbert and Venter (1999) on the toxic effects of treated sewage effluent discharges in rivers situated in the Johannesburg and Pretoria area, it was found that all the acute toxicity tests had positive results indicating pollution of these surface waters.

In two independent studies done on the impacts of treated wastewater effluent on the quality of the receiving aquatic environment, both in the Eastern Cape Province in South Africa, by Igbinosa and Okoh (2009) and Odjadjare *et al.* (2010), it was found that the physical and chemical parameters did not meet the recommended standards. The results showed increased levels of nutrients, DO, COD and even certain pathogens. The study concluded that the poor quality of the effluent has a negative impact on the receiving water resources as well as posing a human health risk.

According to a study done by Morrison *et al.* (2001) on the impact of sewage treatment plant effluent on the Keiskamma River, the effects of these effluents being discharged into the river was once again demonstrated when the study showed that there were pollution of the river with high levels of orthophosphate, COD and ammonia. These pollutants posed a threat to the environment due to the possibility of causing eutrophication.

Various environmental problems can occur from discharging inadequately treated sewage into aquatic ecosystems. This was demonstrated in a study done by Oberholster *et al.* (2008) on sewage water pollution in the Rietvlei area. Macro-invertebrates were used to indicate possible pollution of the water. It was found that large concentrations of nutrients were present in the samples taken downstream from the discharged treated effluent. The presence of these pollutants was the cause of a decrease in species richness as well as premature hatching off certain organisms' eggs.

It is thus clear from the above literature review that there are many controversies surrounding the subject of package plants and their efficiencies for treating sewage and providing good quality effluent. However, it can be seen from the literature that proper maintenance and constant monitoring is very essential when it comes to operating a package plant so as to ensure a safe and clean environment and therefore the next section will deal with pollutants associated with sewage effluent from treatment facilities.

2.3.4 Key issues and major pollutants

2.3.4.1 Physical parameters

There are seven main water quality variables of concern. These are: temperature, electron conductivity (EC), turbidity, pH, dissolved oxygen (DO), BOD and suspended solids - all very important to the natural ecosystem (Strangeways, 2003). Of these seven parameters, pH, BOD and EC are recommended for waste water quality test (Dettrick and Gallagher, 2000).

High levels of **BOD** indicate human activity and high concentrations of organic matter, which lead to a decrease in oxygen levels in the receiving water. Low levels of dissolved oxygen (**DO**), causes animals and plants to die and is an important indicator of ecosystem health and reflects the capacity of the river to sustain life. **Temperature** fluctuations affect the metabolism of organisms. It also affects physical, chemical, biological and microbial activity. Increases in temperature also decrease the DO of the receiving water (Campbell, 2001).

Complex formation between acids and bases results in a solution having a **pH** value. The pH of water does not have direct health effects on humans (Department of Water Affairs, 1996a) but most aquatic organisms require a pH close to 7. Imbalances in pH may denature enzymes and proteins in aquatic organisms, inhibiting biological processes and affecting microbial activity. Water with a very acid pH cannot support life as it affects fish by increasing the gill permeability (Wright and Welbourn, 2002). This results in a loss of sodium and chloride ions through the fish's gill epithelium and finally the death of the fish.

The toxicity of other chemicals is also affected by pH changes, by changing their chemical states and increasing their solubility, and thus, increasing toxicity as is the case with ammonia (Department of Water Affairs, 1996a; Morrison *et al.*, 2001). It can also change the valence of metals allowing them to be taken up more easily by fish where they are then stored in the organism's body tissue and released again in the water when they die (Atlas, 1997; GeoCities, 1997; Campbell, 2001; Wright and Welbourn, 2002; Strangeways, 2003).

Suspended solids cause turbidity and decreased light penetration which leads to vegetation and fish deaths and also contribute to sediment formation in rivers. **Turbidity** is the measurement of the optical ability of water to cause light to be scattered and absorbed. It has no direct health effects but indirectly it affects microbiological quality. Thus, the more turbid the water the more growth of viruses and bacteria occur (Department of Water Affairs, 1996a). **Conductivity** is also important because it measures the ability of the water to conduct a current which indicates the concentration of ions/salt concentrations in the water. It gives the water a brackish taste and affects ecology and aquatic biota of the receiving water (Campbell, 2001; Morrison *et al.*, 2001).

2.3.4.2 Nutrients in package plant effluents

Some elements that occur naturally are important nutrients for living organisms and their normal growth. These nutrients, however, can become toxic at certain concentrations and effect organisms and human health (Das *et al.*, 2008). Nitrogen is primarily present as organic nitrogen, or the oxidised forms of nitrate and nitrite, or in the reduced form of ammonia (Dettrick and Gallagher, 2002). Sources of nitrogen include raw faeces and even treated sewage (Department of Water Affairs, 1996c). According to a study done by Oberholster *et al.* (2008) on sewage water pollution, it was found that nutrients lead to low concentrations of dissolved oxygen in the receiving water and caused ecosystem degradation.

An excess of nitrogen and phosphate pose a threat to water quality, ecology and biodiversity and can cause severe pollution of the receiving water (Nhapi and Tirivarombo, 2004; De Villiers and Thiart, 2007). These nutrients control biomass growth/are growth limiting factors and stimulate the growth of undesirable aquatic plants, algae and algal blooms which leads to eutrophication, oxygen depletion and ultimately death of aquatic organisms (Department of Water Affairs, 1996c; Morrison *et al.*, 2001; Dettrick and Gallagher, 2002; Nhapi and Tirivarombo, 2004; De Villiers and Thiart, 2007).

Nutrient enrichment can also be toxic to humans. Increased concentration of ammonia causes the formation of nitrite which is toxic to infants (Department of Water Affairs, 1996a). When nitrate (NO_3) is ingested, it is converted to nitrite (NO_2) in the gastrointestinal tract, this leads to natural intestinal bacteria reduction and gastrointestinal diseases (Department of Water Affairs, 1996a; De Villiers and Thiart, 2007).

Nitrite also combines with red blood cells in the human body, making these cells incapable of binding oxygen molecules. This blood disorder is known as methaemoglobinemia and is dangerous to infants and pregnant women. Nitrite can also react with amines or amides to form complexes known as nitrosamines. These complexes are carcinogens (Department of Water Affairs, 1996a; Morrison *et al.*, 2001). It is clear that high concentrations of nutrients such as nitrogen and phosphate have great impacts on the receiving water and its surrounding ecosystem, and also causes great concern when it comes to human health.

2.3.4.3 Pathogens that may occur in effluents of certain package plants

Pathogens/disease causing micro organisms can enter rivers via pollution caused by human activities such as discharging of untreated or inadequately treated sewage effluents. When humans use the receiving water or come into contact with waste water/sewage effluents, there is always a risk of disease transmission (Dettrick and Gallagher, 2002; Department of Water Affairs, Department of Health, Water Research Commission, 2002a). The pathogens in waste water that are of concern are listed in Table 2.3.

Table 2.3: Pathogens in waste water (Driscoll, 1986; Department of Water Affairs, Department of Health, Water Research Commission, 2002a).

Pathogen		**Disease**	**Source**
Bacteria	*Salmonella*	Typhoid fever	Human and animal faeces
	Shigella	Dysentery	
	Vibrio cholera	Cholera	

Table 2.3: Pathogens in waste water continued

Pathogen		Disease	Source
Enteric viruses	Poliovirus	Poliomyelitis	Human and animal faeces
	Rotavirus	Gastroenteritis	
	Adenovirus	Gastrointestinal and respiratory illness	
	Hepatitis A virus	Hepatitis	
Protozoan	*Giardia lamblia*	Giardiasis	
	Cryptosporidium parvum	Cryptosporidiosis	

Various pathogens can be transmitted via faecal polluted water. Indicator organisms are used to monitor the potential presence of these disease causing pathogens. The recommended indicators include: total coliforms, faecal coliforms, *Escherichia coli,* enterococci (faecal streptococci) and bacteriophages (Department of Water Affairs, 1996b). Paul *et al.* (1995) also indicated that faecal coliform, Clostridium and enterococci are very good indicators of faecal contamination.

Escherichia coli (E. coli) are used globally as warning of possible contamination with pathogens and, thus, as indicators of water quality deterioration (Department of Water Affairs, 1996b). Indicator organisms themselves do not pose a threat and are fairly easy to assay. They are, thus, chosen because they indicate that more serious pathogens are likely to be present (GeoCities, 1997). Due to the fact that coliform bacteria are abundant in the faeces/excreta of warm blooded animals they are commonly used as indicators of the sanitary quality of water bodies because their presence indicates or confirms faecal contamination.

In South Africa, many cases of diarrheal diseases are reported and treated each year and are one of the leading causes of death among young children (Steynberg *et al*., 2008). *E. coli* are, thus, used as an index to rate the purity of the water. Coliform bacteria are rod shaped Gram negative, lactose fermenters and produce acid gas when incubated at 35-37° C. They are easy to culture, show growth and colour reactions on certain types of culture media and tests are cheap, reliable and rapid.

E. coli is almost exclusively of faecal origin and its presence is an effective confirmation of faecal contamination and the presence of other waterborne pathogens. The World Health Organization (WHO) guidelines also state that indicator bacteria (Table 2.4) such as *E. coli* provide conclusive evidence of faecal pollution (Campbell, 2001; Morrison *et al.*, 2004; Robins-Browne, 2007).

Table 2.4: Indicators, genera and the pathogens they indicate (Department of Water Affairs, 1996a).

Indicator	**Genera**	**Pathogens**	**Diseases caused by pathogens**
Total coliforms	*E. coli, Citrobacter, Enterobacter, Klebsiella, Serratia, Rahnella*	*Salmonella, Shigella, Vibrio cholera, Campylobacter jejuni, Yersinia*	Gastroenteritis, Salmonellosis, Dysentery, Cholera, Typhoid fever.
Faecal coliforms	*E. coli, Klebsiella, Enterobacter, Citrobacter*	*Salmonella, Shigella, Vibrio cholera, Campylobacter jejuni, Yersinia*	Gastroenteritis, Salmonellosis, Dysentery, Cholera, Typhoid fever.

Many primary and secondary treatment options used in package plants do not destroy all the viruses and parasites due to the fact that they are resistant to purification processes such as chlorination. Cysts of parasites are heavy and thus, reach the final effluent easier. These cysts and eggs then reach the environment through discharge of the effluent where they remain infective for many years because they are very resistant to environmental stress and extreme conditions. Only one *Giardia* cyst is sufficient to cause infection. Thus, there is no guarantee that viruses or parasites will be completely destroyed during treatment processes and the fact that only occasional monitoring of viruses and very few monitoring of parasites are being done is cause for great concern (England, 1972; Hays 1977; Kfir *et al.*, 1995; Department of Water Affairs, 1996a).

Bacteria, viruses and parasites limit the use of natural water sources and pose a serious human health risk (Table 2.5). Once these pathogens are introduced into a community, it can be transmitted from person-to-person. Untreated or inadequately treated sewage effluent can thus be harmful to the environment and humans (Muller *et al.*, 2003; Kistemann *et al.*, 2008).

Table 2.5: Viruses and parasites of concern in waste water (Department of Water Affairs, 1996a).

Virus/ Parasites	Types	Disease
Enteric viruses	Enterovirus, Adenovirus, Reovirus, Rotavirus, Hepatitis virus, Calcivirus, Astrovirus	Paralysis, meningitis, hepatitis, respiratory illness and diarrhoea, pneumonia, gastroenteritis
Protozoan parasites	*Giardia lamblia*, *Cryptosporidium parvum*	Gastroenteritis, diarrhoea, vomiting, anorexia

2.3.4.4 Package plant treatment chemicals

Chlorine is used as a disinfectant chemical in waste water treatment plants. The process is known as chlorination and involves the treating of water or sewage with chlorine. This traditional method is used globally and is relatively inexpensive (Atlas, 1997; Williams *et al.*, 2003; Freese and Nozaic, 2004). The use of this disinfectant chemical has helped save many lives by preventing diseases such as cholera, typhoid, dysentery and other water borne diseases. Chlorine is very potent, easy to use and to measure the dose, very cost effective and shows good residual effect (Freese and Nozaic, 2004). It is used in three forms: gaseous, liquid and solid form depending on the size of the treatment plant and their economic state (Voortman and Reddy, 1997; Freese and Nozaic, 2004).

According to Williams *et al.* (2003), little research has been done on the effects of chlorine on the environment. It was discovered in 1970, that chlorinated compounds are formed during the chlorination process, and that these compounds can have possible effects on environmental and human health. These chemical by-products known as THMs (trihalomethanes), are highly toxic, carcinogens, accumulate in the food chain, leads to destruction of proteins and sexual reproduction problems (Hays, 1976; Atlas, 1997; Wright and Welbourn, 2002; Freese and Nozaic, 2004; Botkin and Keller, 2005). There was discontinuation of chlorination practices in 1990 in Germany after it became known that chlorine had a toxic effect on the environment and humans (Kistemann *et al.*, 2008). However, according to a study done by Freese and Nozaic (2004), on the effects of chlorine on the environment, there is no conclusive prove that THMs cause health problems when ingested via treated water sources.

Various other alternatives to chlorine have been suggested and used such as, iodine, ozone, hydrogen peroxide, silver, ultraviolet, paracetic acid and bromine. Some of these chemicals prove to be very effective in treating sewage, but they also have a few disadvantages. High concentrations of iodine can lead to thyroid problems (Guyton and Hall, 2000; Wright and Welbourn, 2002). Ozone is very expensive to use, has no residual activity and thus re-growth occurs, affects the respiratory system and does not remove all bacteria (Atlas, 1997; Freese and Nozaic, 2004; Botkin and Keller, 2005). Silver accumulates in biota and sediments, causing low productivity, altered reproduction and death of organisms (Wright and Welbourn, 2002). UV is costly and re-growth occurs. Paracetic acid does not kill parasites and bromine has a strong medicinal taste and does not kill all bacteria (Freese and Nozaic, 2004). Chemicals used in package plants may be very effective in treating sewage but the effects of these treatment chemicals on the environment and human health should be considered before it is released into the ecosystem or river catchments.

2.3.5 Summary

This section provided a literature review on various studies that was done, globally as well as in South Africa. These studies provided conclusions on the quality of effluent produced by various types of package plants and treatment systems as well as the important role that monitoring and maintenance of these waste water treatment systems play. The various pollutants that may be found in the effluent produced by certain treatment systems was also discussed as well as the effect that these pollutants have on the environment and humans and this only re-enforces the need for constant monitoring of not only the sewage effluent but also the surrounding aquatic environment receiving these discharged effluents to ensure that treatment systems adhere to guidelines and legislation and that effluent quality comply with standards.

2.4 Legislation and Standards

2.4.1 Water quality guidelines

Water quality guidelines as defined by the Department of Water Affairs and Forestry and the Water Research Commission (1995), are provided for water quality constituents and include quality criteria and target ranges that are used to assess the fitness of water for its intended use as well as treatment options. Requirements for treatment of domestic sewage effluents must adhere to either the General or the Special standards of wastewater quality standards. General limits are generally used unless wastewater is being discharged into sensitive areas such as dolomite or protected areas. In these cases the special limits apply (Government Gazette No 991, 1984). The standards applicable for discharge of waste water are listed in comparison Table 2.9 appearing later in this chapter.

According to Damafakir *et al.* (2009) and Gaydon *et al*. (2007), the current legislation in South Africa is not adequate enough to deal with package plants. The only current legislation relevant to package plants or more generally domestic waste water discharge include:

- National Environmental Management Act (Act 107 of 1998).

- National Water Act (Act 36 of 1998).
- Water Services Act (Act 108 of 1997).
- Local Government: Municipal Structures Act (Act 117 of 1998).

However, these legislative frameworks only provide general authorizations for discharging into rivers and do not state compliance levels of package plants. There is thus a need for a single set of regulations and discharge standards that are specific to package plants (Gaydon *et al*., 2007).

Damafakir *et al.* (2009) lists proposed legislative requirements (Table 2.6) for package plants in a four step process.

Table 2.6: Legislative requirements for package plants (Damafakir *et al.*, 2009).

Step One	Inform municipality of intent to install plant.
Step Two	Do Environmental Impact Assessment.
Step Three	Water Use Authorisation or Water Use License application.
Step Four	Audit done by Department of Water Affairs.

According to Damafakir *et al.* (2009) the minimum requirements that package plant owners should adhere to when applying for permission include:

- Providing of motivation for use.
- Provide exact location of installation.
- Provide information on the development type, package plant type and its flow characteristics.
- Catchment water quality objectives.
- Information on how effluent and sludge will be disposed of and type of disinfection methods.
- Installation must adhere to package plant specifications and building regulations.
- Provide copy of contract with supplier.
- Provide copy of operation and maintenance contract and employ a qualified operator.

- Supplier must provide training and operational manual and specifications plate.
- Registration at the Department of Water Affairs for Water Use Authorisation.
- Perform daily monitoring such as power checks, ensure air flowing, effluent looks and smells clean, pumps and motors running efficiently
- Perform compliance monitoring on qualities, quantities, frequency and reporting.

Damafakir *et al.* (2009) proposes quality requirements/ standards to be implemented with regards to package plants (Table 2.9).

A short anecdotal questionnaire (Appendix A) was given to the operator at the package plant used in this research project to see whether some of the above requirements were met in this specific situation. The results from the questionnaire showed that the plant manager/operator had no prior experience or qualification with regards to sewage treatment systems. The only training/information they received was a five page manual briefly explaining the system. They also did not receive a specifications plate for the system and there is no regular communication between the owner and the supplier. The operator do however monitor the system by doing daily inspections of the pumps and blowers, pH, chlorine and electrical conductivity checks every two weeks as well as analysis of effluent samples by the laboratory once every six months. They do keep record of all their data but only for personal use. When asked if the operator had any comments about the system or the country's waste water legislation the answer was no. He did however indicated that he had to install a chlorine dispenser into the system due to the fact that disinfection was not as successful when just placing the chlorine tablet into the tank as the suppliers suggested.

2.4.2 South Africa's legislative acts

The Constitution of the Republic of South Africa (Act no 108 of 1996) states that everyone has the right to a safe and protected environment through legislation that prevents pollution, degradation, promote conservation and sustainability (Constitution of the Republic of South Africa, Act 108, 1996). In South Africa the National Water Act (Act 36 of 1998) and Water Services Act (Act 108 0f 1997) are mainly used to manage wastewater. There are also 170 municipalities that act as Water Service Authorities in the country (United Nations World Water Development Report 2, 2006).

2.4.2.1 Water Services Act, Act 108 of 1997

According to Damafakir *et al.* (2009) this act clearly states that everyone has the right to access of water services but is subject to

- Allocation of resources

- Access regulation
- Payment by consumers
- Conservation of water
- Resource availability
- Topography, nature of the land.

The last two factors are some of the main reasons for installation and use of package plants due to the fact that some owners are not able to connect to municipal sewage systems. The Water Services Act (Act 108 0f 1997) makes provision for the regulation of only general wastewater treatment works operation, setting of general wastewater standards, gathering and publishing of information and record keeping (Water Institute of South Africa, Water Research Commission and East Rand Water Care Company, 2002).

2.4.2.2 National Water Act, Act 36 of 1998

The National Water Act (Act 36 of 1998) states that water is a natural and scarce resource that needs to be protected so as to ensure sustainability and that is why monitoring and management of sewage treatment works are of the utmost importance. The National Water Act (Act 36 of 1998) makes provision for all management aspects of water resources and provides general and special standards for waste water effluent (Table 2.9). It also clearly states that anyone who discharges waste water is required to have a license (whether it is municipal or privately owned), do monthly monitoring/analysis and keep records.

The National Water Act (Act 36 of 1998) also requires that acceptable maintenance is done, emergency measures and practices are in place as well as sludge removal in accordance with the requirements of the Department of National Health and Population Development (Appendix B) (National Water Act, Act 36 of 1998; Water Institute of South Africa, Water Research Commission and East Rand Water Care Company, 2002). Damafakir *et al.* (2009) argues that according to the National Water Act, Regulation 2834 only applies to municipal treatment works and not package plants. The National Water Act (Act 36 0f 1998) clearly states discharge of waste water of up to 2000 m³ per day is allowed – and 2000 m³ is the standard being used as part of the definition of a package plant in other literature (Laas and Botha, 2004; Gaydon *et al.*, 2007; Damafakir *et al.*, 2009). If viewed in this manner then it would seem that the National Water Act (Act 36 of 1998) does indeed make provision for package plants.

2.4.3 Policies in the country

2.4.3.1 Durban municipality policies

The need for legislation for package plants was becoming apparent and in the City of eThekwini guideline documents were set up with regards to existing package plants and installation of new package plants. The documents (Policy Documents 8 and 12) clearly states that operation and performance monitoring of package plants must be done by the department's pollution division with regards to type, design and efficiency and that all package plants must comply with general limits for domestic wastewater discharge as it is stated by the National Water Act (Act 36 0f 1998) (Laas and Botha, 2004) (Table 2.9 and Table 2.7).

Table 2.7: Monitoring requirements for package plants (Laas and Botha, 2004; Gaydon *et al*., 2007).

Discharge Volume per day	**Monitoring Requirements**	**Monitoring frequency**
Less than 10 m³	Basic tests should include: faecal coliforms (per 100 mℓ) Chemical Oxygen Demand (mg/ℓ) Ammonia as Nitrogen (mg/ℓ) Suspended Solids (mg/ℓ)	Annually
10 to 100 m³ And 100 to 1000 m³	Intermediary tests should include the basic tests above, plus: pH Electrical Conductivity (rnS/m)	Monthly
1 000 to 2 000 m³	Advanced tests should include the intermediary tests above, plus: Nitrate/Nitrite as Nitrogen (mg/ℓ) Free Chlorine (mg/ℓ) Ortho-Phosphate as Phosphorous (mg/ℓ)	Monthly

According to Laas and Botha (2004) inspections and sampling of package plants are done every six months by the Pollution Division and owners are required to submit analysis results on a regular basis to the local municipality. The policies also indicate that an application for permission to install a package plant must be made to the eThekwini Water and Sanitation Unit.

This application must include details of the developer/engineer/manufacturer, information of the property/area/position of installation, package plant size, type, quantity, point of discharge and an environmental assessment report (eThekwini Municipality, 2005).

2.4.4 Bylaws in South Africa

2.4.4.1 East Rand municipality

The Ekurhuleni Metropolitan Municipality Public Health by-laws also seem to make provision for privately owned sewage works but do not specify size or volume of these works and therefore it is difficult to establish whether it includes package plants. These by-laws state that a permit is required for installation of any sewage works, the plant must be maintained at all times and disposal of effluent may not cause environmental or health concerns (Ekurhuleni Metropolitan Municipality Public Health By-Laws, 2009).

2.4.4.2 Johannesburg municipality

<u>Water services by-laws</u>

The Johannesburg City by-laws stipulate that any person who wishes to operate any sort of sewage disposal system must have authorization by the municipality. The by-laws also states that if there is no infrastructure/connection to the municipality, owners can apply for approval to install on-site sanitation services at their own cost, in accordance with council specifications and the municipality may also specify the type of on-site system that is to be installed (City of Johannesburg Metropolitan Water Services By-Laws, 2004). Although the by-laws make provision for on-site systems, there is no mention whether it is privately owned and the capacity of the systems, again making it difficult to establish if it includes package plants.

<u>Public health by-laws</u>

The public health by-laws of Johannesburg City however makes mention of private sewage works and states that a permit is required for installation of these sewage works and that it must be maintained at all times (City of Johannesburg Metropolitan Water Services By-Laws, 2004). But no mention is made of the capacity of the systems.

2.4.4.3 West Rand municipality

In the West Rand District Municipal Health Services by-laws provision is also made for private sewage works and states once again that a permit is required for installation of these sewage works and that these systems must be maintained and cleaned. Private sewage works may only be installed if there is no connection to the municipal system available but do not specify the size of the systems (West Rand District Municipality: Municipal Health Services By-laws, 2010). These health services by-laws also indicates the laboratories to be used for analysis of effluent samples that is acceptable by the West Rand District Municipality and states that waste water effluent should be sampled and analysed twice a year, every six months (West Rand District Municipality: Municipal Health Services By-laws. 2010). See Table 2.8.

Table 2.8: Laboratories to be used for analysis (West Rand District Municipality: Municipal Health Services By-laws. 2010).

Laboratory	Bacteriological	Physical	Chemical
National Health Laboratory Services	√	√	√
National Health Laboratory Services - Departments of Health – Forensic Laboratory – Pretoria & Cape Town.	X	√	√
Mogale City Local Municipality – Water Care Works Laboratory	√	√	√
CSIR	√	X	X

2.4.4.4 Mogale City municipality

There are various package plants in the Mogale City area. The analysis of the samples taken for this research project was done by the Mogale City Laboratory. General waste water standards from the Department of Water Affairs are used by this laboratory and are shown in the comparison Table 2.9.

2.4.5 Comparisons of South Africa's standards and legislation

It is clear from the above information that there is still not absolute clarity to whether provision are made for package plants in South Africa's legislation. Most of the current legislation only make provision for general sewage and do not consider package plants as a separate factor. Where mention is made of on-site or privately owned systems no clear distinction is made of the type or capacity (whether the systems discharge more or less than 2000 m^3 per day). Tables 2.9

and 2.10 attempt to compare and summarize standards and legislation available in South Africa for general sewage and effluent from package plants.

Table 2.9: Comparison of waste water quality standards in South Africa (National Water Act, Act 36 of 1998; Water Institute of South Africa, Water Research Commission and East Rand Water Care Company, 2002**;** Government Gazette No 399, 2004; City of Johannesburg Metropolitan Water Services By-Laws, 2004; Damafakir *et al.*, 2009; West Rand District Municipality: Municipal Health Services By-laws. 2010).

Analysis	**National Water Act**		**Government Gazette No 399**	**JHB Water Service by-laws**	**West Rand council by-laws**	**Mogale City Lab**	**WISA, ERWAT & WRC**	**Proposed standards by Damafakir *et al.*, 2009.**
	Gen. limit	**Special limit**						
Faecal Coliform (per 100 mℓ)	1000	0	1000	*	0	1000	*	1000
Faecal Strep per 100mℓ	*	*	*	*	*	230	*	*
COD (mg/ℓ)	75	30	75	*	75	75	40 – 70	75
DO %	*	*	75	*	*	*	*	*
pH	5.5 – 9.5	5.5 – 7.5	5.5 – 9.5	*	5.5 – 9.5	5.5 – 9.5	6.5 – 8.0	5.5 – 9.5
Ammonia as Nitrogen (mg/ℓ)	3	2	6	*	10	10	8	6
Nitrate/ Nitrite as Nitrogen (mg/ℓ)	15	1.5	15	50	*	*	40	15
Chlorine as Free Chlorine (mg/ℓ)	0.25	0	0.25	*	*	*	*	0.25
SS (mg/ℓ)	25	10	25	*	25	25	5 – 25	25

Table 2.9: Comparison of waste water quality standards in South Africa continued

Analysis	National Water Act		Government Gazette No 399	JHB Water Service by-laws	West Rand council by-laws	Mogale City Lab	WISA, ERWAT & WRC	Proposed standards by Damafakir *et al.*, 2009.
	Gen. limit	Special limit						
TDS (mg/ℓ)	*	*	*	*	*	1625	*	*
EC (mS/m)	70 - 150	50 – 100	70 - 150	500	*	250	*	70 - 150
Ortho-Phosphate as P (mg/ℓ)	10	1 – 2.5	10	*		1	0.5 – 10	10
Chlorides	*	*	*	1000	*	*	*	*

*No standard provided

Table 2.10: Comparison between laws/acts making provision for private sewage works (National Water Act, Act 36 of 1998; City of Johannesburg Metropolitan Water Services By-Laws, 2004; Ekurhuleni Metropolitan Municipality Public Health By-Laws, 2009; West Rand District Municipality: Municipal Health Services By-laws. 2010).

	National Water Act	JHB Water Services By-Laws	JHB Municipality public health By-Laws	West Rand District Municipality health by-laws	EKURHULENI health by-law
Waste water limit values/standards	√	√	x	√	x
Bylaws on domestic sewage	√	√	√	√	√
Bylaws on private sewage works	x	x	√	√	√
Capacity of sewage works	2000 m^3	x	x	x	x

2.4.6 Summary

The above literature review discussed the importance of South African water resources and the impact that untreated or inadequately treated sewage have on the surrounding environment. The importance of treatment as well as the various types of treatment methods was mentioned. Package plants in general and the one selected for this research in particular were discussed and previous literature and case studies were highlighted. A brief discussion of the legislation and standards available on waste water was also provided. With regard to the information gathered during this literature review, the research problem (statement) for this study is that the overall quality of the water resources of Mogale City and the domestic sewage effluent produced by the specific package plant and discharged into the environment is unknown.

2.5 Problem Statement

Due to the rapid increase in population in the area which has led to an increased need for treatment and disposal of domestic waste, the aim of this study is to determine the quality of the effluent that is being discharged from the package plant into the environment via natural waterways and whether maintenance and monitoring has an impact on the final effluent quality.

The main research question for this research study:

What is the overall quality of the water resources at the study site as well as the effluent that is being discharged from the package plant into the environment via natural waterways and does maintenance and monitoring have an impact on the final effluent quality?

2.6 Sub-questions

In order to obtain information and a better understanding of package plants and water resource assessment, the following *sub-questions* were addressed in this study:

- What is the overall quality (physical parameters) of the sewage effluent of the selected package plant?
- What is the concentration of coliforms present in the sewage effluent discharged by the package plant?
- What is the concentration of nutrients (N and P) in this sewage effluent?
- Is this type of package plant efficient in treating effluent?
- What impacts do maintenance and monitoring of the package plant have on the quality of the sewage effluent?

- What is the overall quality (physical, chemical and biological) of the water resources (river, two boreholes and two dams) on the study site?

2.7 Hypotheses

A review of the background information led to the following *hypotheses*:

H0) Effluent of the selected package plant (submerged biological contactor) for this study is of good quality and has no effect on the surrounding environment.

H1) Effluent of the selected package plant (submerged biological contactor) for this study is of poor quality and has an impact on the surrounding environment.

H2) Effluent of the selected package plant (submerged biological contactor) for this study is of poor quality but has no effect on the surrounding environment.

H3) Effluent of the selected package plant (submerged biological contactor) for this study is of good quality and has a positive impact on the surrounding environment.

2.8 The Objectives

- To measure the physical parameters of effluent being discharged so as to determine the effluent quality.
- To determine the concentration of coliforms present in the sewage effluent.
- To determine the nutrient concentration present in sewage effluents.
- To determine the efficiency of the selected type of treatment system used in this study by determining the quality of the effluent it produces.
- To determine the effect that maintenance and monitoring of the selected treatment system have on the sewage effluent quality.
- To determine the overall water quality (physical, chemical and biological) of the river, two dams and two boreholes located on the study site.

2.9 Motivation, Value and Benefit of Study

The rapid increase in population has led to an increased need for treatment and disposal of domestic sewage. There are various reasons for the importance of efficient sewage treatment such as:

- environmental considerations – unacceptably treated sewage is a source of pollution. It causes oxygen depletion which leads to the death of aquatic organisms, as well as built up of solids and eutrophication of natural waterways.
- human health considerations - sewage contains a large amount of disease-causing pathogens that can be potentially harmful to the community (Water Institute of South Africa, Water Research Commission and East Rand Water Care Company, 2002).

Various South African studies have been done to show the impacts of inadequately treated sewage on the environment as well as health risks to humans. According to Hays (1976) and Paul *et al.* (1995), discharging of treated sewage into rivers and streams causes high levels of pollution and nutrient loading and thus, eutrophication as well as microbial contamination and the spread of disease. Toxic metals enter the waterways and accumulate in the ground water and soil. According to De Villiers and Thiart (2007), point source pollutants such as sewage effluent, is one of the major contributors of nutrient loading in South African rivers. Sampling results from 20 large rivers in South Africa showed that nutrient levels are exceeding the recommended water quality standards and are a cause of concern with regards to water quality, environmental health and biodiversity (De Villiers and Thiart, 2007).

The need for proper monitoring and treatment is also reinforced with a study done by Kfir *et al.* (1995), which stated that there is very little information available on the spread of parasites in South African water ways and water quality standards or guidelines for protozoan parasites should be implemented. According to Kistemann *et al.* (2008), there are no regulations with regards to microbial pollution, parasites in particular, of sewage effluents and pathogens such as *Giardia* and *Cryptosporidium*. These pathogens will limit utilization of water sources as well as pose serious health risks to humans and with South Africa's demand for water increasing, management of quality is essential and a need for frequent quality testing are increasing. Thus, it can be concluded that waste water causes toxic effects on the aquatic environment and the quality of effluent needs to improve drastically so as to conserve the ecosystem (Oberholster *et al.*, 2008).

It is clear that sewage treatment and disposal have a significant impact on the environment and communities, therefore, it is of the utmost importance that there are standards and legislation with regards to domestic sewage effluent from package plants, whether discharged into rivers or used for other purposes such as irrigation. These package plants need to operate and function efficiently and need to be monitored on a regular basis so as to produce good quality effluent. It is crucial that certain analytical tests be done on a monthly basis and systems are inspected regularly. Records should also be kept of the construction, operation and maintenance of these plants. These records should include the plans of the design, laboratory records, flow and performance records and emergency and maintenance records (Water Institute of South Africa, Water Research Commission and East Rand Water Care Company, 2002).

Three main factors impacting South Africa's water resources have been identified and they include climate, rapid population growth and management of water resources. The freshwater resources of this country are under severe stress due to the increasing population and consequent demand for water. This demand, however, is leading to increased volumes of industrial and domestic effluents being discharged which in turn are polluting the ground and surface waters and ultimately affecting the natural ecosystems. Pollution of these water resources remains a huge problem and constant monitoring and assessment is needed to ensure good quality and sustainability of South Africa's natural waterways (Walmsley *et al.,* 1999).

2.10 Justification for Research Project

Mogale City has identified an opportunity for UNISA to work together with Mogale City Council on improving the efficiency of monitoring package plants in the area. There has been an increase in on-site treatment sewage systems over the years in the Mogale City area. Various research studies have been done on package plant systems involving the types, processes and single aspects of effluent quality. However, it was identified in that very little research has been done on effluent quality from small on-site domestic sewage treatment systems in the Mogale City area. A NEXUS search was done on the database of the National Research Foundation for current and completed research. Twelve research projects were found on sewage effluent and none on package plants. No research title was found that is similar to this proposed research. Therefore, it was recognized that Mogale City needs to be able to advise package plant owners on monitoring and managing their systems with regards to effluent quality, standards, system approval and license application procedures and government legislation.

This research is based on a case study approach and determines the quality of the effluents produced by the package plants and whether the effluent quality is of acceptable standards. The study analyses domestic effluent quality with regards to the microbial, chemical and physical parameters and includes a comparison between:

- Types of package plant systems.
- Literature – comparing previous, existing literature/ case studies.
- Comparing results and data obtained during this study to existing standards, guidelines and legislation.

Results of this study may be beneficial in developing management/monitoring strategies for package plants and providing possible recommendations with regards to on-site domestic sewage treatment works' effluent standards and specific legislation/guidelines for package plants in the Mogale City area so as to improve service delivery to the community, effluent quality and overall environmental and human health. This research project thus formed part of a

Memorandum of Agreement that was signed between UNISA and Mogale City on the 23rd March 2011 (Appendix C Fig. 2.20 and 2.21).

According to the State of the Environment Report for the Mogale City Local Municipality (2003), there are also various other gaps/recommendations that still require attention. These include development of an integrated water pollution management system, development of a ground and surface water monitoring program which should include identification of point and non-point pollution sources as well as promoting education and awareness about water management and conservation. It is proposed that this research study not only focuses on the package plant but also include a water resource quality assessment of the rivers, dams and boreholes that are located on the study site so as to not only provide the owners of the site, but also the Mogale City Local Municipality with an assessment report. The information/data obtained during this study could aid in making future decisions and recommendations with regards to impact studies/assessments or risk assessments/water safety plans for all parties involved.

Chapter Three

3. Methodology

Research involves solving specific problems through the use of various methods so as to gain new knowledge or reach a desired goal. Research methodology is concerned with the planning, design and implementation of methods used to gather data (Sheehan, 1986).

The research design selected for this research study is a mixed-method design consisting mainly of quantitative research but includes some aspects of qualitative research as well as (Mouton, 2001). Mixed method research is defined by Johnson *et al.* (2007) as the type of research that combines aspects of qualitative and quantitative methods for the broad purpose of understanding and validation.

This research design included a field or natural experimental study (Mouton, 2001). Experimental research is concerned with cause and effect relationships that are expressed in different variables (Sheehan, 1986).

The aims and objectives, measurements and sampling were specified prior to the data collection. A literature study was also included on all the factors and aspects of the variables and phenomena. Secondly a questionnaire was given to the plant operator to gather information on the treatment system that was selected for this research (Leedy, 2005).

Data from both the quantitative and qualitative research was used and integrated to draw conclusions from the findings, answer the research questions and support the recommendations.

The flow chart in Figure 3.1 outlines the approach that was taken to conduct this research study.

3.1 Qualitative Research

Qualitative research is used to attempt to make sense of phenomena or to interpret data in terms of the meanings/opinions of other people through the use of interviews or questionnaires (Murray, 2003). The data for this section of the research study was collected through the use of an anecdotal questionnaire (Appendix A) that was given to the package plant operator.

Various questions were asked about the monitoring, maintenance and efficiency of the plant as well as personal experiences of the operator. The answers or personal views given by the plant operator was integrated and compared with the findings from the quantitative research as well as with the existing literature available on package plants and used to assist in drawing a conclusion and making of recommendations (Leedy, 2005).

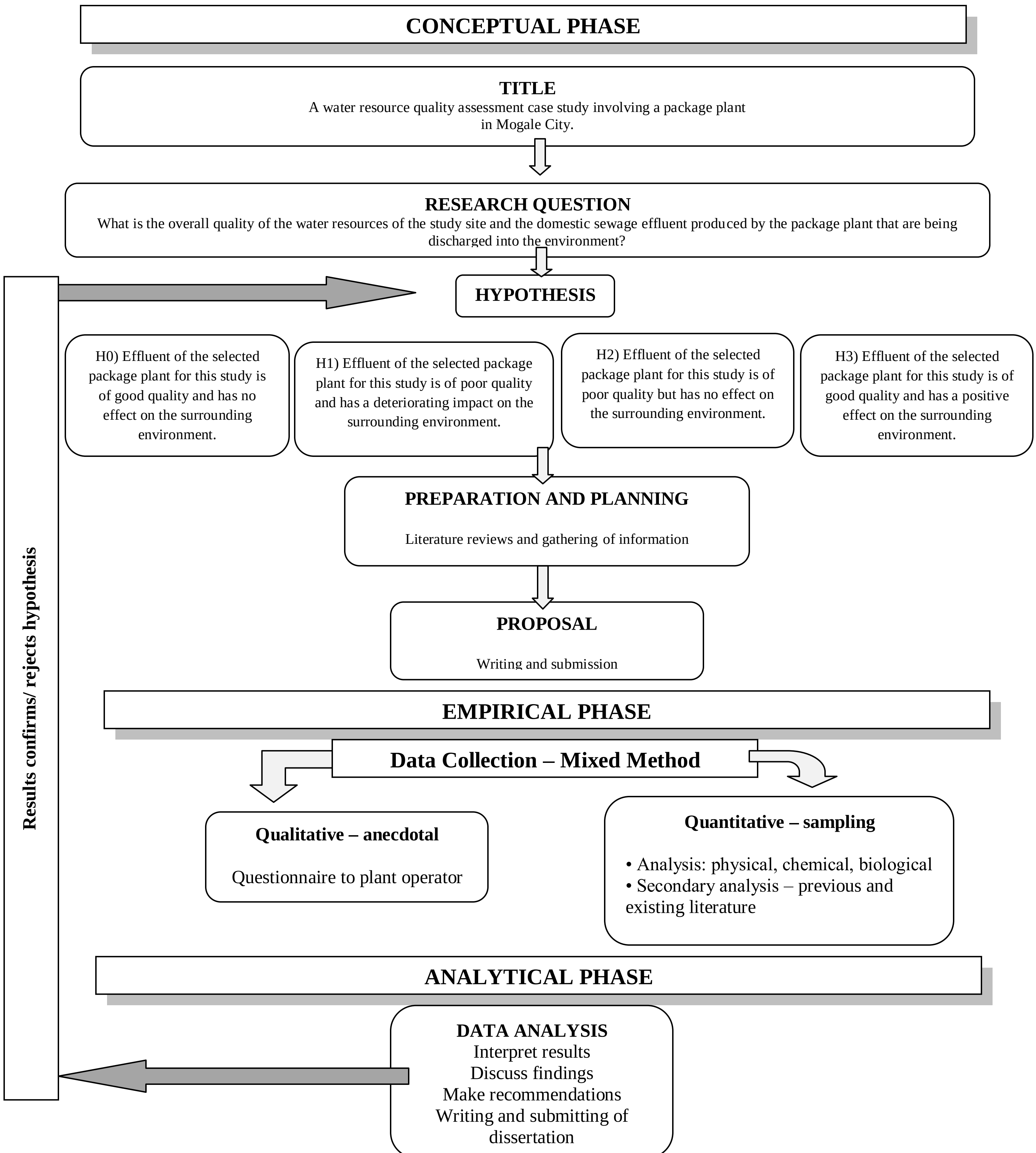

Figure 3.1: Research design

3.2 Quantitative Research

Quantitative research involves the use of numbers and statistics. It is the measurement and observation of phenomena to test a hypothesis by use of sampling and experimentation that provide results. These measurements and analyses however, must be easily replicable by other researchers (Murray, 2003).

Quantitative research is used to answer questions about cause and effect relationships between different variables that can be measured. These variables are dependent and independent. The ***independent*** variables (IV) are variables that caused a change in the dependent variable, thus the presence of certain pollutants in the final sewage effluent causing the poor quality of the effluent, or pollutants from the effluent causing deterioration in the quality of the river. The ***dependent*** variables (DV) are variables that are influenced, and include effluent produced by the package plant or the receiving river (Sheehan, 1986; Leedy, 2005).

3.3 The Research Site

The research site for this research project is situated in Mogale City and falls within the boundaries of the Cradle of Humankind (Fig. 3.2).

Mogale City is considered as a unique area within Gauteng, South Africa due to its rich natural and cultural heritage. The city was named after Chief Mogale, heir to the Po Chiefdom (State of the Environment Report for the Mogale City Local Municipality, 2003). This area is still developing and the infrastructure in certain parts of the city, are still insufficient. Mogale City has exclusive suburbs, middle class residential areas, townships/informal settlements and rural areas[19]. The specific research site for this research is about 600 hectares in size and part of the property has been set aside for development. This site consists of a wide variety of natural habitats, animal and bird species.

The water resources on the research site include two boreholes, two dams and a river flowing through the site. Access to the site was gained with the help of the Mogale City Council and information and consent forms were provided to all parties involved which also stated that the site will remain confidential (Appendix D). A good working relationship was established with Mogale City Council, Mogale City Laboratory as well as the owners of the research site.

[19] www.mogalecity.gov.za

Figure 3.2: Map of South Africa[20], indicating the location of Mogale City[21]

[20] http://www.nationsonline.org/oneworld/map/za_provinces_map.htm

3.4 Data Collection

Ten sample sites were selected for this research study and they include:

- Two dams – one sample site at each dam
- Two boreholes – one sample site at each borehole
- River – four sample sites along the river (where river enters the property, where river exits the property, directly before and after the package plant).
- Package plant – two sample sites within package plant (one where sewage enters plant and one site where sewage exits plant).

3.4.1 Type of samples

Grab samples was taken at each sample site. Samples were taken at the same area each time to ensure consistency.

3.4.2 Method of sample collection

Water samples were taken at the dams and river as set by the requirements of the SABS:

- Holding base of container/glass bottle
- Immersing at approximately 300mm
- Allow to fill upstream
- Stored in container at 4°C-10°C
- Samples were taken to a laboratory in Mogale City to be analyzed within 24 hours
- Glass bottles/containers were cleaned prior to use with diluted nitric acid and distilled water (SABS, 1984; Das *et al.*, 2008; Oguttu *et al.*, 2008).

Water samples from the one borehole was taken directly out of the tank/reservoir by holding bottle at base and immersing at approximately 300mm. Samples from the second borehole was taken from a tap that was installed for easy access. The tap was opened and allowed to run for approximately five minutes before samples were taken. These water samples were stored in container at 4°C-10°C and taken to a laboratory in Mogale City to be analyzed within 24 hours.

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[21] http://www.geda.co.za/G_Atlas/index.php?option=com_content&view=article&id=86:mogale-city-mineral deposits&catid=45:gauteng-mineral-deposits-and-status&Itemid=37

Samples from the package plant influent was taken from a pipe with a valve that open and closes for easy access and is attached to the first tank (septic tank) of the system and samples from the effluent were taken from a tap that was installed on the disinfection tank to allow easy access. In both instances the waste water was allowed to run for approximately 2-3 minutes before the samples were taken. These influent and effluent samples were stored in container at 4°C-10°C and taken to a laboratory in Mogale City to be analyzed within 24 hours.

Macroinvertebrates samples for the habitat assessment were taken at the same upstream and downstream sites of the river used for the other samples. Collection of macroinvertebrates for the SASS 5 assessment were done by kicking big rocks in and out of current for approximately two minutes and capturing organisms with a handheld sampling net. The contents were then emptied into a tray filled with water. Small rocks, pebbles, mud and sand were also kicked for approximately one minute and then the contents of the handheld net was again emptied into a second tray filled with water. Lastly vegetation submerged in river water was sampled with the handheld net (5 to 7 nettings) and the contents were emptied into a third tray. IHI and IHAS assessments were done through observations and filling in of scores on assessment sheets. Fish were sampled using an electro shocker and a net.

3.4.3 Frequency and time of sampling

To monitor efficient performance of a treatment works a certain amount of sampling and analysis is required. Weekly analysis is preferred but due to research restrictions, monthly samples are acceptable (Water Institute of South Africa, Water Research Commission and East Rand Water Care Company, 2002). Table 3.1 provides information on the minimum and recommended sampling frequencies for different sampling points.

Table 3.1: Minimum and recommended sampling frequencies (Department of Water Affairs and Forestry, Department of Health, Water Research Commission, 2000a).

Sample point	**Minimum sampling frequency**	**Recommended sampling frequency**
River or stream	3-monthly	2-weekly
Dam	6-monthly	2-weekly
Borehole	Once a year	6-monthly
Treatment works	3-monthly	Monthly/weekly/daily

Samples of all the points were taken every second week for a time period of 12 months. This was done to ensure a representative sample. Samples were taken on approximately the same time of day for each site and in the same order every time. This was done to ensure consistency in sample taking and the outcome of the results due to the fact that the time of day may influence the results as a result of temperature changes. Duplicate samples of each site were also taken – one sample was used for the biological assay and the other for the chemical assay. The samples for the habitat assessment were taken once every six weeks (a total of six samples throughout the 12 month time period) so as to allow the river enough time to recover after each sampling session.

3.4.4 Equipment used during sampling

- Protective clothing such as boots and gloves
- Sterile glass Schott sample bottles with lid (one 500mℓ bottle for the chemical assay at the dams, boreholes and river sample sites)
- Sterile plastic Whirl packs (500mℓ plastic bags) for all microbiological samples of boreholes, river and dams.
- 500mℓ HDPE Gamma sterilised plastic bottles with lid for all samples (chemical and microbiological samples) of package plant.
- Waterproof marker
- Cooler box with plastic ice packs
- On site data recording book/sample diary which was kept for data recording and providing information to the laboratory.
- Waders for entering river
- Macroinvertebrate handheld sampling net (approximate size 30x30cm)
- Three macroinvertebrate trays (approximate size 40x50cm)
- Electro shocker and fish net

3.4.5 Other data collection techniques used

- Observations – on the state/condition of the surrounding environment, types of animals and vegetation present in the area and state/condition of treatment plant. Photographs were taken to record certain aspects of the research observations.
- Documentation – journals, literature texts, reports and articles, as well as information on the internet was collected from the data bases of the UNISA libraries. This was then

integrated with the data already obtained through observations and measurements, so as to compare and add any new insights and information during the research process (Leedy, 2005).

3.5 Data Analysis

3.5.1 Physical analysis

The analysis for the physical parameters (electrical conductivity, pH, temperature, dissolved oxygen, Total Dissolved Solids) was done on-site with a Martini MI 806 pH/EC/TDS/Temperature Portable Meter and a hand held EcoSense DO200 Field/Lab Dissolved Oxygen and Temperature Instrument, according to the supplier manual instructions. These parameters are determined on-site due to the fact that they may change as soon as the sample is taken (Department of Water Affairs and Forestry, Department of Health, Water Research Commission, 2001). A sample was taken with a 500mℓ glass Schott bottle, the probes of the hand held meters were inserted into the sample, stirred gently and a reading was taken of the specific parameter as soon as the reading stabilised or the clock symbol on the display screen stopped blinking. The results were then noted in a sample diary. These physical parameters were done on all samples.

The analysis of free chlorine concentrations in samples was done using an on-site chlorine test kit called a Visocolor HE Chlor kit and was done according to the supplier manual instructions. A water sample was taken with a 500mℓ glass Schott bottle. The colour comparison disc was then placed into the comparator block. Two glass tubes were opened, rinsed with the water sample and then filled up to the mark with the water sample. One level black measuring spoon of Cl-1 was then added to the tube on the right hand side as well as 12 drops of Cl-2. The tube was then closed and shaken to mix the content. The reading was then taken immediately by turning the colour disc until both colours of both tubes match by transmitted light from above. The results are read from the mark on the front side of the comparator. These free chlorine tests were done on all river samples as well as the package plant effluent samples.

The biological and chemical analysis for this research study was done by the Mogale City Laboratory as per their Standard Operating Procedures. This laboratory belongs to the SABS Water check Proficiency testing programme as well as the National laboratory Association for proficiency testing. The following methods listed and described below are similar to those used at the Mogale City Laboratory and are according to the standard methods for the examination of water and wastewater (Greenberg *et al.*, 1992).

3.5.2 Biological analysis

The following biological analysis was done according to the methods listed in Table 3.2.

Table 3.2: Methods used to analyse indicator organisms in water samples (Greenberg *et al.*, 1992).

Indicator organism	**Analytical procedure**	**Growth medium**	**Incubation**	**Colony growth**
E. coli cells/100 mℓ	Membrane filter procedure	MacConkey Agar	Incubate agar plate upside down at 44.5 °C for 20 - 22 h	Count all colonies with yellow colour
Faecal coliform cells/100 mℓ	Faecal coliform Membrane filter procedure	(m-Fc Agar)	Incubate agar plate upside down at 44.5 °C for 24h	Count all colonies with dark blue colour
Faecal *Streptococcus* cells/100 mℓ	Membrane filter procedure	m-*Enterococcus* agar	Incubate t agar plate upside down at 35 °C for 48 h	Count all colonies with dark red colour

Materials and equipment used:

Membrane filtration unit with vacuum pump, sterile forceps, culture dishes and an incubator, growth medium (Greenberg *et al.*, 1992).

Membrane filtration method:

A volume of sample was selected and a sterile filter was placed with sterile forceps over the porous plate of the receptacle. The funnel was locked on and filtered with the vacuum. The funnel was rinsed and the membrane filter was removed with the forceps. The filter was then placed on the growth medium in the petri dish and incubated (Greenberg *et al.*, 1992).

3.5.3 Chemical analysis

3.5.3.1 Ammonia

Selective Electrode Method.

Apparatus used:

Electrometer, ammonia selective electrode, magnetic stirrer and a beaker (Greenberg *et al.*, 1992).

Reagents used:

Ammonia free water, sodium hydroxide solution, stock ammonium chloride solution and standard ammonium chloride solution (Greenberg *et al.*, 1992).

Selective Electrode Method:

A series of standard solutions were prepared (1000, 100, 10, 1 and 0.1mg/ℓ) and placed into a beaker. The electrode was then immersed into the solution and stirred with the stirrer. 10*N* of sodium hydroxide was then added to the solution and the reading was taken after five minutes (Greenberg *et al.*, 1992).

Calculation:

mg NH_3 – N/ℓ = A x B x (101 + C/101).

A = dilution factor

B = concentration of NH_3 – N/ℓ

C = volume of added 10*N* Sodium hydroxide

3.5.3.2 Nitrate

Automated cadmium reduction method.

Apparatus used:

Automated analytical equipment (Greenberg *et al.*, 1992).

Reagents used:

Distilled water, copper sulphate solution, wash solution, copper cadmium granules, hydrochloric acid, ammonium hydroxide, colour reagent, ammonium chloride solution, stock nitrate solution, intermediate nitrate solution and standard nitrate solution (Greenberg *et al.*, 1992).

Automated cadmium reduction method:

The general procedure as supplied by the manufacturer should be followed (Greenberg *et al.*, 1992).

3.5.3.3 Ortho-phosphate

Vanadomolybdophosphoric acid colorimetric method.

Apparatus used:

Colorimetric equipment such as a spectrophotometer and a filter photometer, acid washed glassware, filtration apparatus and filter paper (Greenberg *et al.*, 1992).

Reagent used:

Phenolphthalein indicator aqueous solution, hydrochloric acid, activated carbon, vanadate-molybdate reagent, standard phosphate solution (Greenberg *et al.*, 1992).

Vanadomolybdophosphoric acid colorimetric method:

If the pH of the sample is greater than 10 the pH must be adjusted by adding one drop phenolphthalein indicator to the sample and discharge the red colour with 1 +1 HCl then dilute to 100 mℓ. 35mℓ of the sample was placed in a volumetric flask and 1.0mg of P was added. Then 10mℓ of vanadate-molybdate was added and diluted with distilled water. The sample along with a blank was inserted into the instrument and the absorbance was measured (Greenberg *et al.*, 1992).

3.5.3.4 Chemical Oxygen Demand

Closed reflux, colorimetric method.

Apparatus used:

Digestion vessel, heating block, oven, ampule sealer, spectrophotometer (Greenberg *et al.*, 1992).

Reagent used:

Digestion solution, sulphuric acid reagent, sulfamic acid, potassium hydrogenphthalate standard (Greenberg *et al.*, 1992).

Closed reflux, colorimetric method:

A measured volume of sample and reagent was placed into the ampule and digestion solution was added. The sulphuric acid reagent was then added down the side of the vessel. The ampule was sealed and inverted to mix properly. Time was allowed for the solids to settle and the absorbance was measured (Greenberg *et al.*, 1992).

Calculation:

COD as mg O_2/ℓ = mg O_2 in final volume x 1000/mℓ sample.

3.5.3.5 Total Alkalinity

Titration method.

Apparatus used:

Electronic titrator, titration vessel, magnetic stirrer, volumetric pipets, volumetric flasks, glass burettes and a glass bottle (Greenberg *et al.,* 1992).

Reagents used:

Sodium carbonate solution, standard sulphuric acid or hydrochloric acid, bromcresol green indicator solution, metacresol purple indicator solution, phenolphthalein solution and sodium thiosulfate (Greenberg *et al.*, 1992).

Titration method:

A volume of sample was selected and placed into a flask. 0.2mℓ of indicator solution was added and titrated over a white surface until a colour change occurred. An appropriate amount of standard sodium hydroxide was added and titration continued until a pH of 4.5 was reached (Greenberg *et al.,* 1992).

Calculation:

Alkalinity = A x N x 50000/mℓ sample

A = mℓ standard acid used

N = normality of standard acid.

3.5.3.6 Sulfate

Turbidimetric method.

Apparatus used:

Magnetic stirrer, photometer (Nephelometer or spectrophotometer), stopwatch/timer, measuring spoon (Greenberg *et al.*, 1992).

Reagents used:

Buffer solution A and B, barium chloride and standard sulfate solution (Greenberg *et al.*, 1992).

Turbidimetric method:

100mℓ of sample was placed into a flask. 20mℓ of buffer solution was added and mixed. A spoonful of barium chloride was added and timing began. The solution was stirred for 60 seconds and poured into the cell of the photometer. The turbidity was then measured (Greenberg *et al.*, 1992).

Calculation:

mg SO_4^{2-}/ℓ = mg SO_4^{2-} x 1000/mℓ sample

3.5.3.7 Chloride

Argentometric method.

Apparatus used:

Erlenmeyer flask and a burette (Greenberg *et al.*, 1992).

Reagents used:

Potassium chromate indicator solution, standard silver nitrate titrant, standard sodium chloride and special reagents for removing interference (Greenberg *et al.*, 1992).

Argentometric method:

A 100mℓ of sample was used and titrated to a pH range of 7-10. 1mℓ of potassium chromate indicator solution was added and solution was titrated again with standard silver nitrate until a pinkish yellow colour was reached (Greenberg *et al.*, 1992).

Calculation:

mg Cl^-/ℓ = (A-B) x N x 35450/mℓ sample

A = mℓ titration for sample

B = mℓ titration for blank

N = normality of silver nitrate

mg NaCl/ℓ = (mg Cl^-/ℓ) x 1.65

3.5.3.8 Magnesium, Calcium, Sodium, Potassium

Atomic Absorption Spectrometry.

Apparatus used:

An atomic absorption spectrophotometer, a burner, a readout meter, lamps, pressure–reducing valves and a vent (Greenberg *et al.,* 1992).

Reagents used:

Air, acetylene, metal free water, calcium solution, magnesium solution, potassium solution, sodium solution, hydrochloric acid and lanthanum solution (Greenberg *et al.,* 1992).

Atomic Absorption Spectrometry method:

A cathode lamp was installed into the instrument for each of the desired metals, the wavelength dial was set and the instrument turned on. The burner was installed and the air was turned on and adjusted as well as the acetylene. A blank was inserted and the instrument was zeroed. The sample was then placed in the instrument and a reading was taken (Greenberg *et al.,* 1992).

3.5.4 Habitat assessment

This assessment was done on-site to determine the condition or health of the river. Macroinvertebrates are used for assessment due to the fact that they are visible to the naked eye and easy to identify. The SASS method has become a standard method for bioassessment and impact assessments of rivers (Dickens and Graham, 2002). After collection of the samples the contents of the handheld sampling nets were emptied into three separate trays (one tray for each of the biotopes that were sampled). The three trays were then viewed for approximately 15 minutes per tray by identifying the type and amount of organisms collected in each tray according to taxon or family level and filling in of the SASS 5 scoring sheet (Appendix E). Each taxon is assigned a predetermined quality score based on the organisms susceptibility or resistance to pollution (Dickens and Graham, 2002). Scores were given for different aspects and factors for the IHI and IHAS assessments and filled in on assessment sheets after which different classes and categories were determined for each sample.

3.6 Statistical Analysis

Nonparametric statistics were used to analyse the data due to the small sample size and data containing very high outliers. The methods or tests used included the Wilcoxon statistical test and the sign test. The Wilcoxon statistical test reflects magnitude and significant difference. Three levels of significance were used: 05, 01 and 001. The sign test focuses on direction of difference.

Means, maximum, minimum and median values were determined for all data and it was decided to use median values for the statistical analysis due to the fact that there are various outliers with extreme values within the data. This results in the mean values being pulled up by these very few high values. The median, however, are impervious to these outliers and are thus a more accurate measure. The data was also analysed and checked for serial dependence between time/sampling periods with auto correlation tests. If any correlation did occur it was extremely weak. Thus, any differences detected in the data are not correlated/related and thus be said to be independent.

Box and whisker graphs were used to show the range of the data across the different conditions. Upper whiskers reflect extreme/outlier values again indicating that the mean values therefore are not reliable and that the median values are more accurate measures. Time graphs were also used to show the range of data across time for different parameters and also to compare different sample sites with each other, to rainfall and to the quality standards.

3.7 Validity and Reliability

To ensure validity and reliability with this research project samples were taken from the river at upstream as well as downstream points so as to compare incoming and exiting water quality. The same was done with samples from the package plant. Samples from the influent were compared to samples from the exiting effluent. This was done so as to validate findings with regards to water and effluent quality. The habitat assessment was done upstream and downstream in the river so as to compare and validate the findings that was made with the sampling (Leedy, 2005).

The samples were taken at the same specific sites each time and in the same order and manner. The hand held meters used to do on-site analysis was calibrated before each sampling according to the manufactures specifications and the same type of equipment was used throughout the project. This was done to ensure accuracy and consistency. The sampling and analysis methods can therefore be easily replicated by other researchers. Sample analysis was performed in a controlled laboratory setting/environment and the methods of analysis were done according to the standard operating procedures of the Mogale City laboratory (Leedy, 2005).

Triangulation was also used to validate the conclusions drawn from the findings by collecting and comparing multiple sources of data such as existing literature, sampling data, habitat assessment data and a questionnaire (Leedy, 2005).

3.8 Limitations of Study

This research study offers findings and information but may have some limitations with regards to errors occurring during sampling, measuring and analyzing of samples, both in the field as well as in the laboratory.

3.9 Ethical Considerations

Ethical considerations impacts on all types of research and includes respect for people, their rights, privacy, integrity etc (Sheehan, 1986). To ensure ethically acceptable research and to adhere to UNISA’s policy on Ethics the research proposal was approved by the Ethical

Committee and consent forms was provided to the owners of the research site as well as the operator who participated in the questionnaire (Appendix D).

3.10 Summary

This section discussed the methodology and research design that was used in this research study. The above information showed the difference between the qualitative and quantitative methods that was used and how the methods were combined to form a mixed method research design. The data collection process as well as the analysis of the data were highlighted which led to the results that will be given in the next chapter.

Chapter Four

4. Results and Discussion

Water resources are limited in South Africa and its quality affects human and environmental health. For this reason constant monitoring and management is essential. Urbanisation affects water quality and causes fluctuations in parameters for example sewage discharges from businesses, informal settlements, agricultural activities, seepage and leachates due to broken pipes or septic tanks. Rainfall is also responsible for fluctuations in water quality and parameter concentrations as a result of atmospheric washout or concentrations at first flush (Stephenson, 2003). Pollution of water resources include: suspended solids (debris or sediment), various chemicals and metals, physical pollutants (temperature, pH, colour, odour etc.) and biological pollutants such as bacteria, pathogens and viruses. These pollutants can cause environmental degradation (such as eutrophication) and pose risks to human health (water borne diseases). Monitoring is therefore essential to ensure that the quality of the water comply with quality standards. Water quality standards are certain criteria that are used to quantify or indicate the level of permitted pollution/parameter concentration (Stephenson, 2003).

Pollutants/parameters of concern that usually tend to fluctuate in concentration and effect environmental and human health are physical parameters such as EC, SS, pH, temperature and DO. These parameters will fluctuate due to season changes (rain and temperature fluctuations) and increasing levels of pollution such as discharging of sewage, seepage and leaching (Department of Water Affairs and Forestry, 1996a; Campbell, 2001; Morrison *et al.*, 2001). Other pollutants of concern are nutrients (N and P) and bacteria or pathogens. These parameters will fluctuate in concentration as a result of increased faecal pollution either as a result of direct discharge or from heavy rain thus increasing loads with first flush events (Department of Water Affairs and Forestry, 1996a; Morrison *et al.*, 2001). Fluctuations in concentrations of all of the above parameters have impacts on the quality and health of the receiving aquatic ecosystem and also pose risks to human health.

The data for this research project was gathered over a period of 12 months and samples were taken at 10 different sample sites within the research site so as to determine the quality of the effluent discharged by the package plant as well as the quality of the surrounding water resources as can be seen in Figure 4.1:

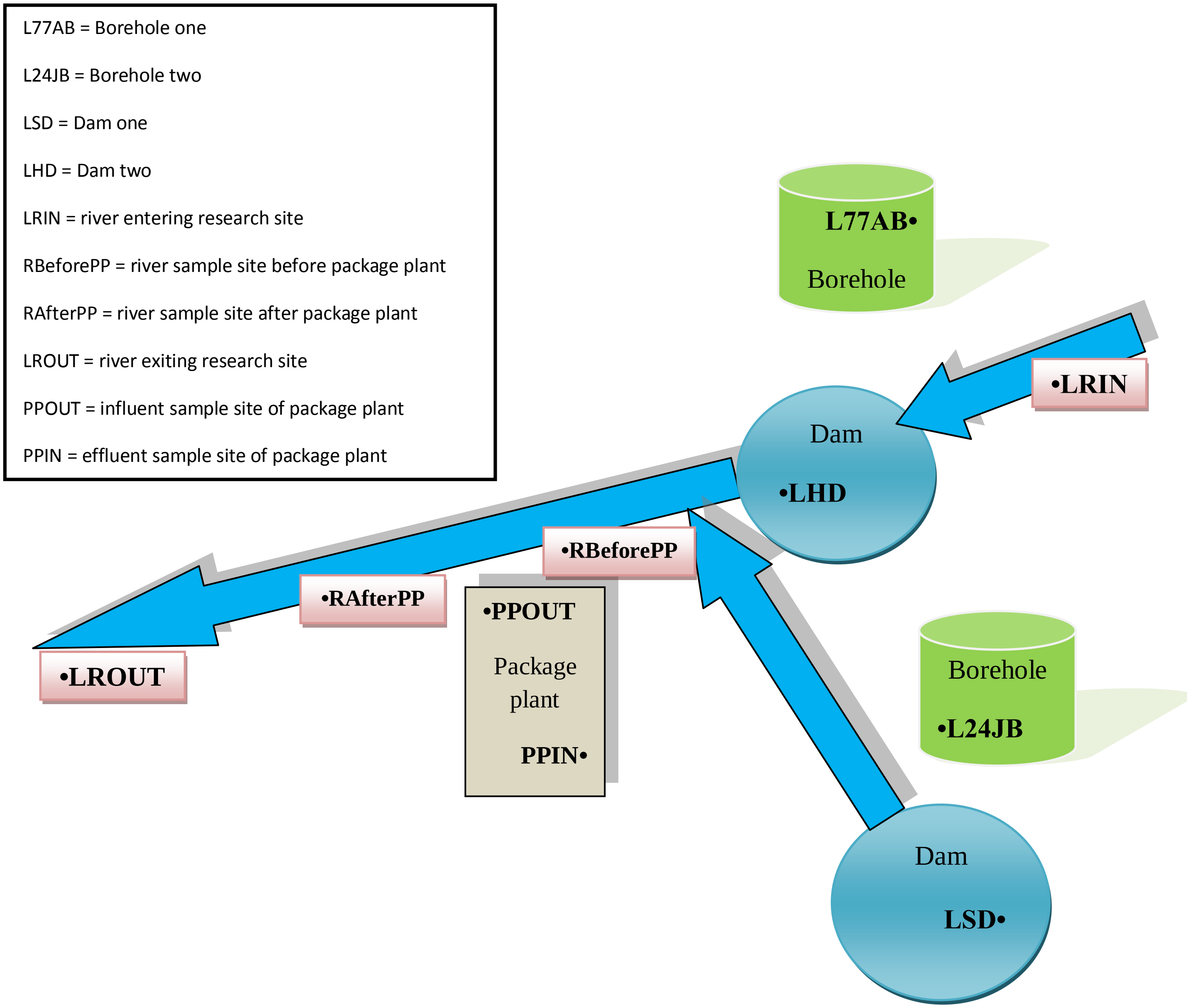

Figure 4.1: Diagram illustrating 10 samples sites at research site

At the research site all the water resources as well as the package plant were sampled. These included one sample from each of the two boreholes, one sample from each of the two dams, four samples along the whole stretch of the river (where it enters and exits the property, before and after the package plant) and finally two samples from the package plant itself (one of the influent and one of the effluent). Samples were analysed according to the methods described in section 3.5. The results of all the sample sites was statistically analysed (Tables 4.1 – 4.5; Appendix F) and median values of all the sites are given in Tables 4.6a – c (Appendix G). Results from the Wilcoxon statistical test and Sign tests are in given in Tables 4.7a and b (Appendix H). Results for the ten sample sites are given in Appendix I (Table 4.8 – 4.16).

Issues arising/difficulties encountered during research study

Because this study was conducted in a field or natural environment external factors should be accounted for. During the sampling period of 12 months the owners of the borehole site L24JB switched to municipal water for a certain period of time. The borehole L77AB experienced a low water level during one of the sampling periods and thus the reservoir level was too low to be reached for sampling. The sampling period stretched over four seasons (spring, summer, autumn and winter) and heavy rains were experienced during the summer months this could possibly affect the data due to the fact that some sample sites could not be reached for sampling due to flooding. Increased water levels also cause increases in certain parameter concentrations/loads and can also have a dilution effect on certain parameters.

The package plant did not have a constant flow/load during the sampling period (loads vary according to time of day/week or year). The package plant receives its input/inflow from a kitchen area, bathrooms and toilets but not from the laundry and the main water source is from the municipality thus, not only raw sewage was passed through the system but grey water as well. Design problems were encountered and changes were made to the package plant system during the sampling period. The system was also cleaned out once during the 12 months and only included cleaning of the septic tanks. Due to heavy rains experienced in December 2010 and January 2011 the system was flooded once between sampling periods.

4.1 Dams

Microbial analysis:

Sample site LSD (Table 4.12 – 4.14) indicated high faecal coliform concentrations above the standard of 1000 cfu/110 mℓ in three of the samples, two of which were determined as "too numerous to count" (TNTC). Two of the samples indicated very high concentrations of *E. coli* (on 9/11/2010 and 15/03/2011) and two samples had faecal *Streptococcus* concentrations of 480 cfu/100 mℓ and 1564 cfu/100 mℓ respectively also above the standard of 230 cfu/100 mℓ. The sample site LSD has an underground water source/wetland that is supplying the dam with its water.

This sample site is also located in close proximity of a septic tank. The high COD concentration and faecal coliform counts could result from leakage from this septic tank before seeping into the underground water/wetland. High faecal coliform counts were detected in the borehole that is next to the septic tank and will be discussed later. These high coliforms counts could also be as a result of higher rainfall during those sample periods (first flush effect in November 2010 and flash floods in March 2011) carrying high numbers of bacteria through the system. The first flush phenomenon is defined as the period of initial or first rains of the season and these increased water loads then carry greater pollutant concentrations (Soller *et al.*, 2005).

Chemical analysis:

Sample site LSD indicated levels of chemical oxygen demand (COD) that exceeded the standard limit of 75 mg/ℓ in three of the samples, 180 mg/ℓ, 77 mg/ℓ and 206 mg/ℓ (Table 4.15).

Physical parameter analysis:

The quality standard for suspended solids (SS) is 25 mg/ℓ and as can be seen from Table 4.8 various samples from **sample site LSD** contained SS with concentrations higher than that of the standard ranging from 26 mg/ℓ to 48 mg/ℓ respectively. Chemical and physical analysis of all the other parameters for site LSD showed concentrations within the applicable water quality standards.

Chemical analysis:

Sample site LHD inicated high concentrations of COD (Table 4.15) in three of the samples with values of 97 mg/ℓ, 83 mg/ℓ and 84 mg/ℓ (above the standard of 75 mg/ℓ). Other chemical and physical parameters that were analysed for site LHD had concentrations below the applicable water quality standard figures.

Microbial analysis:

Sample site LHD (Table 4.12 – 4.14) indicated high levels of faecal *Streptococcus* in three of the samples (384 cfu/100 mℓ, 984 cfu/100 mℓ and 1400 cfu/100 mℓ) that are above the standard of 230 cfu/100 mℓ and could be of animal origin. This increase may be due to this dam being inhabited by hippopotomi. The hippopotomi spend most of their day in the water and will defacate in the water as well as on land (Jones, 2008).

One sample indicated high levels of faecal coliform bacteria (1400 cfu/100 mℓ) that are above the standard of 1000 cfu/100 mℓ and two samples with high *E. coli* counts of 4068 cfu/100 mℓ and 2712 cfu/100 mℓ respectively. These high concentrations occurred during high rainfall periods in the beginning of the rainy season (9/11/2010) and when extreme rainfall was experienced in March 2011.

It appears that there exists a relationship between SS concentration and rainfall. In Figure 4.2 the rainfall for each month was plotted (in mm) against the concentration of the SS of sample sites LSD and LHD and compared to the quality standard.

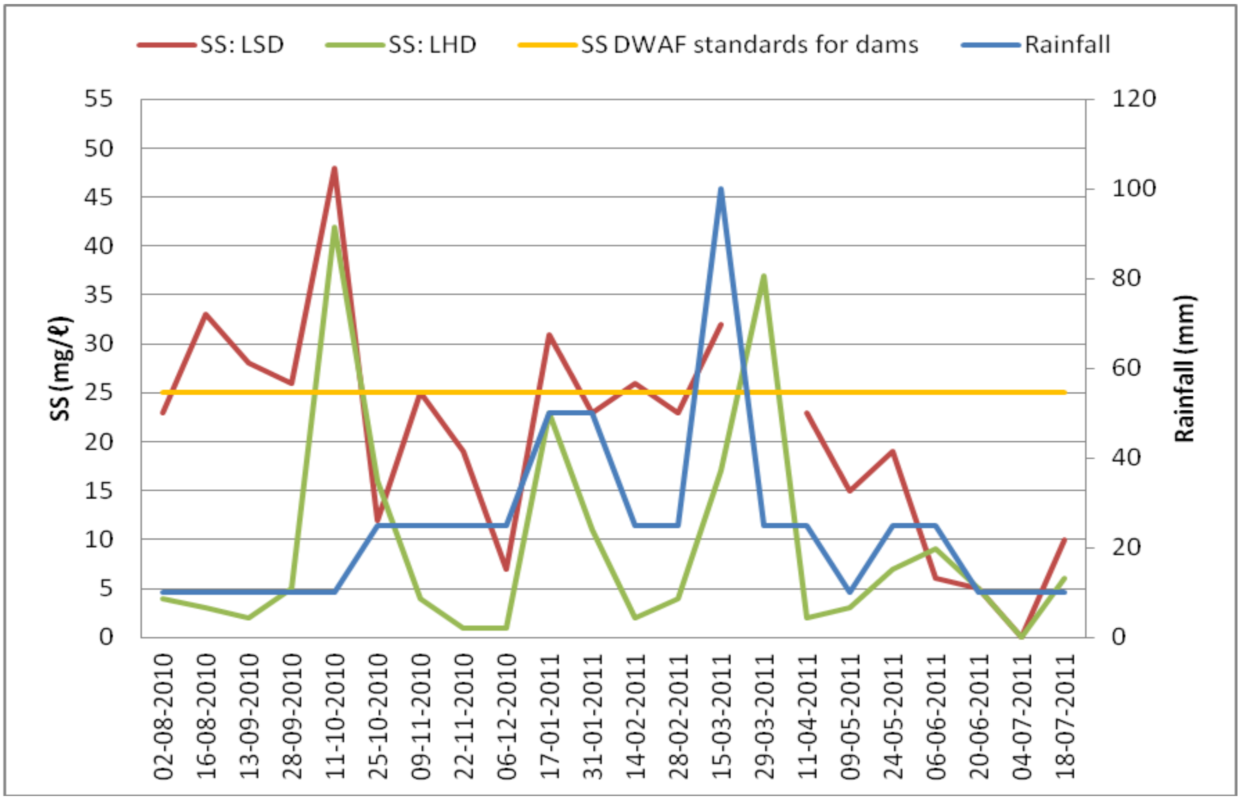

Figure 4.2: The relationship between SS concentrations and rainfall (mm) for sample sites LSD and LHD (rainfall source: www.weathersa.co.za).

As can be seen from Figure 4.2, during the month of August to early October the rainfall was low and the SS concentrations was high, between 26 mg/ℓ – 48 mg/ℓ for site LSD and 42 mg/ℓ for site LHD (above the SS standard of 25 mg/ℓ). When the rainfall increased a little from mid-October to December, the SS concentrations decreased (7 mg/ℓ – 25 mg/ℓ for site LSD and 1 mg/ℓ -16 mg/ℓ for site LHD) and during January and March heavy rains were experienced with occasional flash floods, during this period SS concentrations were also higher (23 mg/ℓ - 32 mg/ℓ for site LSD and 2 mg/ℓ – 23 mg/ℓ for site LHD) probably due to erosion and debris being flushed through the system with the increased rainfall.

Because the site LSD receives its water from an underground wetland, the SS concentrations tend to be higher during lower rainfall and lower during higher rainfall, the opposite was detected at site LHD. The reason for this may be that wetlands acts as filters and remove SS during high flow periods and retains the solids, thus, during the rainy season relatively little SS are flushed down the system (except with first and flash flush phenomena) because they are removed from the water flow by and settle in the wetland. When the water levels are low during the dry season SS concentrations in samples tend to be higher due to lower water levels and sampling of trapped SS (Johnston *et al.*, 1990; Kotze, 2000).

On the other hand dam LHD forms part of a normal river system. Normally, higher concentrations of SS would be detected during high flow periods. Sediment is transported as suspended solids through turbulance. As flow increases the sediment transport or concentration increases, and with floods SS concentrations are the highest (Kondolf, 1997). It is clear from Figure 4.2 that during high rainfall periods the SS concentrations of site LHD increase as particulate matter is flushed through the system while during low rainfall periods the SS concentration decreases due to less water turbulance, erosion etc.

Bacterial counts are also associated with particulate matter as sediment adhere to other pollutants such as bacteria or pathogens (Adeyemo *et al.*, 2008). Thus, as can be seen from Tables 4.12 – 4.14, associated with an increase in rainfall and SS concentration, there is an associated increase in bacteria counts.

From the data that were collected it can be said that the overall, general water quality of these two dams are good with regards to physical, chemical and biological parameters.

4.2 Boreholes

Various communities rely entirely on groundwater sources for their daily activities. Boreholes provides a source of water for many and thus monitoring and quality of these water sources are crucial. Sources of groundwater pollution include: leaking septic tanks, decomposing of organic matter on land surfaces, industrial deposits, agricultural activities, seepage, leaching and runoff of pollutants. These pollutants dissolve in the water/rain and gets transported into the ground and groundwater (Stephenson, 2003).

An assessment of the quality of the boreholes were done according to the guidelines as set out by the Department of Water Affairs, Department of Health and the Water Research Commission (1998) to determine the overall water class of sample site L24JB and L77AB (Appendix J).

Chemical analysis and physical parameter analysis:

Samples from **site L24JB** indicated concentrations below the quality standards where provided.

Microbial analysis:

Sample site L24JB (Table 4.12 and 4.13) did indicate high faecal coliform bacteria and *E. coli* counts, ranging from 1 cfu/100 mℓ to 78 cfu/100 mℓ. This borehole is situated near a septic tank and the high coliform counts could possibly result from leakage from the septic tank seeping into the borehole reservoir tank.

Microbial analysis:

Sample site L77AB (Table 4.12 – 4.14) indicated an increase in faecal coliform bacteria and *E. coli* bacteria counts was also noted from November 2010 ranging from 1cfu/100 mℓ to TNTC. Three samples also indicated faecal *Streptococcus* concentrations (384 cfu/100 mℓ, 984 cfu/100 mℓ and 1400 cfu/100mℓ) that exceed the standard of 230 cfu/100 mℓ.

Chemical analysis:

Sample site L77AB indicated one sample with a high magnesium concentration of 72.53 mg/ℓ (above the standard of 70 mg/ℓ; Table 4.24, Appendix J) and an increase in nitrate concentrations (Table 4.10) from the month of February 2011 ranging from 10.32 mg/ℓ to 19.71 mg/ℓ (above the water quality standard of 10 mg/ℓ).

Note that the low nitrate figure obtained for the specimen collected on the 14th February 2010 may be due to the time interval (14 days) between sampling and that these results may reflect a linear increase in nitrates in the borehole from the beginning of December 2010 through to the middle of March 2011. All the other chemical and physical parameters analysed for borehole L77AB showed concentrations within quality standards.

It was noted that a poultry farm is operated in close proximity to **site L77AB** and also shares the borehole reservoir. Furthermore, a great deal of poultry manure was stored close to this borehole reservoir and inadequate manure management could account for the increase in nitrate and coliform bacteria present in these borehole samples.

Improper management of poultry manure can lead to nitrate leaching into groundwater and release of bacteria that can contaminate surface and groundwater resources (Moore *et al.*, 1995). In support of this, concentrations of nitrate and bacterial counts for sample site L77AB increased progressively during the rainy season and from March 2011 the concentration of NO_3N increased above the standard 10 mg/ℓ.

The nitrate concentration, amount of rainfall and quality standard for sample sites L77AB and L24JB was plotted on a graph (Fig. 4.3).

In the United States, groundwater containing less than 3 mg/l are considered uncontaminated and groundwater over 10 mg/ℓ as highly polluted. Boreholes with concentrations between 3 mg/ℓ and 10 mg/ℓ are suspected to be as a result of human activities (Power and Schepers, 1989).

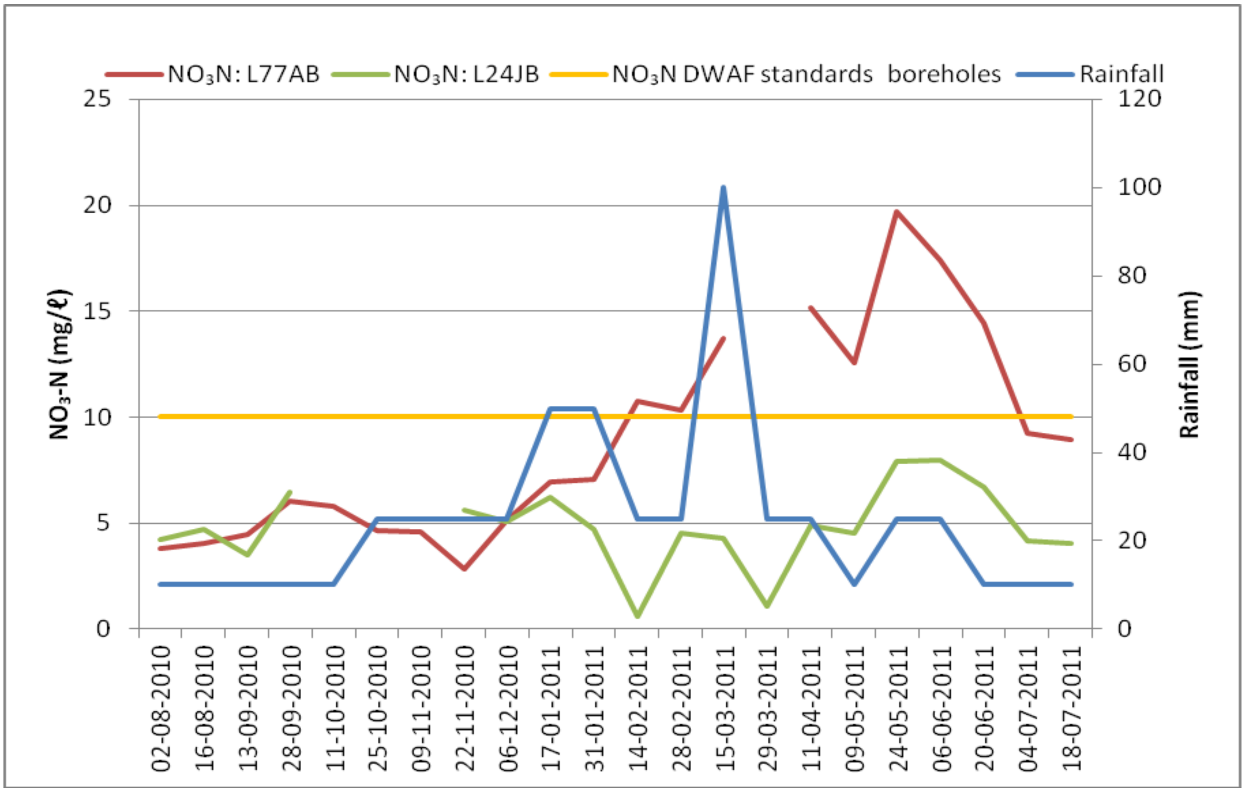

Figure 4.3: The relationship between NO_3N concentrations and rainfall (mm) for sample site L77AB and L24JB (rainfall source: www.weathersa.co.za).

Human activities such as poultry farming can lead to increased concentrations of nitrate in the surrounding environment. Nitrate and nitrite are very soluble in water and can easily enter surface and ground water through leaching during periods of rain[22]. It is clear from Figure 4.3 that during high rainfall periods there is an increase in nitrate concentrations for site L77AB as a result from nitrates leaching at high concentration from the poultry faeces into underground water or the reservoir. However, it can also be seen from Figure 4.3 that the NO_3N concentrations for site L24JB was not effected by the rain in the same manner as for site L77AB. This is due to the fact that site L24JB is not situated in close proximity to the poultry farm and thus no leaching occurred at this site.

Literature indicates that point sources such as manure from poultry farming can cause the spread of pathogens or bacteria to water supplies through runoff or leaching. High concentrations of faecal coliform bacteria can be transported to the groundwater after rainfall periods (Gagliardi and Karns, 2000). This could also explain the high faecal coliform bacterial and *E. coli* counts detected during periods with higher rainfall in the borehole samples for site L77AB (Stephenson, 2003) as can be seen from Figures 4.4 and 4.5.

[22] http://www.ead.anl.gov/pub/doc/nitrate-ite.pdf

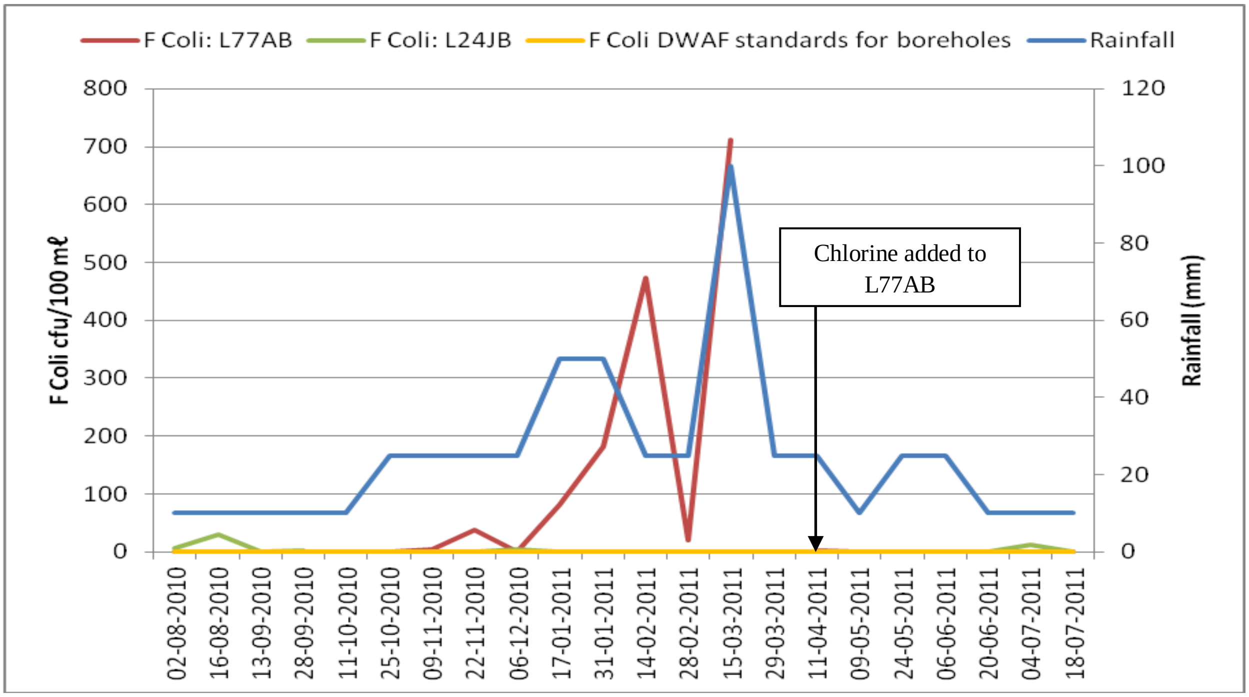

Figure 4.4: The relationship between faecal coliform bacteria and rainfall (mm) for sample site L77AB and L24JB (rainfall source: www.weathersa.co.za).

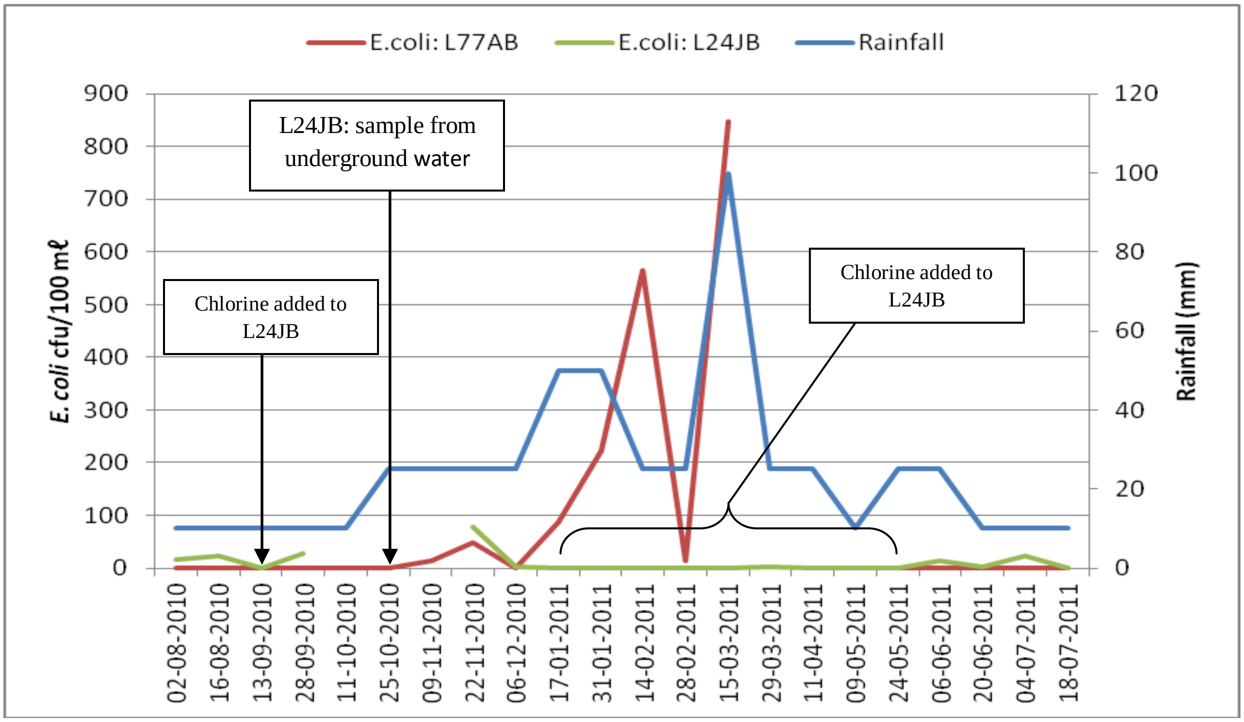

Figure 4.5: The relationship between *E. coli* and rainfall (mm) for sample site L77AB and L24JB (rainfall source: www.weathersa.co.za).

Again, it can be seen from the Figures 4.4 and 4.5 that site L24JB had very low, if any, concentrations of faecal coliform and *E. coli* bacteria leaching with the rain in comparison with site L77AB which is situated nect to the chicken farm. Figure 4.4 also indicates that when chlorine was added to the borehole reservoir at site L77AB the coliform counts decreased to 0 cfu/100 mℓ. It can be seen from Figure 4.5 that for chlorine to be an effective antimicrobial, it needs to be added consistently to the borehole reservoir tank. A once-off chlorine treatment for site L24JB (on 13/09/2010) showed little effect whereas addition of chlorine on a weekly basis (from January onwards) resulted in a dramatic decrease in the *E. coli* counts while the faecal coliform counts decreased to 0 cfu/100 mℓ. Bacterial contamination appeared to be associated with the reservoir tank next to the septic tank and not the underground water from the borehole as can be seen from Figure 4.5: when a sample was taken from site L24JB on 25/10/2010 directly from the groundwater there were 0 cfu/100 mℓ coliform bacteria present. This borehole is being used for human consumption and should thus continue to be regularly monitored to ensure that there are no threats to human health. Various viruses, protozoa and bacteria may be transmitted by drinking water and can cause disease such as gastroenteritis, hepatitis, cholera and various other infections. The presence of faecal coliforms and *E. coli* indicates the presence of other pathogens such as *Salmonella, Shigella, Vibrio cholerae* etc (Department of Water Affairs, 1996b).

The high concentrations of NO_3N and coliform bacterial counts are of concern with regards to human health and it is not recommended that these boreholes (site L77AB and L24JB) are used as a water source due to the fact that nitrate is microbially reduced and then converted to nitrite in the human body (Department of Water Affairs and Forestry, 1996a). The nitrite then combines with oxygen-carrying red blood cells and reduces efficient oxygen carriage in these cells. This leads to a condition known as methaemoglobinaemia in infants. High concentrations of nitrates can also form carcinogenic compounds (Department of Water Affairs and Forestry, 1996a).

The water quality of the two boreholes is not up to standard with regards to chemical and biological parameters and if the boreholes are used for human consumption it could pose threats to human health if chlorine treatment is stopped and coliform counts allowed to increase while nitrate concentrations remain high. Constant monitoring is required for these two boreholes.

4.3 River

The data for NH_3-N, NO_3N, O-PO_4, faecal coliforms and chlorine concentrations will be discussed in this section as these are the major constituents of concern in the package plant effluent being discharged into the river. These pollutants can impact the health of the river system and, thus, samples were taken from four sites along the river (Fig. 4.1):

- where the river enters the study property,

- where it exits the study property,
- before the package plant and
- directly after the package plant.

Physical parameter analysis:

Sample site LRIN indicated two samples with SS concentrations (45 mg/ℓ and 32 mg/ℓ) above the standard of 25 mg/ℓ (Table 4.8).

Chemical analysis:

Sample site LRIN indicated a high COD concentration (Table 4.15) of 92 mg/ℓ in one sample (above the standard of 75 mg/ℓ). NO_3N concentrations were also detected in various samples (Table 4.10). The other chemical and physical parameters analysed for site LRIN had concentrations within the water quality standards.

Microbial analysis:

Sample site LRIN (Table 4.12 – 4.14) indicated two samples with high faecal coliform bacterial counts (1624 cfu/100 mℓ and 1360 cfu/100 mℓ). Four of the samples were determined to have high streptococcal counts (240 cfu/100 mℓ, 544 cfu/100 mℓ, 1072 cfu/100 mℓ and 1472 cfu/100 mℓ) and two samples indicated high concentrations of *E. coli* on the 09/11/2010 which was the beginning of the rainy season (1808 cfu/100 mℓ) and on the 15/03/2011 which was during a heavy rainfall period (2784 cfu/100 mℓ).

Physical parameter analysis:

Sample site RBeforePP had one sample with a SS concentration (Table 4.8) of 45 mg/ℓ (that is above the standard of 25 mg/ℓ).

Chemical analysis:

Sample site RBeforePP indicated one sample with a COD concentration (Table 4.15) of 79 mg/ℓ (above the standard of 75 mg/ℓ). Other chemical and physical parameters analysed for sample site RBeforePP were determined to have concentrations within the given quality standards.

Microbial analysis:

Sample site RBeforePP indicated only one of the samples had a high faecal coliform bacterial count of 2136 cfu/100 mℓ (above the standard of 1000 cfu/100 mℓ). At this site three of the samples were determined to have faecal Streptococcal counts above the standard of 230 cfu/100 mℓ (1208 cfu/100 mℓ, 2260 cfu/100 mℓ and 384 cfu/100 mℓ). Two samples also indicated high *E. coli* concentrations of 1032 cfu/100 mℓ on the 17/01/2011 and 3616 cfu/100 mℓ on the 15/03/2011. These dates and sample falls within the rainy season.

Chemical and physical parameters analysed:

Sample site RAfterPP had concentrations that complied with the water quality standard, however, various samples did indicated levels of NO_3N concentrations (Table 4.10).

Microbial analysis:

Sample site RAfterPP (Table 4.12 – 4.14) indicated that three of the samples had faecal coliform bacterial counts well above the standard of 1000 cfu/100 mℓ (1360 cfu/100 mℓ, 1032 cfu/100 mℓ and 1288 cfu/100 mℓ) and four samples were determined to have faecal streptococcal counts well above the allowable standard of 230 cfu/100 mℓ (648 cfu/100 mℓ, 672 cfu/100 mℓ, 1448 cfu/100 mℓ and 648 cfu/100 mℓ). *E. coli* concentrations in four of the samples were determined to be high (1544 cfu/100 mℓ, 1112 cfu/100 mℓ, 3448 cfu/100 mℓ and 1116 cfu/100 mℓ).

Physical parameter analysis:

Sample site LROUT indicated that three samples had SS concentrations of 30 mg/ℓ, 33 mg/ℓ and 26 mg/ℓ that are above the standard of 25 mg/ℓ (Table 4.8).

Chemical analysis:

Sample site LROUT indicated one sample with a COD concentration (Table 4.15) of 175 mg/ℓ, well above the standard of 75 mg/ℓ and various samples were detected to have levels of NO_3N (Table 4.10). One sample also indicated free chlorine concentrations of 0.4 mg/ℓ on the 06/12/2010 (Table 4.16). The other chemical and physical parameters analysed for sample site LROUT were determined to comply with the given quality standards.

Microbial analysis:

Sample site LROUT (Table 4.12 – 4.14) indicated one sample with a faecal coliform bacterial count of 4560 cfu/100 mℓ that is above the standard of 1000 cfu/100 mℓ. Five of the samples at this site also had high faecal *streptococci* counts (904 cfu/100 mℓ, 1032 cfu/100 mℓ, 280 cfu/100 mℓ, 1808 cfu/100 mℓ and 1464 cfu/100 mℓ) that are all above the standard of 230 cfu/100 mℓ. Three samples also indicated high *E. coli* concentrations of 5360 cfu/100 mℓ, 2344 cfu/100 mℓ and 1244 cfu/100 mℓ.

Rivers are subjected to a variety of natural processes and human activities. Human activities account for high levels of parameter fluctuations due to increased pollutants being discharged into these water resources. Parameters analysed are also influenced by dry season concentrations as well as rainy season runoff and flooding. Seasonal variations may affect parameters such as DO levels (which tend to be lower in dry seasons than in rainy seasons), phosphate and nitrate concentrations, which build up in soils during the dry seasons and with the first rains gets flushed out from the soils into the river (Adeyemo *et al.*, 2008).

The concentration of NH_3-N for sample site LRIN and LROUT as well as site RBeforePP and RAfterPP are given in Figures 4.6 and 4.7. As can be seen from these figures, the sample site RAfterPP showed slightly higher concentrations of NH_3-N. These slightly higher concentrations could be as a result of the package plant discharging its effluent containing high levels of NH_3-N directly into the river. This, then, shows that the package plant effluents may well impact on the quality of the river. A significant difference was detected with the Wilcoxon statistical tests (Appendix H) for NH_3-N and shows slightly higher concentration for site LROUT than for site LRIN, this could be as a result of the package plant discharging effluent into the river. **However, none of the samples showed any concentrations above the standard of 10 mg/ℓ and thus, the overall quality with regards to NH_3-N is considered to be of good standard.**

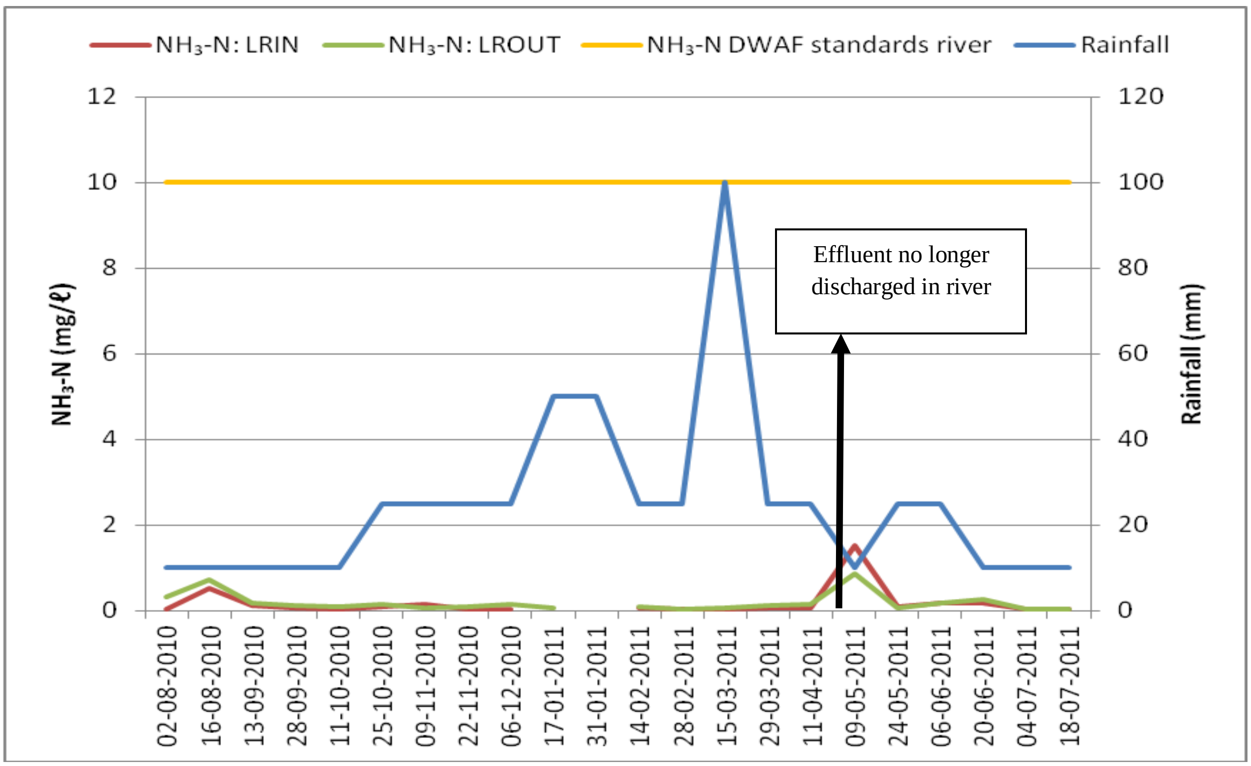

Figure 4.6: Ammonia concentrations for river sample sites LRIN and LROUT.

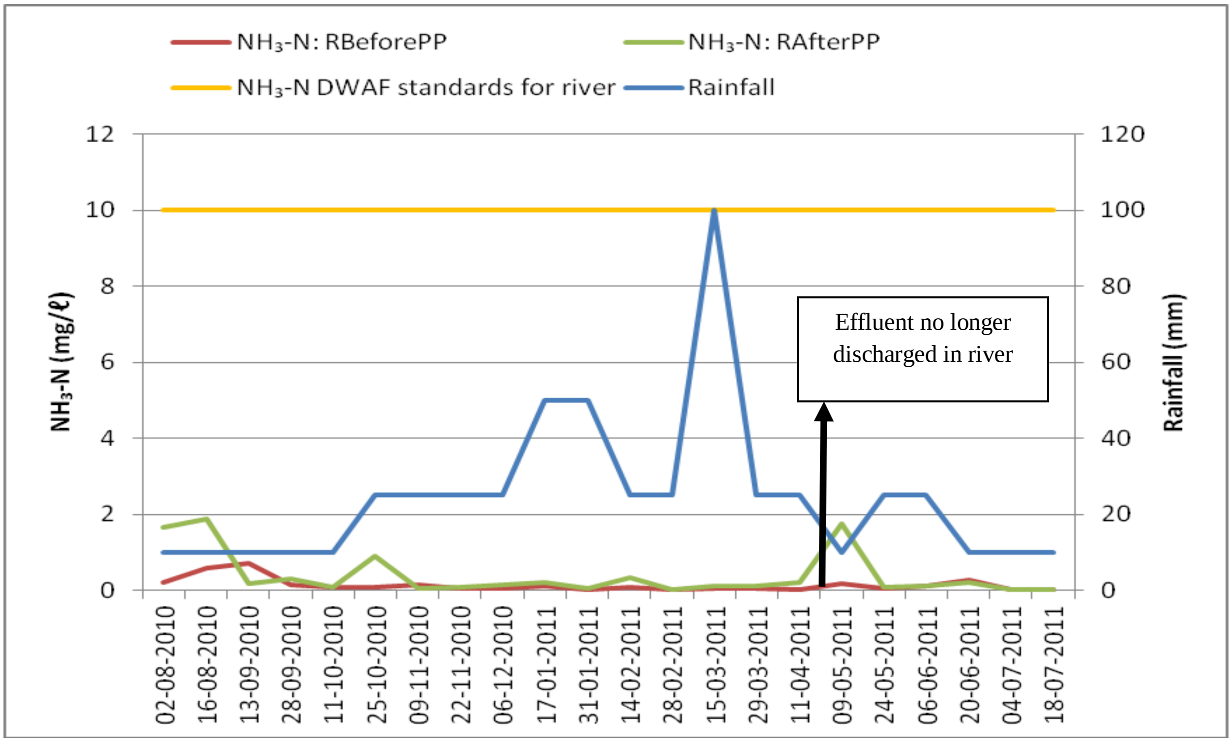

Figure 4.7: Ammonia concentrations for river sample sites RBeforePP and RAfterPP.

It is also clear from Figures 4.6 and 4.7 that during the winter months (August 2010 to October 2010 and from May 2011 onwards) the concentrations of NH_3-N are elevated compared to the summer months/rainy season (November 2010 to April 2011). A reason for this may be that in the dry season the river level is low and does not flush the NH_3-N from this system resulting in a higher concentration of NH_3-N. With rain, the river level and flow increases and flushes the NH_3-N faster through the system, thus, diluting the concentration of NH_3-N.

Between sample dates 11/04/2011 and 09/05/2011, the effluent from the package plant was diverted away from the river and was no longer discharged directly into the river. However, the sample taken on 09/05/2011 showed high concentrations of NH_3-N at sites LRIN, RAfterPP and LROUT. The high NH_3-N concentration at site LRIN could possibly result from an outside source (a nursery upstream from the research site where nitrogen is used as fertiliser). Furthermore, due to the fact that there was no rainfall during this period, the NH_3-N was not diluted by the river system and high levels were detected throughout the river for this sample date. The levels detected after the effluent from the package plant was diverted in samples for June 2011 and July 2011 could possibly be also as a result of an outside, unknown source.

Figure 4.8 and 4.9 shows the concentration of NO_3N for sample sites LRIN, LROUT and RBeforePP, RAfterPP for the 12 month sampling period.

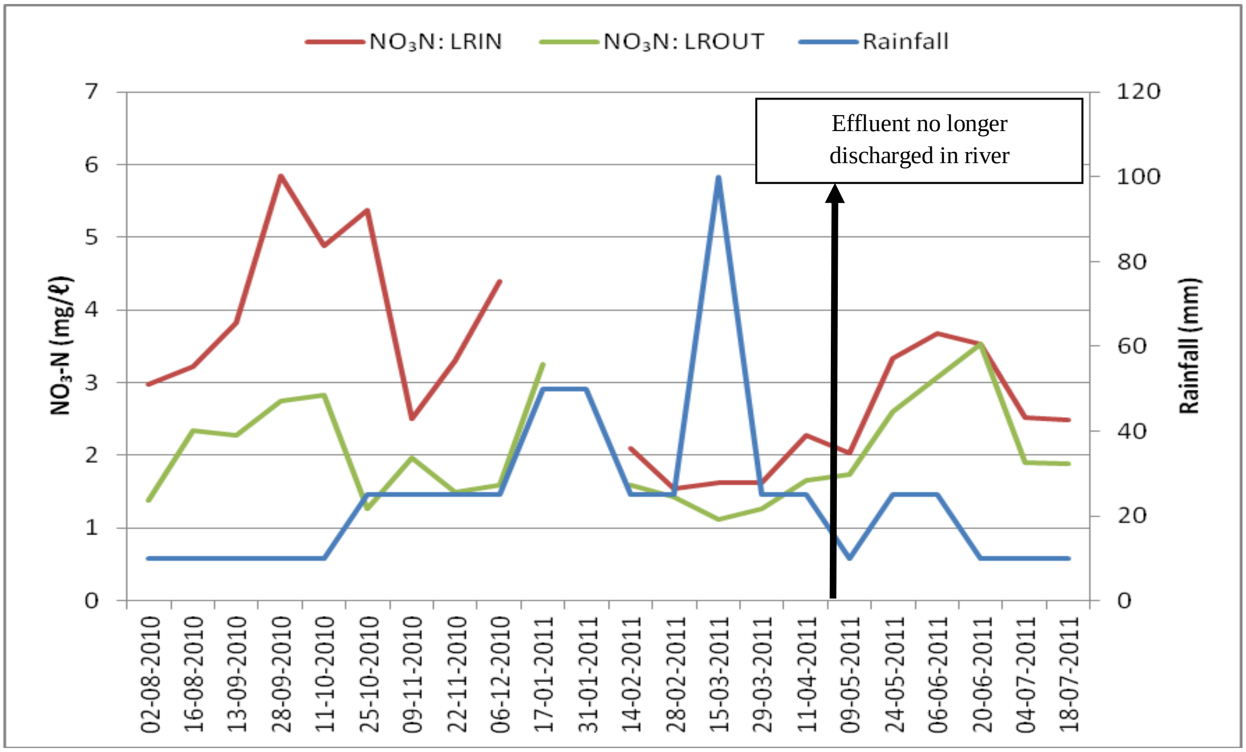

Figure 4.8: Nitrate concentrations for river sample sites LRIN and LROUT.

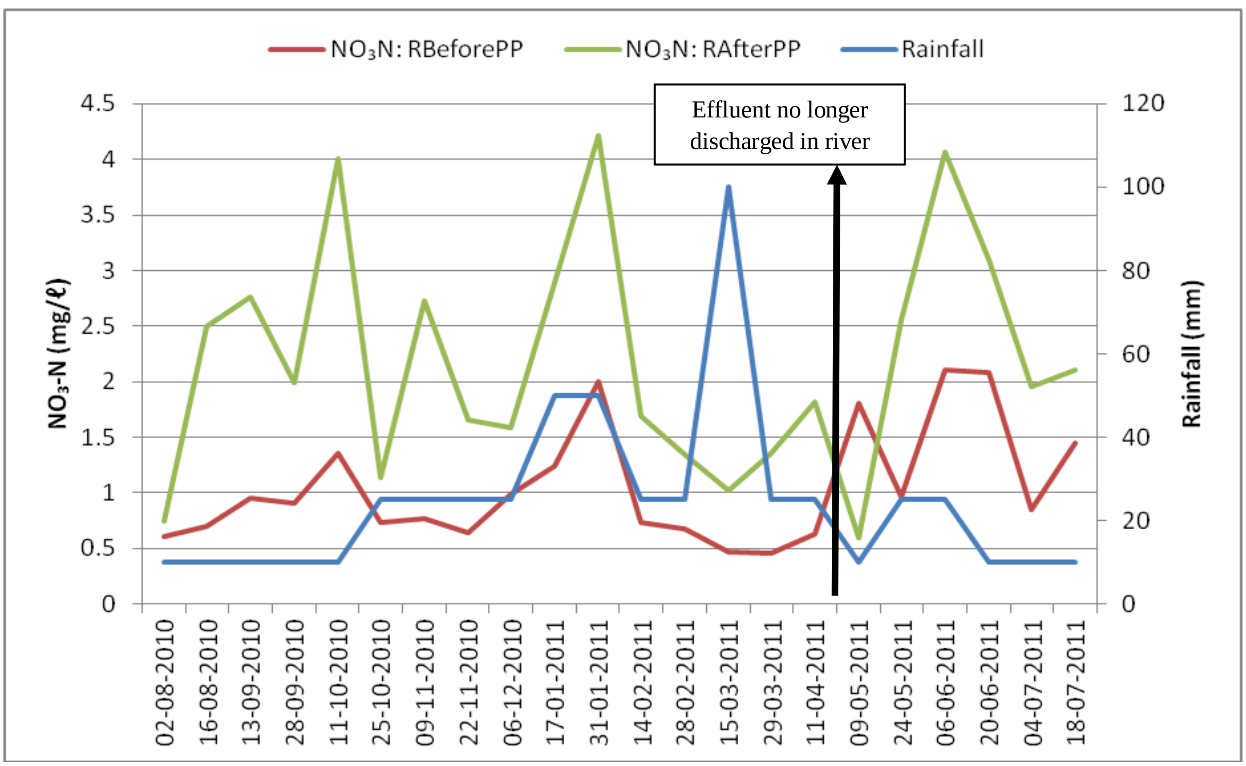

Figure 4.9: Nitrate concentrations for river sample sites RBeforePP and RAfterPP.

Nitrate is an end product of the oxidation process of organic nitrogen (Department of Water Affairs and Forestry, 1996a). Unfortunately, there are no standard figures available for NO_3N concentrations in aquatic systems and it is therefore difficult to determine the overall impact that NO_3N concentrations might have on these ecosystems. Figures 4.8 and 4.9 shows that nitrate concentrations for this river remained high throughout the sampling period. It can also be seen that the concentrations for site LRIN were higher than those of the other sites in most of the samples that were tested. This was also detected with the Wilcoxon statistical tests (Appendix H) which showed a highly significant difference between LRIN and LROUT. It can be concluded that the NO_3N concentrations are from an outside source located upstream from the research site. Although the package plant at the research site showed high concentrations of nitrate in the effluent being discharged into the river (Table 4.10), it is difficult to determine whether the package plant has any effect on the nitrate concentrations detected in all of the river samples, possibly due to a high concentration of nitrate entering the research site before the package plant. Even after the effluent from the package plant was diverted away from the river, high concentrations of nitrate were still detected in the samples.

It appears that seasonality and rainfall play a major role in the concentration of nitrate. From Figures 4.8 and 4.9 it can be seen that during the winter/dry months the concentrations of NO_3N are slightly higher than that of the summer/rainy months. When it rains, nitrates are diluted and flushed through the system whereas in the winter months they remain more concentrated.

The concentrations of ortho-phosphate for sample sites LRIN, LROUT and RBeforePP, RAfterPP are shown in Figures 4.10 and 4.11.

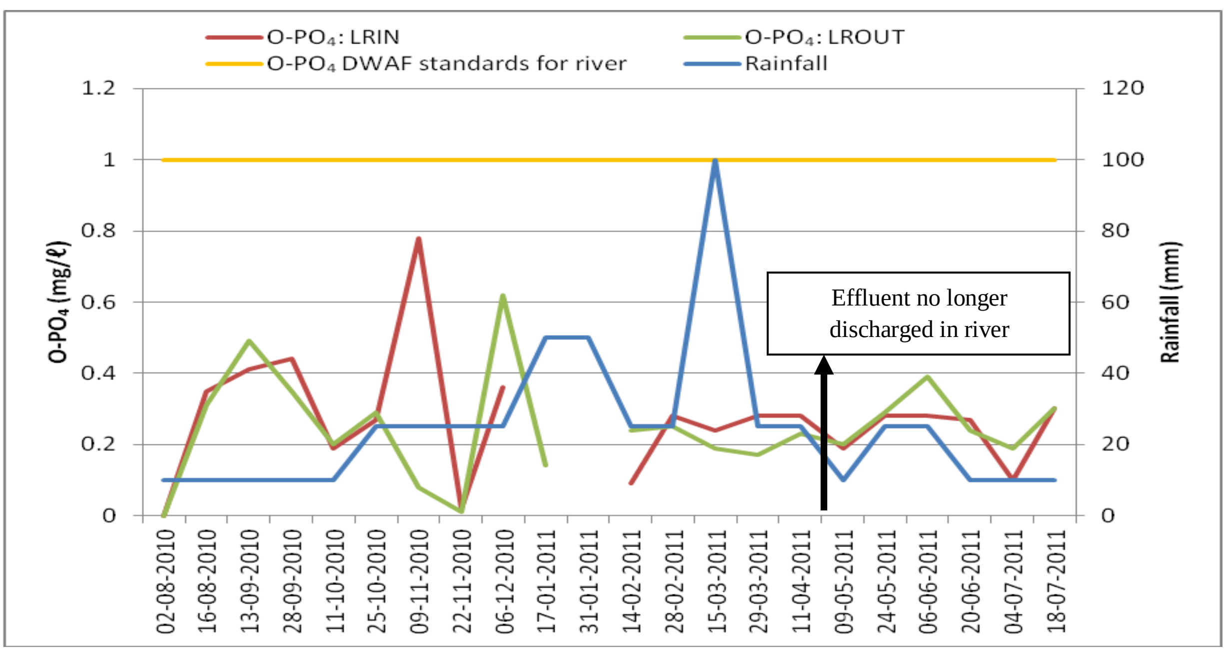

Figure 4.10: Ortho-phosphate concentrations for sample sites LRIN and LROUT.

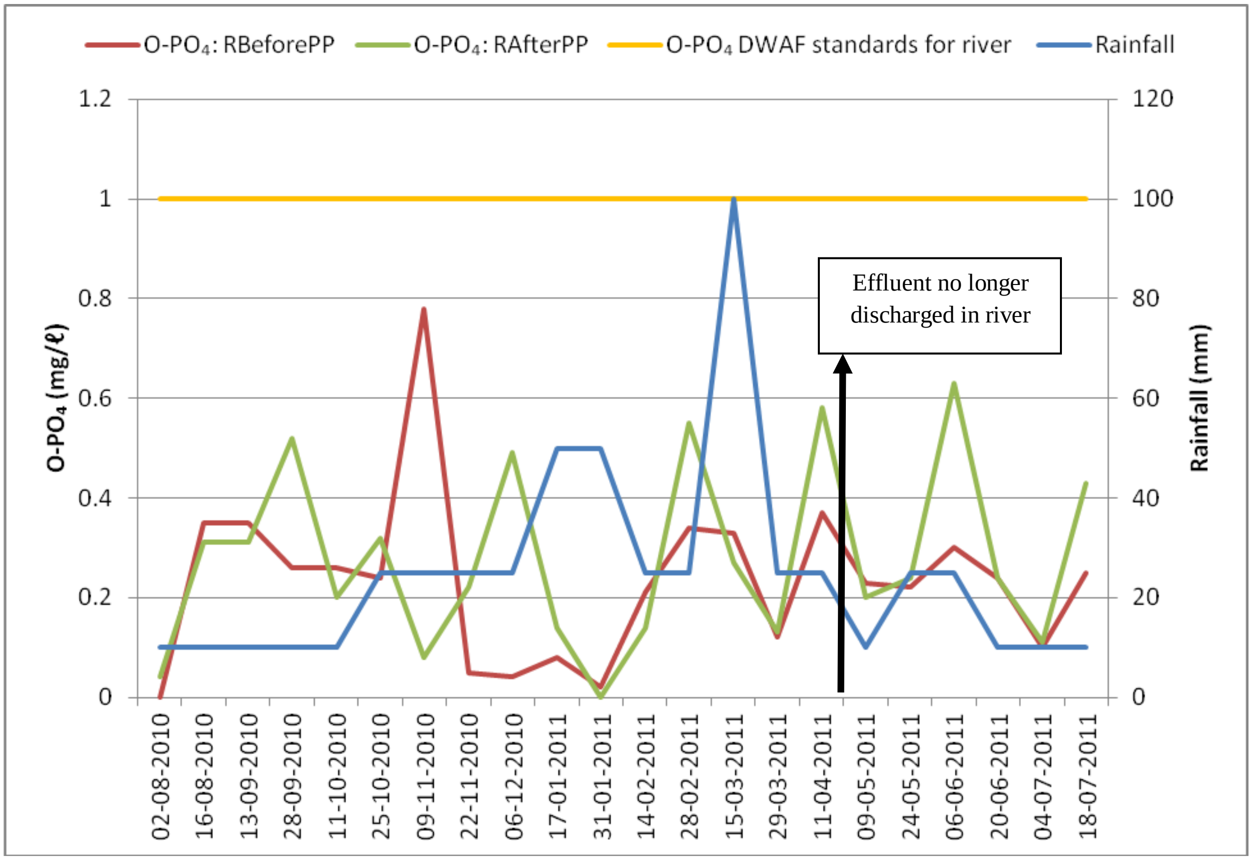

Figure 4.11: Ortho-phosphate concentrations for sample sites RBeforePP and RAfterPP.

Phosphorus occurs in various inorganic forms in water as dissolved or particulate matter. Soluble phosphate or ortho-phosphate is an essential macronutrient to aquatic biota but excess concentrations may lead to eutrophication in aquatic environments and it is, thus, very important to monitor phophate concentrations in these systems (Department of Water Affairs and Forestry, 1996c). From Figures 4.10 and 4.11, it can be seen that concentrations of O-PO_4 are detected in sample sites LRIN and RBeforePP indicating that an outside source upstream from the research site (possibly a nursery in the area) may contribute to the O-PO_4 levels in this river system. On 09/11/2010, the O-PO_4 concentrations at sample site LRIN (Fig. 4.10) and RBeforePP (Fig. 4.11) are very high entering the river at the research site. As this date falls within the first summer rains, these high concentrations could also result from rain flushing high concentrations of O-PO_4 from that particular source through the research site. Various samples of sample sites LROUT (Fig. 4.10) and RAfterPP (Fig. 4.11) from 13/09/2010 to 11/04/2011, showed higher concentrations of O-PO_4 compared to those detected in the section where the river enters the property. Sample sites LROUT and RAfterPP are situated after the package plant and the data would suggest that the package plant effluent containing high levels of O-PO_4 (Table 4.11) do indeed have a small effect on the phophate levles in the river. **However, none of the samples**

showed any $O\text{-}PO_4$ concentrations higher or above the water quality standard of 1 mg/ℓ and, thus, the river is of high quality with regards to phosphates.

On 06/06/2011, the sample showed very high levels of $O\text{-}PO_4$ at the sample site RAfterPP (Fig. 4.11). The reason for this is unknown as this high concentration could not result from the package plant effluent as the effluent was diverted away from the river almost six weeks prior to this sample date. The concentration is also much higher than that of sample site LRIN (Fig. 4.10) and RBeforePP (Fig. 4.11), suggesting that it is not from another source outside of the research site. These results may be due to errors in the sampling technique such as stirring up sediment during sampling. Regarding sediment, phosphorous can be removed from the water to settle out in the sediment which, thus, acts as sink during periods of low flow. When the sample was taken the sediment might have been stirred up/disturbed and the settled phosphate that remained in the sediments released back into the water (Holtan *et al.*, 1988) thus accounting for the high concentrations in this particular sample. However, samples taken after the effluent from the package plant was diverted away from the river still show high $O\text{-}PO_4$ concentrations, thus, suggesting that an outside source could still be contributing to the $O\text{-}PO_4$ concentrations in the samples taken from 09/05/2011.

Figures 4.12 and 4.13 show faecal coliform counts along with the water quality standard (1000 cfu/100 mℓ) for aquatic ecosystems for the sample sites LRIN, LROUT and RBeforePP, RAfterPP:

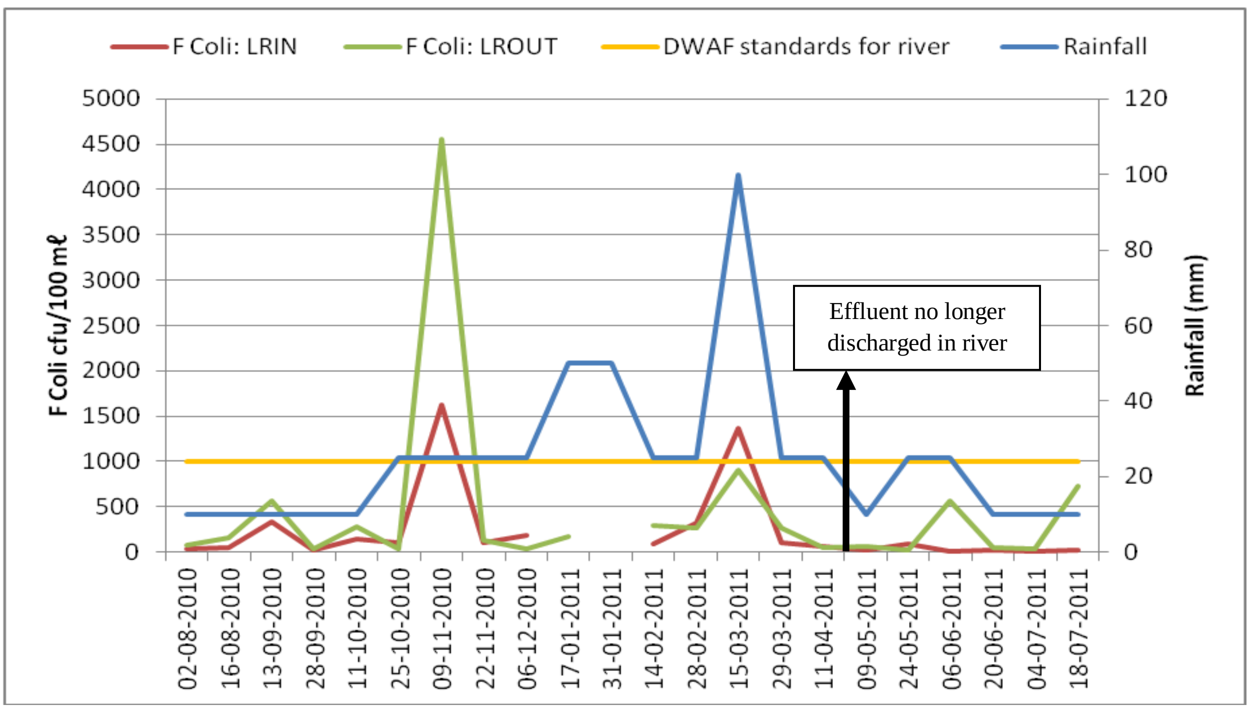

Figure 4.12: Faecal coliform concentrations for sample sites LRIN and LROUT.

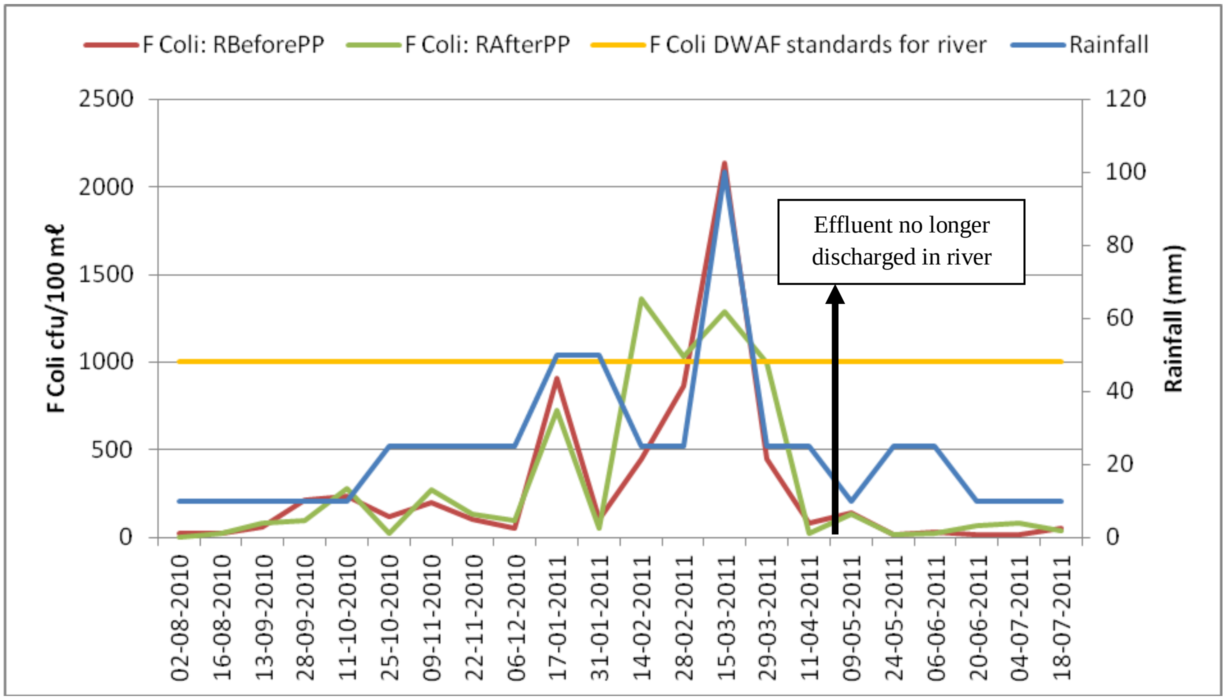

Figure 4.13: Faecal coliform concentrations for sample sites RBeforePP and RAfterPP.

Pathogens that are responsible for waterborne diseases are transmitted by the faecal-oral route. Indicator organisms are used to monitor water resources for the presence of disease causing pathogens. Indicators that are recommended by the Department of Water Affairs for assessment of water are total coliform bacteria, faecal coliform bacteria, *E. coli*, faecal streptococci and bacteriophages. Faecal coliform bacteria indicate faecal pollution and is considered to be more specific than total coliform bacteria. *E. coli* also indicates faecal pollution involving humans and animals. Faecal streptococci tend to survive longer in water than the coliform bacteria (Department of Water Affairs and Forestry, 1996a). For this project, the presence of faecal coliform bacteria, *E. coli* and faecal streptococci was tested in the water samples.

From Figure 4.12, it can be seen that on sample date 09/11/2010 the sample sites LRIN and LROUT showed faecal coliform bacterial counts above the water quality standard of 1000 cfu/100mℓ. The high bacterial counts at site LRIN originate from an unknown source outside and upstream of the research site and could also result from rains flushing faecal coliform bacteria through the system. Sample site LROUT, however, showed an even higher concentration of faecal coliform bacteria than that of site LRIN. Site LROUT is situated below the package plant and the data from this particular sample date for the package plant effluent (Table 4.12) showed levels of faecal coliform bacteria above the allowable quality standard. Thus, the high bacterial counts in the package plant effluent could possibly have contributed to high counts in the river although faecal coliform counts **directly** after the plant at site RAfterPP were low (Fig. 4.13). Note that faecal coliform bacteria could have multiplied in the river downstream from the package plant due to favourable growth conditions such as temperature and nutrients or the extremely high concentrations in this part of the river could be as a result of another localised contaminating source such as animals.

On 17/01/2011, no samples were taken at the sites LRIN and LROUT (due to bad weather conditions but the samples for sites RBeforePP and RAfterPP (Fig. 4.13) showed high faecal coliform bacterial counts. This could be due to heavy rains during this period and, thus, high counts of bacteria being flushed through the system. The package plant effluent for this particular sample date (Table 4.12) showed the absence of bacteria and, thus, the effluent from the plant had no effect on the bacterial counts detected on this sample date.

Figure 4.12 shows that high bacteria counts (above the water quality standard of 1000 cfu/100mℓ) were once again detected on the 15/03/2011 for sample sites LRIN and on Figure 4.13 for sites RBeforePP and RAfterPP. The high counts for sample site LRIN and RBeforePP are from an unknown outside source situated upstream from the research site and during this period heavy rainfalls were experienced, thus, flushing higher concentrations of bacteria through the system.

The sample site RAfterPP generally showed the highest bacteria counts and is situated directly after the package plant. On this particular sampling date, the package plant experienced problems with the chlorine dispenser in the system and the effluent coliform bacteria were determined to be very high (Table 4.12). This explains the high bacterial counts in the river at site RAfterPP due to the fact that the effluent containing extremely high levels of bacteria was discharged into the river. This clearly shows that if problems do occur at the package plant it will have a direct effect on the quality of the river receiving the effluent.

It can also be seen from Figures 4.12 and 4.13 that after the effluent from the package plant was diverted away from the river the faecal coliform bacteria counts in the river decreased. On the 06/06/2011 there was a slight increase in bacterial counts at site LROUT but this could be of animal origin. **Most of the samples taken from the river showed faecal coliform bacteria counts that are within the water quality standard.**

The free chlorine concentrations for sample sites LRIN, LROUT and RBeforePP, RAfterPP are shown in Figures 4.14 and 4.15.

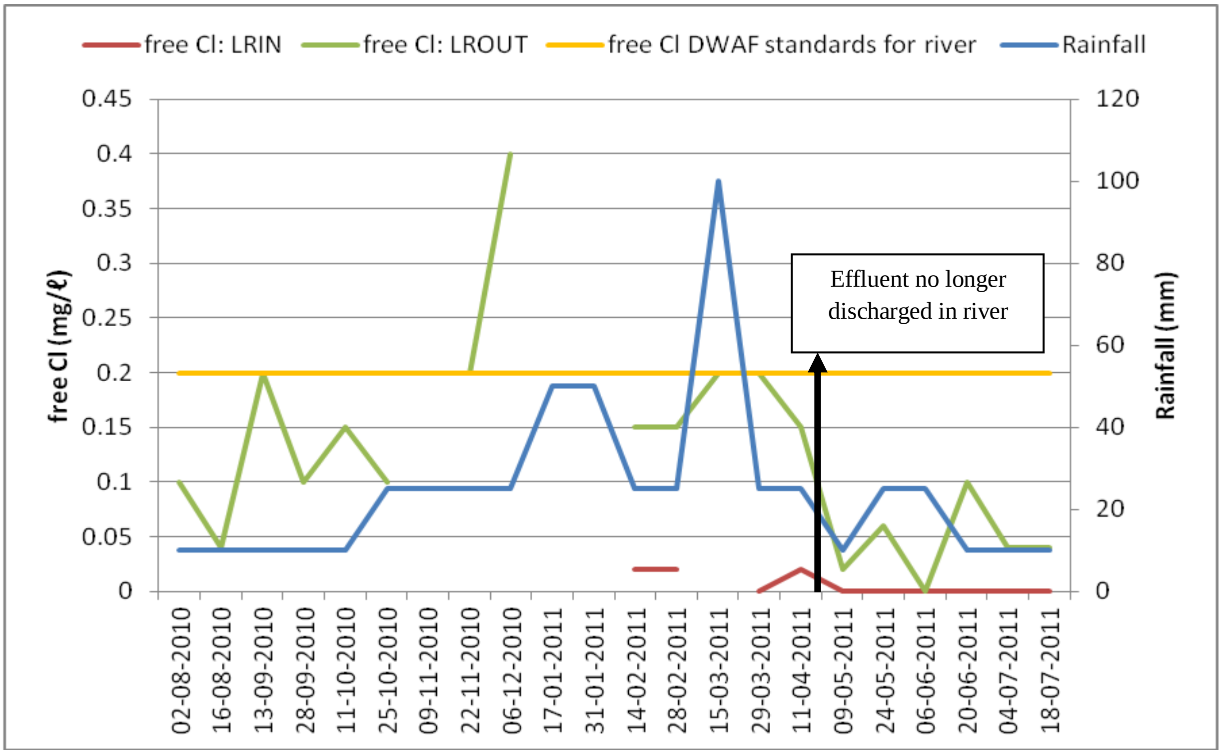

Figure 4.14: Free chlorine concentrations for sample sites LRIN and LROUT.

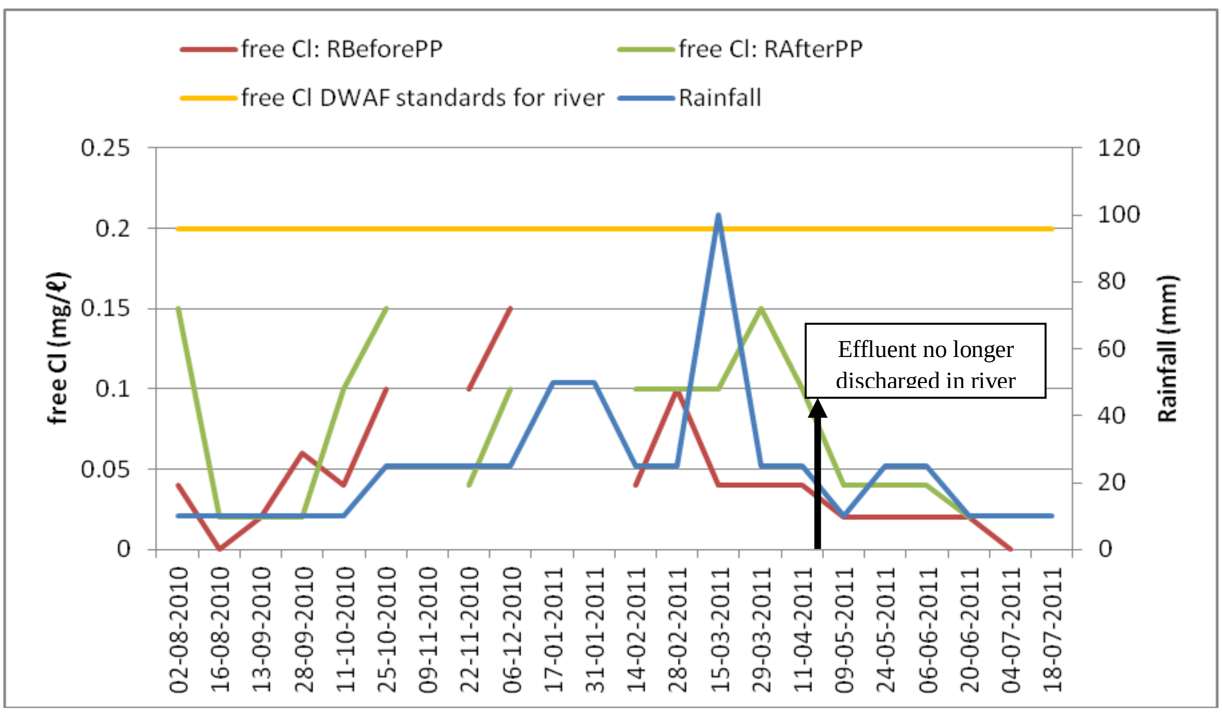

Figure 4.15: Free chlorine concentrations for sample sites RBeforePP and RAfterPP.

The water quality standard of 0.2 mg chlorine/ℓ are as per the Department of Water Affairs and Forestry target water quality range for aquatic systems (Department of Water Affairs and Forestry, 1996c). Figures 4.14 and 4.15 show that **the free chlorine concentrations for all of the samples tested (except one: 0.4 mg/ℓ for site LROUT: Fig. 4.14) comply with the water quality standard.** It is very important to monitor chlorine levels in rivers receiving waste water effluent because these effluents usually contain ammonia which converts chlorine into chloramines, chlorimine and nitrogen trichloride that are less toxic but more persistent in the environment and thus posing a long term threat to aquatic organisms (Department of Water Affairs and Forestry, 1996c). Chlorine can also react with a variety of substances to form chloro-organic substances that can be harmful to fish but free chlorine, however, is more toxic than combined chlorine but less persistent and toxic effects cannot be reversed (Department of Water Affairs and Forestry, 1996c).

The chlorine concentrations for sample sites LROUT (Fig. 4.14) and RAfterPP (Fig. 4.15) tend to be higher than the other two sites. These two sites are situated after the package plant and the effluent from the plant also shows high levels of chlorine (Table 4.16) that are being disharged into the river. Thus, the higher concentrations in the river could be as a result of the high concentrations in the package plant effluent, indicating that the package plant has a small effect on the chlorine concentrations in the receiving river.

On the sampling date 06/12/2010, a very high concentration of chlorine was detected (0.4 mg/ℓ, above the standard of 0.2 mg/ℓ) at sample site LROUT (Fig. 4.14). The chlorine could not be tested for the incoming river at site LRIN on this date due to bad weather conditions and, thus, it is not possible to say whether the high chlorine concentration was as a result of an outside source. The effluent from the package plant that was discharged into the river contained high levels of chlorine on this particular sample date. However, the chlorine for the site RBeforPP shows higher concentrations of chlorine than at the site RAfterPP indicating that there is another source apart from the package plant. It is, therefore, difficult to explain the nature of the high concentration of chlorine at the sample site LROUT for this sample date.

From Figures 4.14 and 4.15 it can be seen that chlorine levels decreased after the effluent from the package plant was diverted away from the river thus indicating that the high concentations of chlorine in the sewage effluent do have a small effect on the chlorine levels of the river.

4.4 Package Plant

Samples from the package plant were taken from the sewage influent/raw sewage coming into the treatment plant and from the treated effluent exiting the plant (Fig. 4.1). Sample site PPIN shows components with concentrations that are typical of raw domestic sewage with high solids, ammonia, COD and coliform bacterial counts.

Physical parameter analysis:

Sample site PPOUT indicated SS concentrations (Table 4.8) that ranged between 26 mg/ℓ – 68.1 mg/ℓ (above the standard of 25 mg/ℓ). On average, with the exception of SS, all the physical parameters for the package plant effluent comply with the given water quality standards where applicable **indicating that the overall quality of the package plant effluent with regards to physical parameters are good.** The concentrations of SS for site PPIN and PPOUT are shown in Figure 4.16.

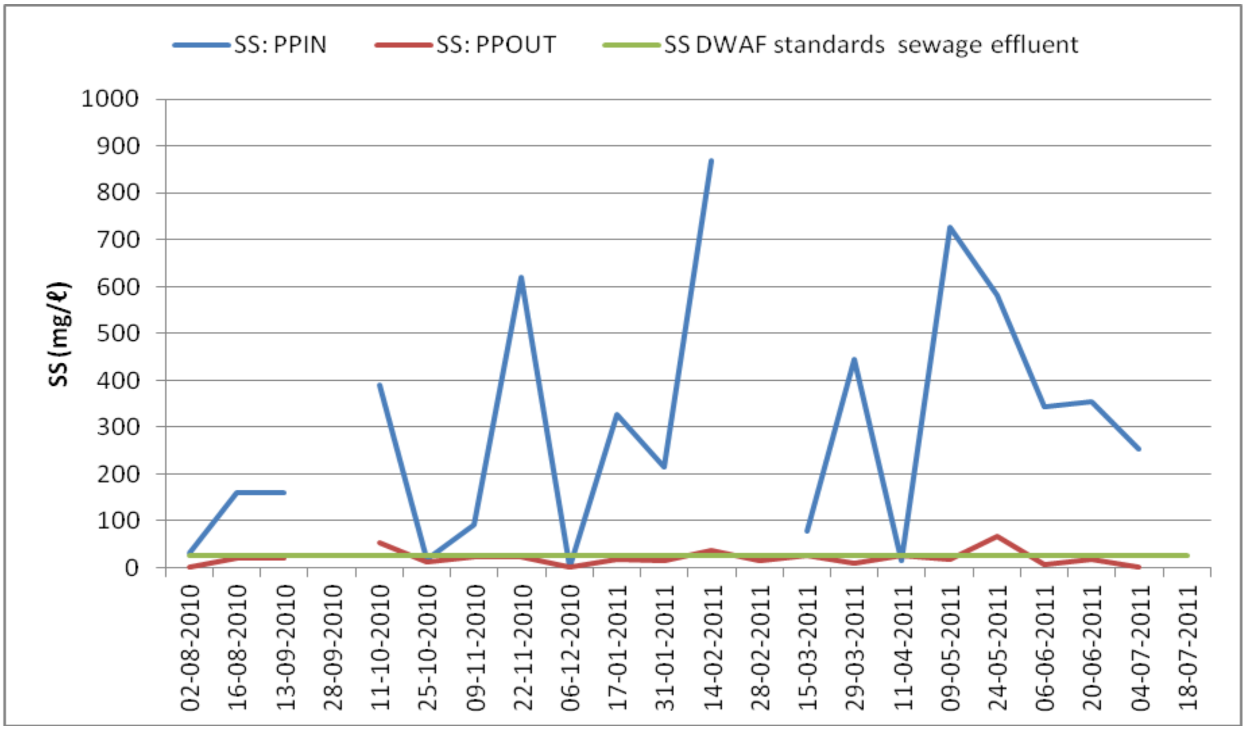

Figure 4.16: Suspended solids (SS) concentrations for sample sites PPIN and PPOUT.

From Figure 4.16, it can be seen that site PPIN shows typical high concentrations for raw sewage and two of the samples for site PPOUT had concentrations (26 mg/ℓ each) just above the standard of 25 mg/ℓ. Three other samples for site PPOUT had concentrations of 54 mg/ℓ, 38 mg/ℓ and 68.1 mg/ℓ, above the standard of 25 mg/ℓ. Suspended solids (SS) are particles or solids that are in suspension in the wastewater and are usually removed through sedimentation and filtration during the treatment process[23]. The final step of solid removal occurs in the cone-shaped clarifier tank (Fig. 2.16), specifically designed to settle out solids. If high concentrations of suspended solids occur in the final effluent it usually indicates problems related to diurnal/flow or the clarifier not performing satisfactory (Damafakir *et al*., 2009). In a study done by Gaydon *et al*.

[23] http://water.me.vccs.edu/courses/ENV149/solids.htm

(2007) it was determined that diurnal fluctuations did indeed affect settling of solids in submerged biological contactor systems. High concentrations of SS can be removed if a final polishing step (wetland) is included in the treatment process (Gaydon *et al.*, 2007, Damafakir *et al.*, 2009).

Microbial analysis:

Sample site PPOUT (Table 4.12 and 4.13) indicated faecal coliform bacterial counts for four of the samples were above the standard of 1000 cfu/100 mℓ and included counts of 1648 cfu/100 mℓ for one sample and 2472 cfu/100 mℓ for the other three samples. The faecal coliform bacteria counts for the package plant effluent (site PPOUT) are shown in Figure 4.17.

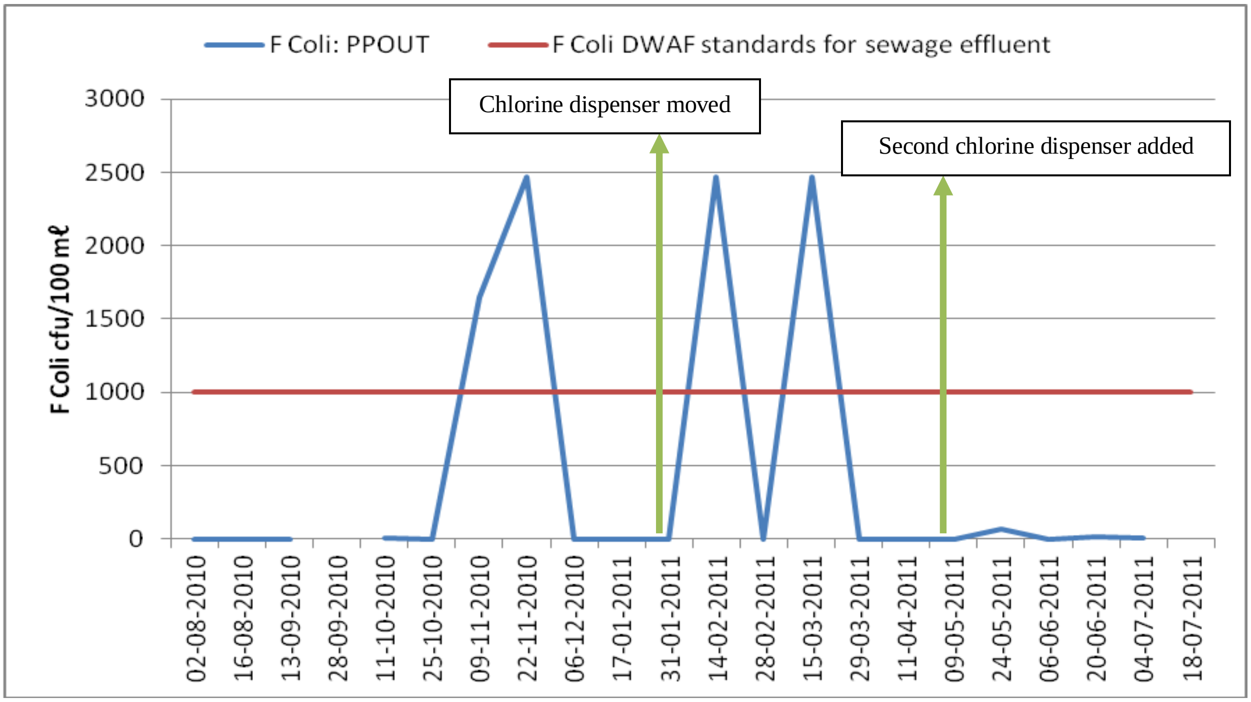

Figure 4.17: Faecal coliform bacteria concentrations detected in package plant effluent (PPOUT).

As can be seen from Figure 4.17, high faecal bacterial counts were detected in three of the package plant effluent samples. The reasons for the first peak noticeable on the Figure 4.17 on the sample date 22/11/2010 are unclear. The chlorine dispenser was situated at the inlet of the last tank (disinfection tank) of the package plant. The position of the dispenser at this tank ensured that the bacteria counts remained low (indicating that disinfection was achieved) but unfortunately very large concentrations of chlorine was detected in the effluent being discharged into the river.

Generally chlorine is used to disinfect wastewater from treatment systems so as to protect humans against disease. Chlorine is a powerful oxidizer and highly soluble in water and can exist in various chemical forms. Toxicity of chlorine to aquatic life depends on the amount of free chlorine remaining in the water resource and can lead to fish deaths downstream from the wastewater treatment facility (Brungs, 1973). High concentrations of chlorine can be converted to other chemical forms or by-products that are toxic to human and aquatic health (Hays, 1976; Atlas, 1997; Freese and Nozaic, 2004; Botkin and Keller, 2005). The health of the river was of concern and in an attempt to improve the effluent quality the chlorine dispenser was moved on the 31/01/2011 to the inlet of the second last tank (clarifier tank) so as to increase chlorine contact time but not concentration.

In a study done by Gaydon *et al*. (2007) it was determined that disinfection remains a weak point in these treatment systems and that it can only be successfully achieved if the design is reviewed and monitoring is done on a constant and regular basis by the operator. Thus, constant monitoring of the chlorine tablet is required and during the period after the dispenser was moved the plant operator was unable to monitor the system himself. The chlorine dispenser was, thus, not sufficiently monitored. The result of this was extremely high counts of faecal coliform bacteria being detected in the samples taken on the 14/02/2011. This then indicates the importance of proper and constant monitoring by skilled operators. On the sample date 15/03/2011 the system experienced flow problems over the dispenser at the new position in the system. It was thought that the flow was too fast over the chlorine tablet resulting in insufficient contact time between the effluent and the chlorine. The result of this, as can be seen from Figure 4.17, is extremely high faecal coliform bacterial counts for this sample date. The problem was detected immediately and rectified and bacterial counts decreased to 0 cfu/100 mℓ. Once more, this underlines the importance of operation and constant, effective monitoring of effluents as was also stated in a study done by Gaydon *et al*. (2007). On 09/05/2011 the chlorine dispenser was moved back to its original position (at the inlet of the last tank/disinfection tank) and a second dispenser was added to the inlet of the second last tank (clarifier tank). Data indicate that this change in design of the system improved the quality of the effluent by effectively decreasing bacterial counts within the quality standard and prolonging chlorine contact time whilst decreasing the concentrations of chlorine in the final effluent discharged into the river.

When the faecal coliform bacteria (Table 4.12) and the *E. coli* counts (Table 4.13) within the influent (raw sewage) and the effluent (treated wastewater) are compared it would seem that the package plant is in fact decreasing the bacteria concentrations with the majority of the effluent samples containing concentrations of 0 cfu/100mℓ, **indicating that the package plant is capable of efficiently removing bacteria in the final effluent**. The Wilcoxon statistical tests also indicated and confirmed a high significant difference going down for faecal coliform and *E. coli* (Appendix H). The samples with bacterial counts above the standard of 1000 cfu/100 mℓ for faecal coliform bacteria resulted from a system/design failure or from monitoring problems.

Chemical analysis:

Sample site PPOUT indicated that of all the samples analysed for NH_3-N (Table 4.9) only one sample (0.93 mg/ℓ) was within the standard of 10 mg/ℓ with the NH_3-N concentrations of the other samples ranging from 15.46 mg/ℓ – 42.52 mg/ℓ. The COD concentrations of samples (Table 4.15) ranged between 76 mg/ℓ – 322 mg/ℓ and only two samples (75 mg/ℓ and 50 mg/ℓ) complied with the standard of 75 mg/ℓ. Analysis done for O-PO_4 (Table 4.11) showed only one sample (0.03 mg/ℓ) complying with the standard of 1 mg/ℓ, the other samples showed O-PO_4 concentrations ranging between 1.8 mg/ℓ – 7.18 mg/ℓ. Concentrations of NH_3-N for sample sites PPIN and PPOUT are given in Figure 4.18.

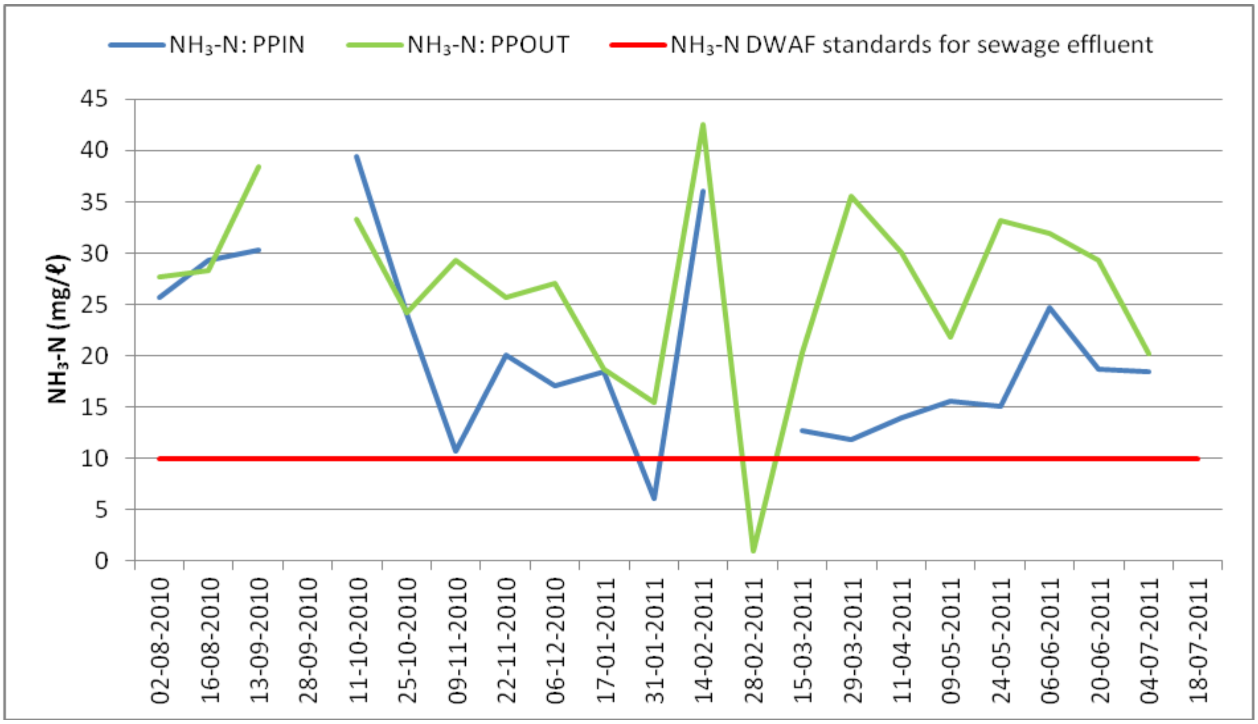

Figure 4.18: Concentrations of NH_3-N for sample sites PPIN and PPOUT.

Figure 4.18 indicates that site PPIN shows typical concentrations for raw sewage and the NH_3-N concentrations throughout the sampling period for site PPOUT remained extremely high and above the standard of 10 mg/ℓ. Only one sample on 28/02/2011 was below the standard with a concentration of 0.93 mg/ℓ. **The majority of the samples had concentrations that did not comply with the standard indicating that the package plant does not sufficiently remove NH_3-N from the waste water.** Statistical analysis also confirmed this by indicating a high significant difference in the opposite direction, indicating that site PPOUT had higher concentrations than site PPIN. When the NH_3-N concentrations in the influent and effluent are compared (Fig. 4.18) it is clear that the effluent leaving the treatment plant contains higher concentrations of NH_3-N than the influent (wastewater entering system), indicating that the NH_3-N is increasing in concentration within the treatment process instead of decreasing.

The same trend is observed in the O-PO_4 concentrations in the effluent. From Figure 4.19, it can be seen that the O-PO_4 concentrations for sample site PPOUT throughout the 12 month sampling period remained high at concentrations above the standard of 1 mg/ℓ. Once again only one sample (on t 22/11/2010) had a concentration of 0.03 mg/ℓ which is below the quality standard. **Thus the majority of the samples had concentrations that did not comply with the standard indicating that the package plant does not sufficiently remove O-PO_4 from the wastewater (a significant difference was also detected with the Wilcoxon statistical tests; Appendix H).**

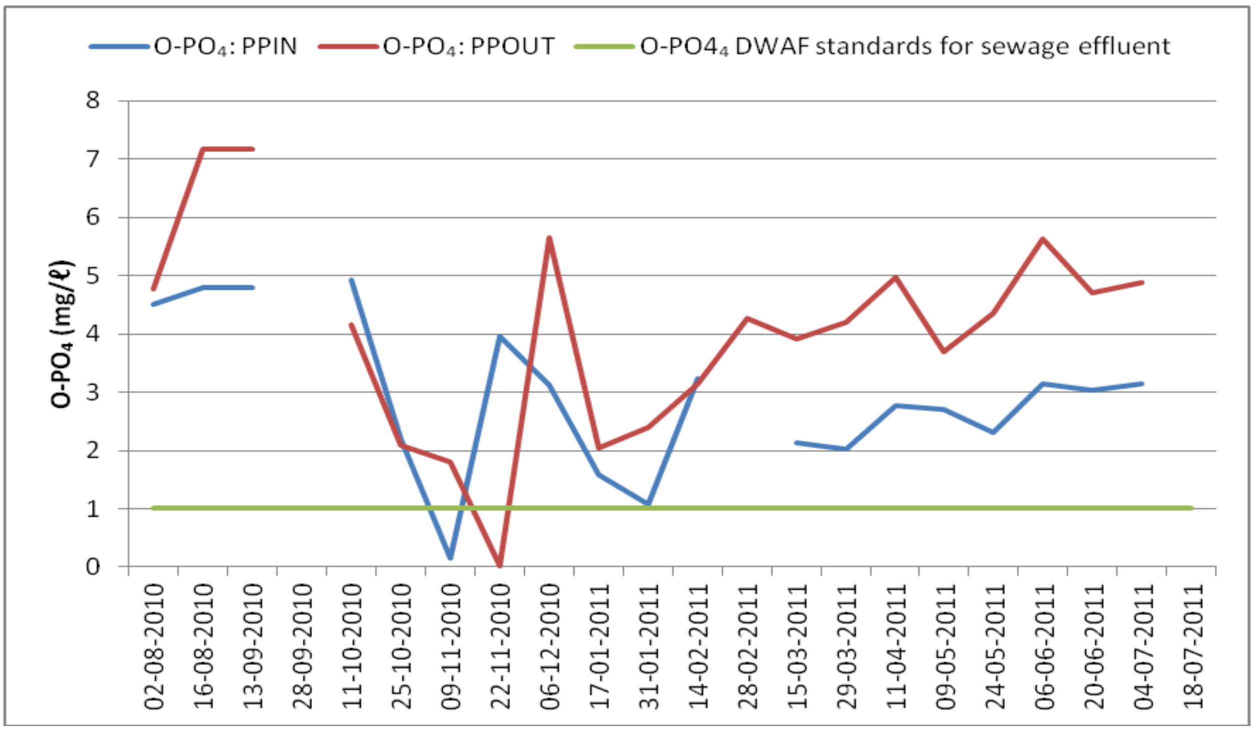

Figure 4.19: Concentrations of O-PO_4 for sample sites PPIN and PPOUT.

If the O-PO_4 concentrations of the incoming wastewater and that of the effluent are compared, the effluent shows higher concentrations than the influent in various samples, again, indicating that the system is not decreasing the O-PO_4 concentrations but instead increasing the levels.

Aerobic digestion takes place in the second part of the system (in the bio-tanks). Nitrification requires bacteria called *Nitrosomonas* and *Nitrobacter* bacteria that convert ammonia to nitrate and nitrite (Akunna *et al.*, 1992) as can be seen in Figure 4.20.

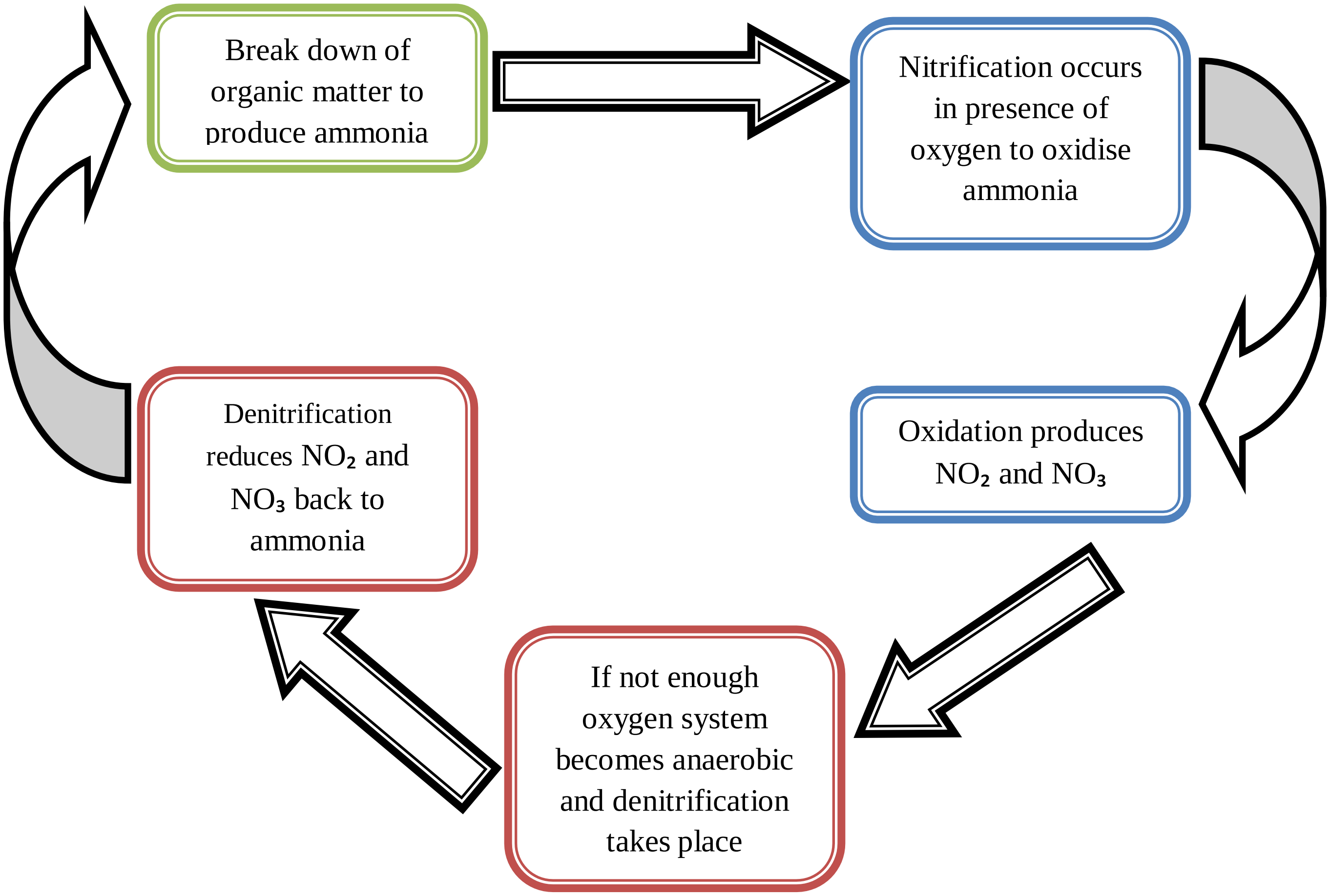

Fig 4.20: Nitrification and denitrification process (Botkin and Keller, 2005).

In the study done by Gaydon *et al*. (2007), it was determined that submerged biological contactor systems have a tendency to not successfully nitrify ammonia. Nitrification is the aerobic oxidation or biological removal of ammonia and nitrifying bacteria are considered to be the weakness of many waste water treatment plants (Wagner and Loy, 2002; Mirhossaini *et al.*, 2010). Microorganisms require oxygen to break down organic material. If more oxygen is used than produced/provided, the DO levels decrease, microorganisms weaken or die, thus leading to improper treatment and the system becomes anaerobic[24].

The depth of the aerators in the bio-tank also plays a role/influence the quality of the effluent. The deeper the aerator or level of wastewater in the bio-tank, the lower the air requirement is or the longer the contact time with oxygen bubbles is. The shallower the aerator or wastewater level in the tank, the more air is required to prolong the contact time with the oxygen bubbles. Due to diurnal problems and the fact that the system is operating at less than half of its capacity (system

[24] http://water.epa.gov/type/rsl/monitoring/vms52.cfm

designed with capacity of 48kℓ/24 hours, currently running at 8-15kℓ/24 hours) the flow through the system is low and the level of wastewater in the tanks are low/shallow and, thus, more air is required to increase the contact time with the bubble path of the oxygen. Thus, there is not enough air provided and the microorganisms in the bio-tank weaken or die. From Figure 4.21 it can be seen that the COD concentrations for various samples of site PPOUT are very high and above the standard of 75 mg/ℓ, indicating that there is not enough oxygen in the system.

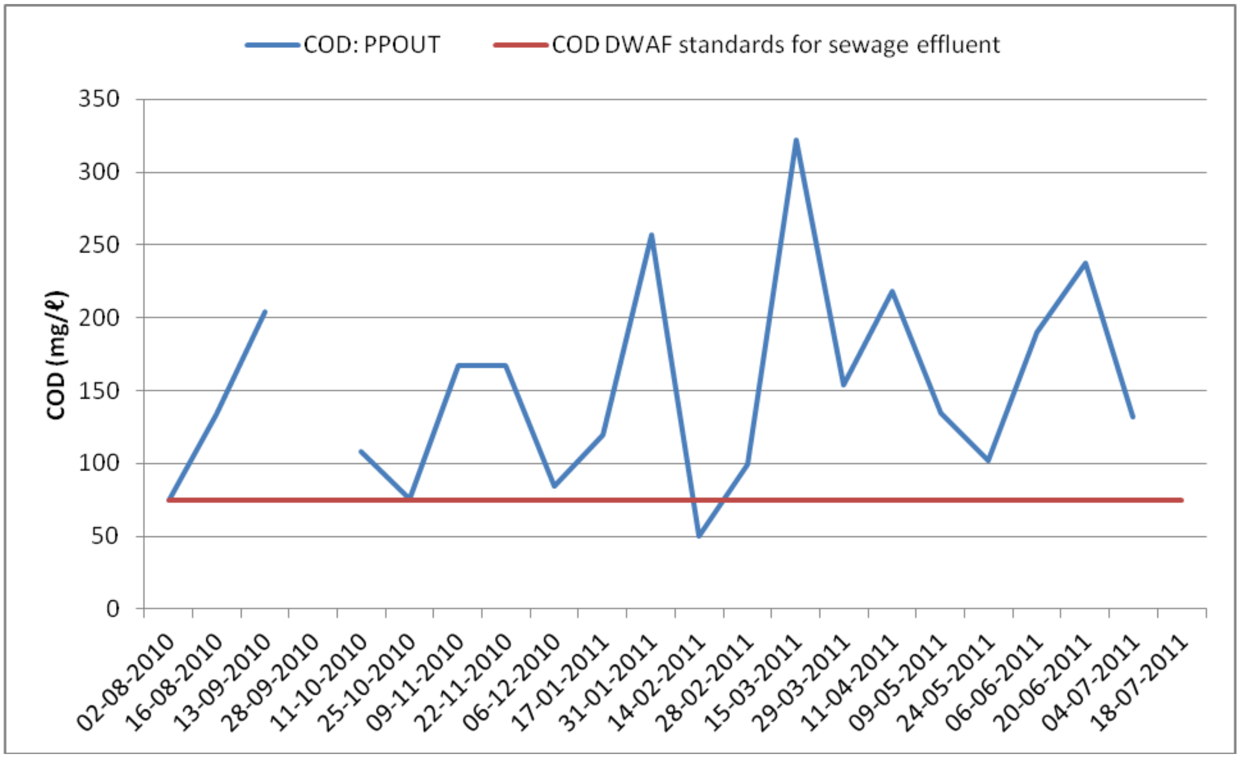

Figure 4.21: COD concentrations for sample site PPOUT.

This may be due to bio-film formation. Bio-film (i.e. microorganisms on the plastic filters) may detach and settles at the base of the bio-tank and form layers. The lower layers become anaerobic and nitrification may stop (because no oxygen is present) and denitrification may replace this process (under anoxic conditions) causing nitrates to be converted back to ammonia. This may explain the high levels of ammonia in the effluent and, in the process also result in an increase in the COD concentrations in the effluent. Settled bio-film particles at the bottom of the tank can also leave the system with the effluent explaining the high SS concentrations in the effluent previously discussed. **Thus, adequate aeration is very important to the overall performance and efficiency of the submerged biological contactor systems** (Akunna *et al*., 1992; Isaacs and Henze, 1995; Damafakir *et al.*, 2009). Comparisons of the median values for each sample site are shown in Figure 4.22 (a) and (b).

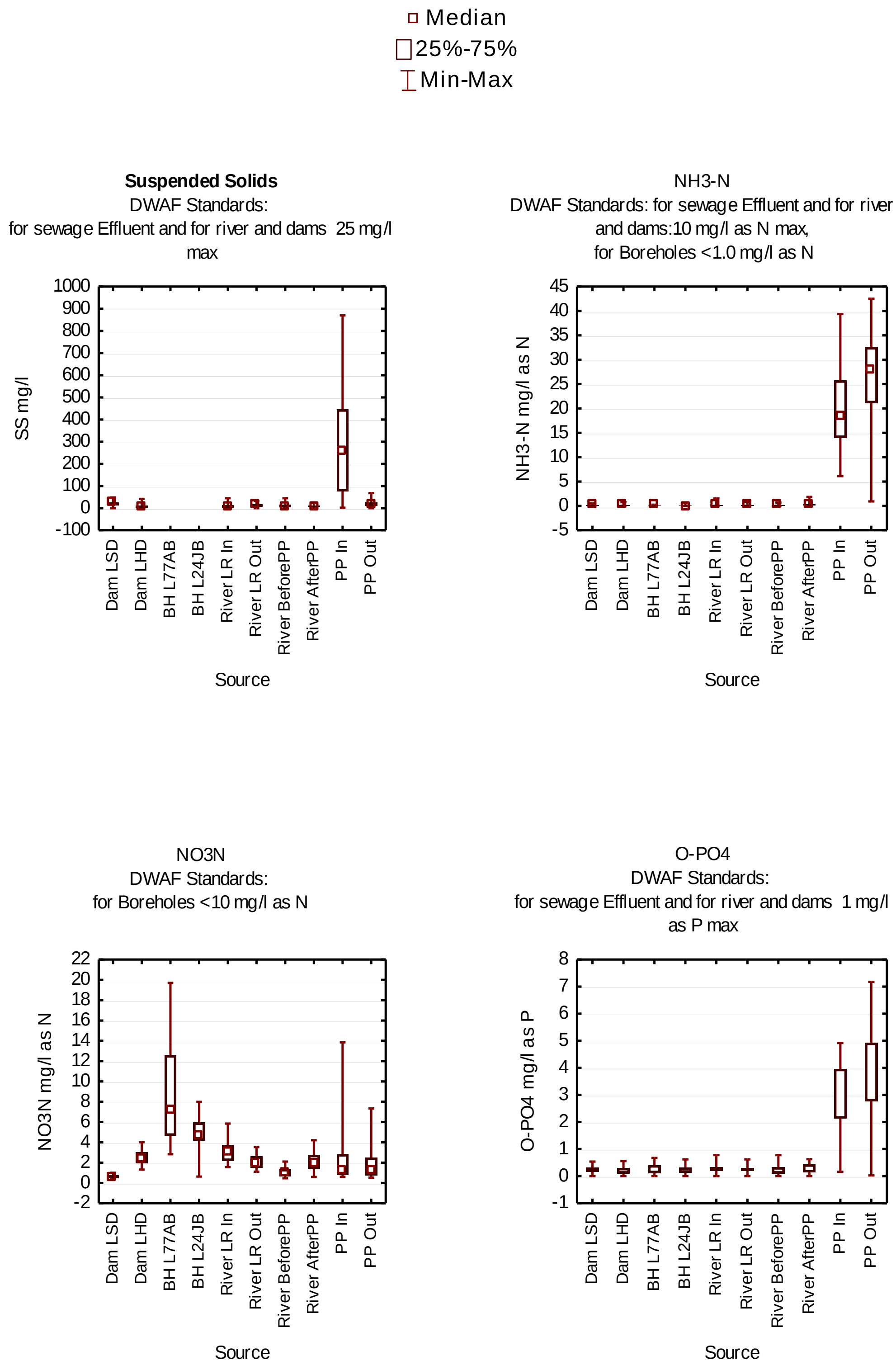

Figure 4.22 (a): Comparisons of median values for sample sites

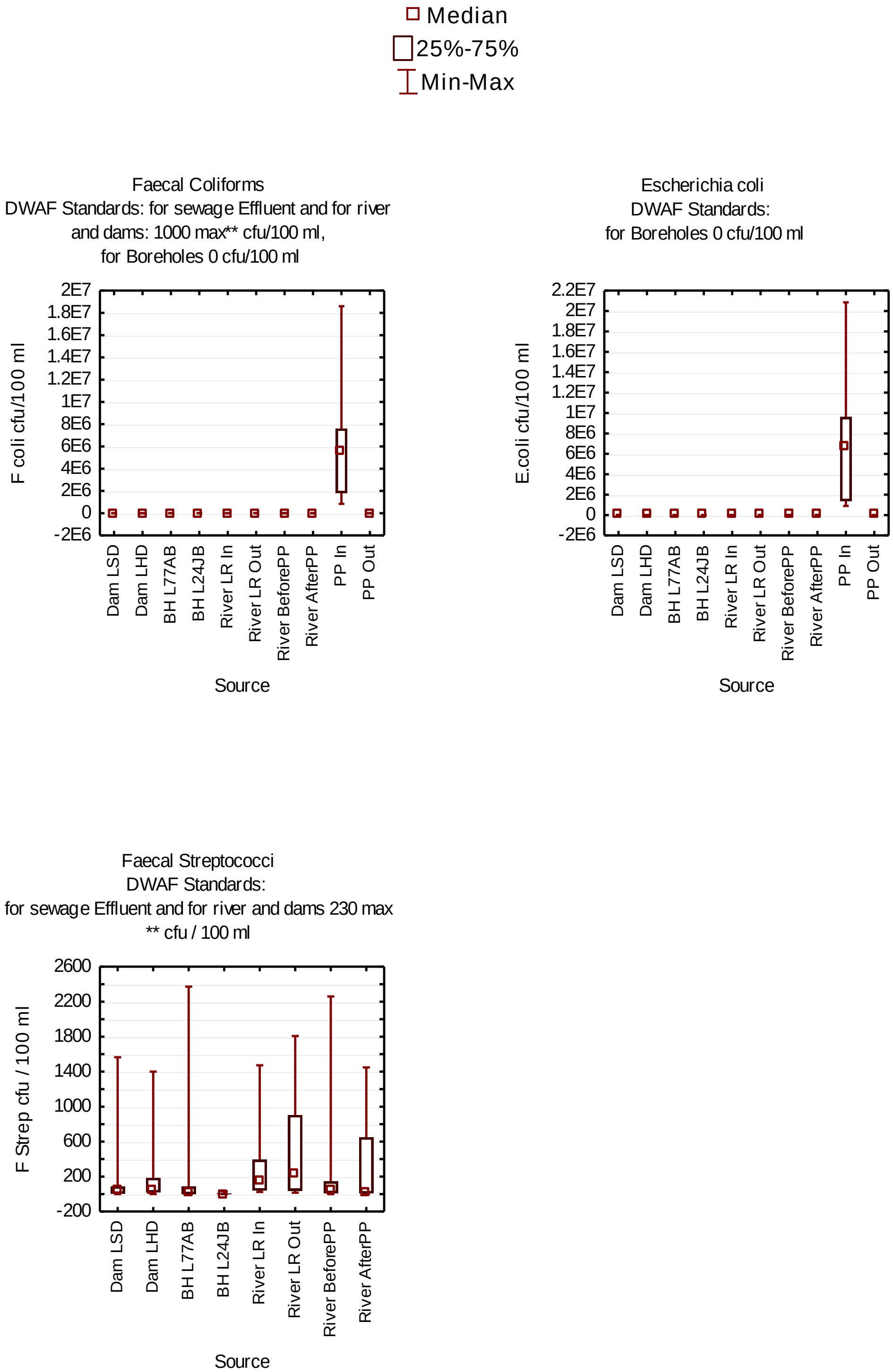

Figure 4.22 (b): Comparisons of median values for sample sites

From Figure 4.22 (a) the high concentration of ammonia and phosphate in the package plant effluent is again visible when compared to the other sample sites.

4.5 Habitat Assessment

Sampling of the river was done with the help of independent consultants over a time period of six months and started in December 2010 and continued until July 2011. Two sample sites were chosen: one upstream where the river enters the research site and one downstream directly after the package plant. Sampling was done once every six weeks and sample sites are coded for each sample visit (Table 4.25). The area is classified as a Western Bankenveld Ecoregion (Dallas, 2007) with mainly bushveld vegetation and with a summer rainfall season. The river is perennial and forms part of the Crocodile West Marico river catchment and the particular section of the river that was sampled is classified as a second order stream (personal communication: Michiel Jonker, October 25, 2010). The channel condition of the river is moderately impacted at the upstream sample site by a bridge and a fence as well as a dam that causes an extensive impact on both upstream and downstream sample sites.

Table 4.25: Key indicating codes for sample sites and sample dates

Code	Description	Date
U/S1	Upstream sample site	06/12/2010
D/S1	Downstream sample site	06/12/2010
U/S2	Upstream sample site	04/02/2011
D/S2	Downstream sample site	04/02/2011
U/S3	Upstream sample site	02/03/2011
D/S3	Downstream sample site	02/03/2011
U/S4	Upstream sample site	11/04/2011
D/S4	Downstream sample site	11/04/2011
U/S5	Upstream sample site	24/05/2011
D/S5	Downstream sample site	24/05/2011
U/S6	Upstream sample site	06/07/2011
D/S6	Downstream sample site	06/07/2011

4.5.1 Results

Index of habitat integrity (IHI)

Various rivers or streams in South Africa have undergone some form of alteration and deterioration. These modifications can affect water quality. In this research study various factors that could cause degradation of the river were assessed to determine the functionality of the river or stream and the ability to provide a suitable environment for the biota. Analysis of the severity of impact of the modifications was done on the instream river channel and the riparian zone according to six modification classes with various ratings (Table 4.26). Ratings were applied to each sample site on each sample visit (Kleynhans, 1996).

Table 4.26: Modification classes with various ratings for each class (Kleynhans, 1996).

Modification class	Rating
None	0
Small	1-5
Moderate	6-10
Large	11-15
Serious	16-20
Critical	21-25

Instream and riperian weights are assigned to the various factors that could cause degradation (Table 4.27).

Table 4.27: Instream and Riperian criteria and weights (Kleynhans, 1996)

Instream	Weight	Riparian zone	Weight
Water abstraction	14	Water abstraction	13
Extend of inundation	10	Extend of inundation	11
Water quality	14	Water quality	13
Flow modifications	13	Flow modifications	12
Bed modifications	13	Channel modification	12
Channel modification	13	Decrease of indigenous vegetation	13
Presence of exotic macrophytes	9	Exotic vegetation encroachment	12
Presence of exotic fauna	8	Bank erosion	14
Presence of solid waste	6		

A rating (Table 4.26) for each criterion from Table 4.27 were given to each sample site with each visit and then the individual variable scores, instream integrity scores, riperian integrity scores and total IHI were calculated with the help of an evaluation model provided by the habitat assessment consultants (Appendix K, Tables 4.28 a and b). Kleynhans (1996) also indicates that the following calculations can be used:

Individual variable score:

- Rating/25 X Weight

Total IHI:

- Instream integrity score + Riperian integrity score/2

The total IHI scores were then used to determine the habitat integrity classes for each sample site (Table 4.28 a, Appendix K). Table 4.28 (a) indicates the IHI assessment class for 10 of the 12 samples were E and only two samples had a D class. The main class throughout the sampling period is E, indicating that the system is seriously modified and that various factors have contributed to a loss of natural habitat and ecosystem functions within this river. The IHI assessment class for upstream (U/S1-6) and downstream (D/S1-6) sample sites however, are the same and very little differences are detected between the upstream and downstream IHI percentage scores, thus indicating that approximately the same amount of habitat and ecosystem function loss occurred throughout the research site (Fig. 4.23).

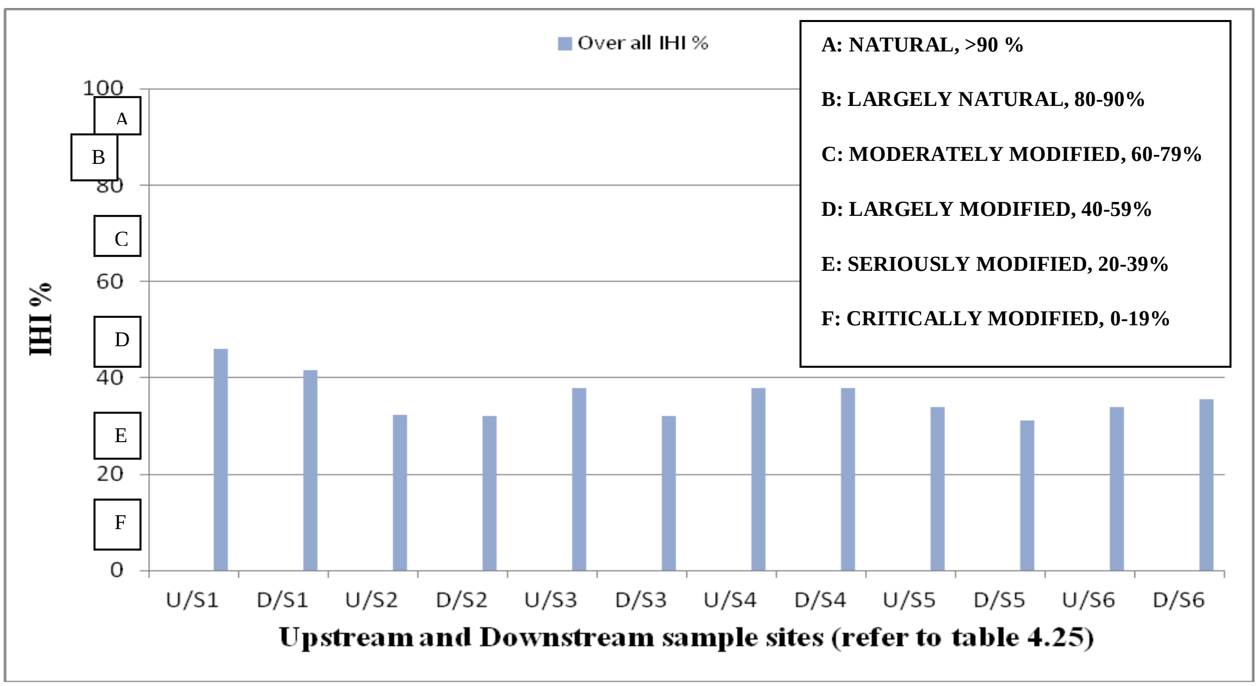

Figure 4.23: Comparison between upstream and downstream IHI percentages and assessment classes (Kleynhans, 1996).

Figures 4.24 to 4.28 illustrate the differences between the upstream and downstream sample sites with regards to stream flow, vegetation and bank erosion.

Figure 4.24: River flow and vegetation at the upstream sample site

Figure 4.25: River flow and vegetation at the downstream sample site

Figure 4.26: Bank erosion at the upstream sample site

Figure 4.27: Bank erosion at the downstream sample site

Figure 4.28: Downstream channel modifications at the downstream sample site

Invertebrate Habitat Assessment System (IHAS)

The physical structure of an aquatic habitat is very important to the diversity and abundance of biota and can affect the integrity of the river system. IHAS methods are used in conjunction with SASS methods to determine the variability of the amount and quantity of aquatic habitat available for invertebrate communities in the river system (Ollis *et al.*, 2006). IHAS was done on the habitat and stream conditions and vegetation types at the upstream and downstream sites over a six month period so as to provide a representative biotope sample (Avianto: Aquatic Specialist Assessment, 2009). Assessment of the site was done by filling in a scoring sheet with various criteria that was scored between 0-5 (Appendix K, Table 4.29). The scores for each site were then summed and the following calculation was used to determine the IHAS percentage:

- Sum of field score X 100/max score (Ollis *et al.*, 2006).

A comparison of the IHAS percentages for the upstream and downstream sites are shown in Figure 4.29.

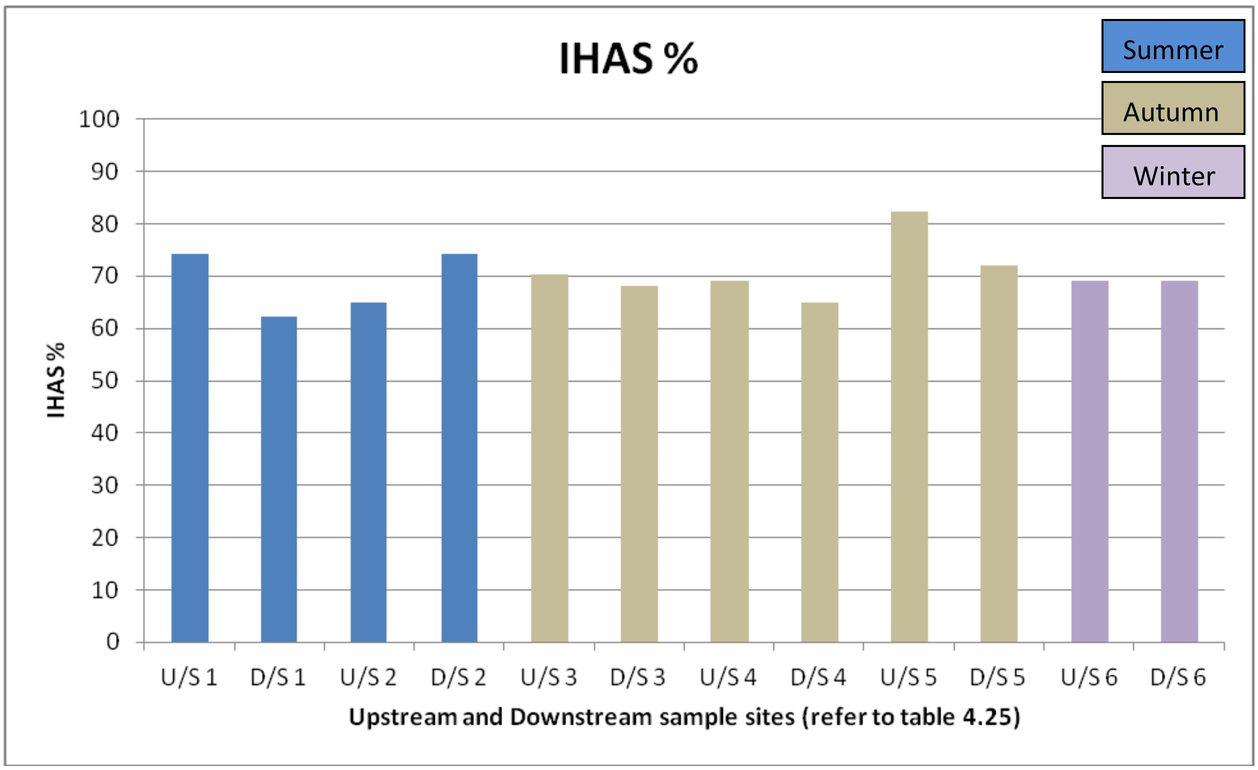

Figure 4.29: A comparison of the IHAS percentages for the upstream and downstream sites

The percentage was then used to determine the overall IHAS class from Table 4.30.

Table 4.30: The overall habitat (IHAS) percentages (Avianto: Aquatic Specialist Assessment, 2009).

IHAS Score %	Description
>75	Very Good
65-74	Good
55-64	Adequate/Fair
<55	Poor

From Table 4.29 (Appendix K) it can be seen that the IHAS for 10 of the 12 samples showed percentages that can be described as "Good", one sample as "Very Good" and one sample as "Fair". Thus, indicating that the quantity, quality and diversity of the biotopes available for aquatic communities are considered to be good for most of the upstream as well as the downstream samples.

South African Scoring System (SASS)

The SASS method is used for rapid bioassessment of rivers and can also be used to determine flow requirements and impact assessments and provides an indication of river quality and health. With the use of SASS the ecological state of the river can be determined as well as spatial and temporal trends, possible problems and changes due to impacts such as developments. When SASS methods are used various factors should also be considered such as habitat quality, availability, diversity, the ecoregion in which the site is situated as well as seasonal changes. Various organisms are listed on the SASS 5 scoring sheet according to family level. Each taxon has a quality score based on its resistance or sensitivity to pollution and disturbances (low scores = resistance, high score = susceptible). Assessment was done by filling in the SASS scoring sheet (Appendix E, Fig. 3.3) by ticking off the taxa that was seen or sampled (Dickens and Graham, 2002). The following calculations were then done according to Dickens and Graham (2002):

- SASS Score = sum of sensitive score
- No. Of Taxa = sum/amount of species sampled
- ASPT = SASS score/no of taxa (Table 4.31, Appendix K)

The SASS score was then taken along with the ASPT score to determine the category class or present ecological state by using a graph with the biological bands for the Western Bankenveld (Upper and Lower zones) ecoregion as provided by Dallas (2007). The class was determined from the provided graph and Table 4.32 was then used to place the site/sample in one of the categories below:

Table 4.32: Present Ecological State (PES) showing class category and description (Kleynhans and Louw, 2007)

Category		Description
A	Unmodified	No impacts
B	Largely natural	Small changes in community
C	Moderately modified	Clear community modifications
D	Largely modified	Impairment of health clearly evident
E	Seriously modified	Most community characteristics seriously modified
F	Critically modified	Extremely low species diversity

Table 4.31 (Appendix K) indicates that for the first sample date the upstream site (U/S1) had a category of C (moderately modified) while the downstream site (U/D1) had a D category (Largely modified). For the second sampling date the two sites (U/S2 and D/S2) both had an E/F category (Serious to critically modified). The third sample date showed a D category (Largely modified) for the upstream site (U/S3) and an E/F category (Serious to critically modified) for the downstream site (D/S3). Sample date four once again showed that upstream and downstream (U/S4 and D/S4) had the same category class of D (Largely modified).

Sample dates five and six both showed the same results in that the upstream sites (U/S5 and U/S6) had B categories (Largely natural) and the downstream sites (D/S5 and D/S6) had D categories (Largely modified). The upstream samples seem to be in better categories than the downstream samples and that the average species per taxon as well as the SASS scores are higher for the upstream sample site than for the downstream sample site (Fig. 4.30 and 4.31) indicating that there are factors affecting the downstream conditions and species more than the upstream site.

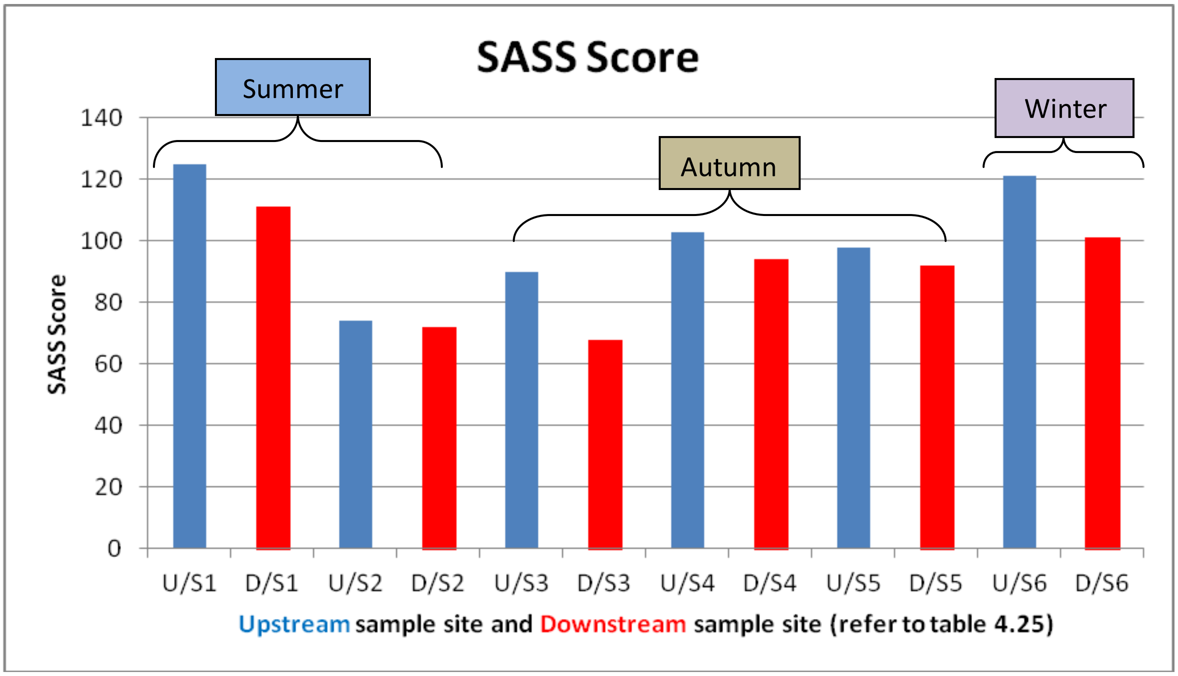

Figure 4.30: Comparison between the SASS scores for the upstream and downstream samples

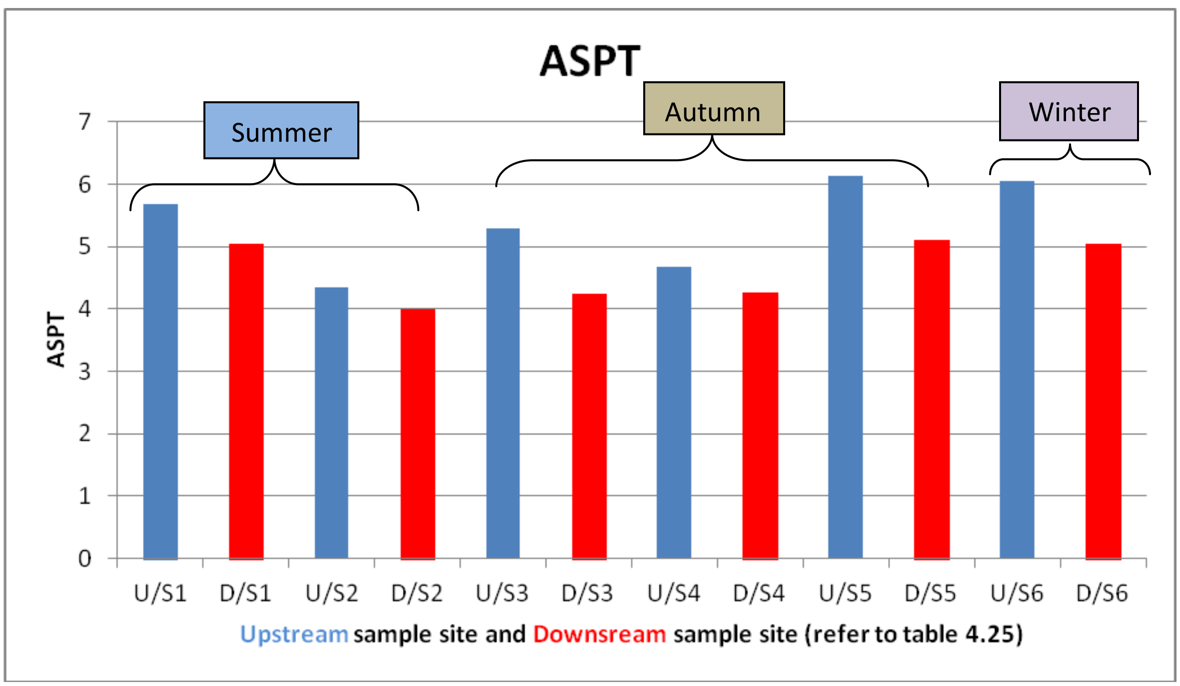

Figure 4.31: Comparison between the ASPT scores for the upstream and downstream samples

Sampling of fish

The habitat sampled for fish species consisted of primarily slow shallow and fast shallow velocity-depth classes and various cover types were present such as substrate, overhanging vegetation, undercut banks, water column and a little amount of aquatic macrophytes at both the upstream and downstream sites. Table 4.33 a and b indicates the list of expected fish species that should be in and around this particular catchment area. These tables also indicate the habitat preferences of each of the species. The habitat sampled can be said to provide suitable conditions for all of these species to be present. The Table 4.34 indicates the species that were caught during sampling throughout the sampling period as well as the overall amount of each species.

Table 4.34: Fish species caught during sampling

Species caught					
Upstream		Downstream		Common name	Scientific name
Name	Amount	Name	Amount		
tspa	3	tspa	3	Banded Tilapia	*Tilapia sparrmanii*
cgar	7	cgar	1	Sharptooth Catfish	*Clarias gariepinus*

The *Tilapia sparrmanii* (Fig. 4.32) had the same amounts upstream and downstream, whilst the *Clarias gariepinus* (Fig. 4.33) were much less downstream than upstream. None of the other species on the expected list (Table 4.33) were caught at these sample sites although habitat was available, indicating that there are factors affecting the fish species at these sample sites. The following alien fish species were also caught (Fig. 4.34) during the six month sampling period and are listed in Table 4.35.

Table 4.35: Alien fish species caught at sample sites

Alien species					
Upstream		Downstream		Common name	Scientific name
Name	Amount	Name	Amount		
None		msal	52	Largemouth Bass (EX)	*Micropterus salmoides*
		ccar	3	Carp (EX)	*Cyprinus carpio*
		gaff	7	Mosquitofish (EX)	*Gambusia affinis*

All of the alien species were caught at the downstream site indicating that the conditions downstream are more favourable for these species.

Figure 4.32: *Tilapia sparrmanii* caught at upstream sample site

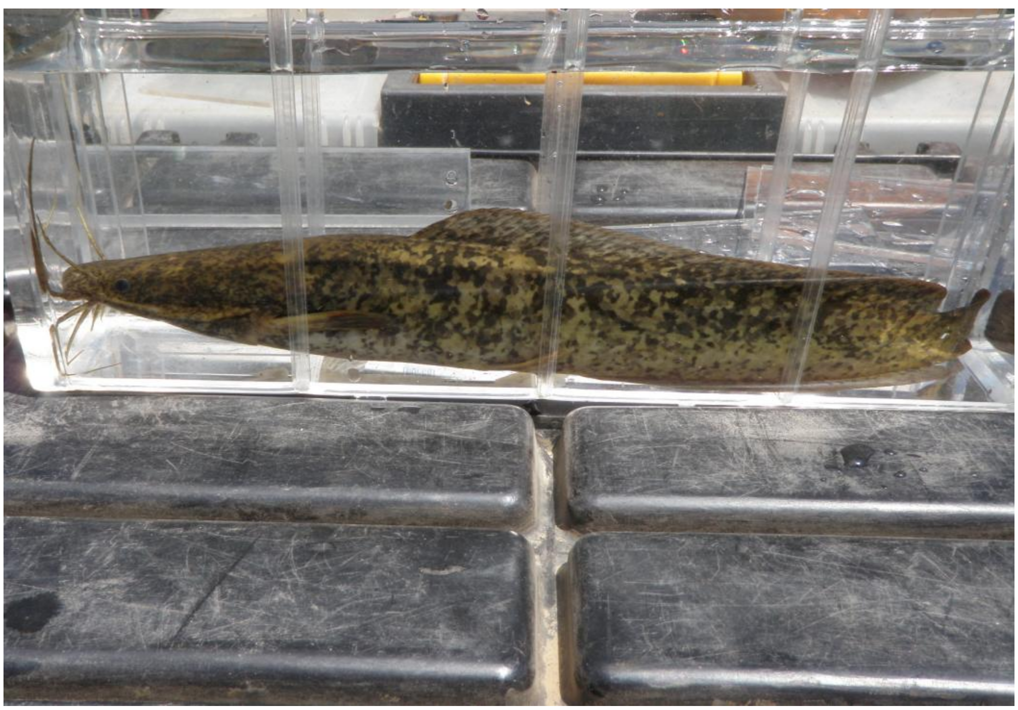

Figure 4.33: *Clarias gariepinus* caught at the upstream sample site

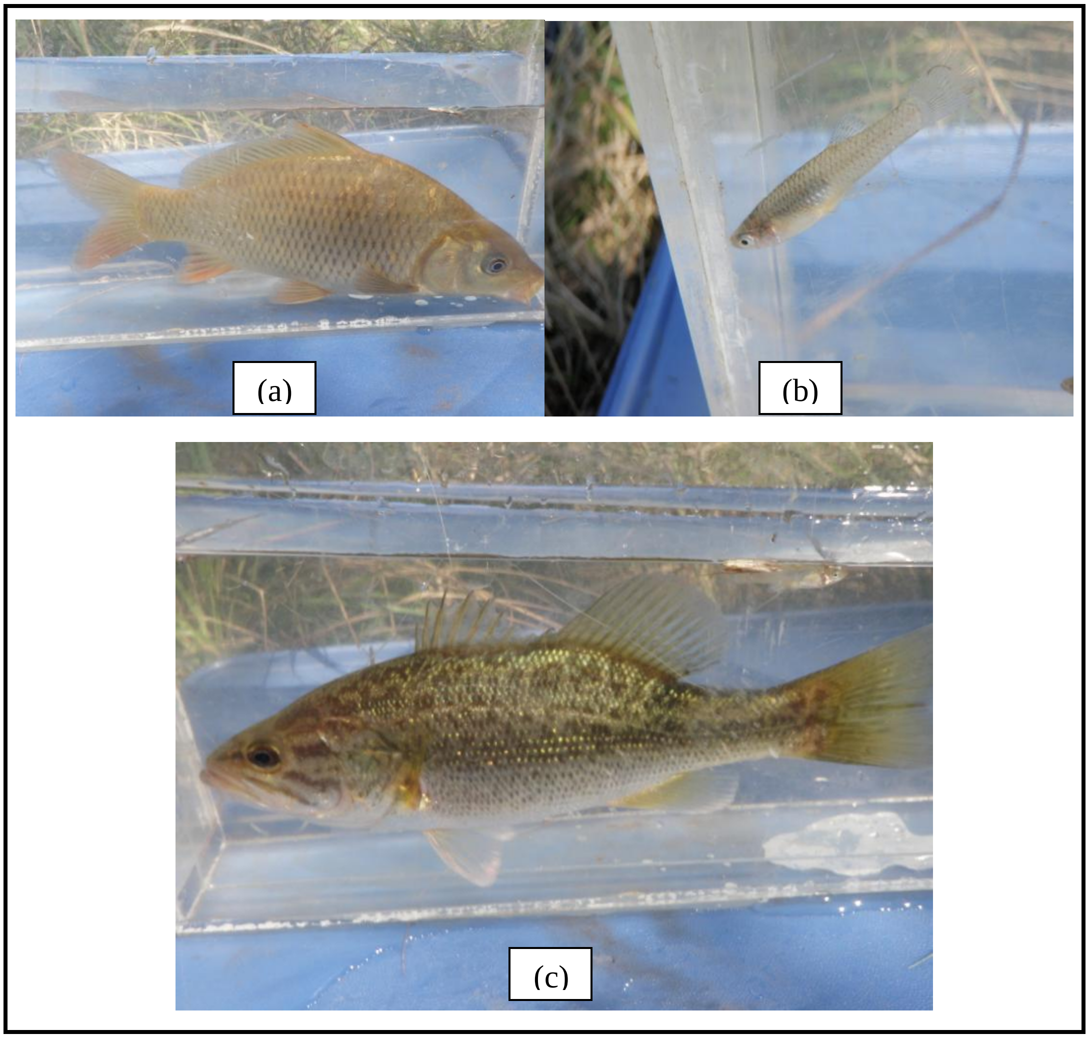

Figure 4.34: The three invasive species caught; (a) carp, (b) mosquitofish, (c) Largemouth bass

4.5.2 Discussion

The health of a river is determined through various factors such as physical, chemical and environmental stressors that disturb and modify the river and riparian areas and the biological responses of the fish, vegetation and invertebrates to these stressors (Kleynhans and Louw, 2007). Table 4.28 (a) indicates that the factors that have the highest impact on the instream habitat of the river are flow modifications, channel modifications and exotic fauna. Other factors that also have an impact are inundation and bed modification. Factors that have the most impact on the riparian zone (Table 4.28 b) of the river are also flow and channel modifications and bank erosion. The impact of water quality are considered low throughout the sampling period which indicates that the physical parameters such as pH, temperature, DO, EC and TDS are of good standard. These findings also support and validate the data, analysis and interpretation that were obtained through the sampling process where the standard of the physical parameters at sample sites LRIN, LROUT, RBeforePP and RAfterPP was considered good.

Table 4.29 indicates that the areas sampled showed a good integrity of the habitat and that various habitat types were sampled such as sand, gravel, cobbles and some marginal vegetation, indicating that there is habitat available for certain species. Algae were also found to be present at both the sample sites throughout the six month sample period, indicating that nutrients (N and P) are present in the river. This also support and validate the results that were obtained through the water sampling process where N and P was found at sample sites LRIN and RAfterPP (Fig. 4.6, 4.7, 4.10 and 4.11).

Table 4.31 indicates very low SASS categories (E/F) for samples U/S2 and D/S2 (sampled in February 2011). These low scores could be as a result of the heavy rains experienced a month earlier when the river was in flood and a lot of the habitat was flushed away, thus the flow and channel of the river was modified to a very large extent. The upstream and downstream sample sites are also separated by a dam with a sluice gate. During the high flow period it is possible that this gate was opened to allow more water to pass through. This could have affected the habitat downstream by flushing away the habitat and could explain why the SASS results for sample U/S3 (upstream from dam) is a D category but is a E/F category for D/S3 sample downstream from the dam for the same sample date. After the rainy season the SASS scores increased and the sites showed improvement and better categories were achieved. Table 4.31 also indicates that the SASS scores are lower for the downstream sample site than for the upstream sample site. Various factors contribute to these low scores.

The flow of the river is one factor that could affect the biological communities. Organisms have different preferences to flow and depth. Certain invertebrate species for example, are adapted to slow flow, and when the flow is suddenly changed with the rainy season or occasional floods the species will not survive (Allan, 1995). This could account for the low SASS scores of E/F (Table 4.31) during the rainy season. The slight differences in flow between the upstream and downstream sites (Fig. 4.24 and 4.25) could also explain the overall differences in SASS scores between the upstream and downstream sites as well as the differences in fish species amounts.

The presence of the dam as previously stated, is also an impact factor on the river and the biological communities. The dam that is situated between the upstream and downstream sample site, affects the flow of the river and during floods release of high discharges cause habitat destruction. The dam also affects migration of fish species and fish reproduction (Moss, 2010). Thus, the presence of the dam could account for the differences in fish numbers between the upstream and downstream sample sites (Table 4.34) as well as explain why certain species are absent from this research site. Dams are also known to reduce species richness of benthic invertebrate communities downstream (Allan, 1995) and this could explain the lower SASS score observed at the downstream site compared to the upstream sample site (Table 4.31).

During the sample period only two of the expected fish species were caught (catfish and the banded tilapia, Table 4.34). The banded tilapia occurred at the same amounts at both the upstream and downstream sites. This could be explained as a result of the feeding habits of this species. They feed on small fish, invertebrates and algae. Both sites had invertebrates and algae, thus supplying a constant food source at both sites for this species (Skelton, 1993). The catfish had higher numbers upstream than downstream. This could be due to the fact that upstream had a slower flow than downstream (Fig. 4.24 and 4.25) and this species prefers slower flowing water. This species also requires migration when breeding and due to the presence of the dam, these fish could be prevented from migrating within the river and thus lower numbers are detected downstream. This fish is also considered to be a dominant ecological presence which could explain why none of the other expected fish species (Table 4.33 a and b) occur at these sites (Skelton, 1993).

Three invasive species were also caught downstream (Table 4.35). These invasive species can cause a decline in native fish numbers, alter habitats and trophic levels as well as cause disease and parasite infections (Allan, 1995). The carp species that was caught are known for its destructive feeding habits. The mosquito fish is a very aggressive species that feeds on small invertebrates and fish larvae. The bass feed primarily on fish and the juveniles feed on invertebrates (Skelton, 1995). All of these factors could explain the lack of expected species, the decline in native fish species as well as the lower SASS score at the downstream site (Table 4.31). The modified river channel downstream (Fig. 4.28) provides an ideal habitat for the predator fish species to hide and ambush their prey. This could explain why the invasive predator species were only found at the downstream sample site (Table 4.35). Predation affects biological communities directly as well as indirectly. The direct impact is the reduction of native fish species. The indirect impact is the fact that they cause injuries to their prey and restrict the prey's habitat use and foraging behaviour as well as their growth and reproduction (Allan, 1995). These invasive species could also account for the fact that only two of the expected species are present at the research site.

The state of rivers can also be affected by other factors such as landscape transformations. These factors can include draining of floodplains, building of roads, houses and other buildings or structures as well as the removal of vegetation. These factors can cause increased runoff and erosion to occur which will affect the flow of the river and cause channel modifications as well as degrade water quality (Allan, 1995). Thus, it is clear that all factors and characteristics should be considered when the state of a river is determined.

Chapter Five

5. Conclusion and Recommendations

The problem statement associated with this research addressed two questions, namely:

- What is the overall quality of the water resources of the study site?
- What is the quality of the waste water effluent produced by the package plant that is being discharged into the environment?

Both of these problems were addressed as follows, namely:

- measuring the physical parameters (EC, pH, temperature, DO and suspended solids) of the domestic sewage effluent that is produced and discharged by a selected package plant
- measuring the chemical parameters (such as COD, orthophosphate, ammonia, nitrites, nitrates) of the domestic sewage effluent that is produced and discharged by a selected package plant
- measuring the concentration of coliforms present in the sewage effluent discharged by the package plant
- determining whether maintenance and monitoring, has an impact on the final effluent quality
- measuring the quality of the surrounding water resources such as a river, two dams and two boreholes.

Validity and reliability of results were achieved by:

- collecting samples from the package plant effluent as well as surrounding water resources (inclusive of a habitat assessment) at the research site using the same sample points over a 12 month period
- analysing samples using calibrated instrumentation as well as specific laboratory sampling procedures throughout the sampling process
- making use of quantitative as well as qualitative research methods, including observations noted by the researcher as well as the completion of an anecdotal questionnaire by the package plant operator.

5.1 Conclusion

After the data were analysed and discussed, the following conclusions were drawn and recommendations made:

Through analysis of physical, chemical and microbiological parameters, it was found that the overall quality of water resources at the research site (dams and river) was good (Fig. 4.22 a and b). These results were supported and validated by the habitat assessment that was done on the river, which indicated that the overall water quality of the river was of a good standard with regards to physical parameters thus, indicating that the package plant had little effect on the river water quality. The habitat assessment did however indicate that the habitat integrity was classed as an E (seriously modified). However, very little differences are detected between the upstream and downstream IHI percentages.

The variability of the amount and quantity of aquatic habitat available for invertebrate communities are considered to be good for both the upstream as well as the downstream samples site. A small difference in the SASS scores and fish species caught was detected between the upstream and downstream sites but this was as a result of various factors such as flow and channel modification during the rainy season, the effect of the dam and invasive predator fish species. The boreholes, however, have unacceptable levels of coliform bacteria and nitrate concentrations (Fig. 4.22 a and b) that are of concern due to the fact that these boreholes are used for human consumption and, thus, need further monitoring.

Package plant data highlighted a few problems with this treatment system. Literature indicates that package plant problems mainly occur within the design of the system as well as with poor construction, operation, maintenance and mechanical failures (Gaydon *et al.,* 2007). Regarding microorganisms, the package plant studied for this research project successfully removed bacteria from the final effluent. At first there were concerns regarding large amounts of chlorine detected in the effluent and being discharged into the receiving river but after some changes was made in the design of the system, mainly involving the chlorine dispenser. This problem was solved and chlorine levels could be reduced whilst still maintaining bacteria concentrations below the accepted standard.

Thus, although three river samples collected throughout the sampling period showed spikes in coliform bacteria levels, generally the quality of the effluent with regards to the coliform bacteria concentrations is of good standard. As indicated, loss in bacterial control could be attributed to system failure caused due to design faults and reinforces the importance of regular and continuous monitoring and maintenance of these systems so that problems can be detected immediately and corrected.

In contrast, flow/diurnals and oxygen problems seem to be the major factors affecting effluent quality. Diurnals can affect COD, nitrification, denitrification, settling and disinfection (Gaydon *et al.,* 2007). Too little flow and not enough oxygen in the bio-tanks cause cessation of nitrification and the associated oxidation/breakdown of ammonia. As a result, microorganisms responsible for the nitrification process die and form layers at the bottom of the tank which then becomes anaerobic. The resulting denitrification (production of ammonia) is associated with increasing COD levels in the effluent. Such dead microorganisms/bio-film may suspend in the effluent before leaving the system with the final effluent and, thus, result in occasional increases in suspended solids (SS).

A final polishing step such as the inclusion of a wetland can remove these remaining pollutants before the effluent is discharged into the river. Thus, the effluent quality with regard to physical parameters is of good standard. The only quality concern for the package plant effluent is that of high concentrations of nutrients (ammonia and phosphate) and COD not being removed efficiently. Although these pollutants are being discharged into the receiving water body they are within the Department of Water Affairs and Forestry quality standards for rivers.

Nevertheless, package plant treatment systems are considered to be a sustainable solution to treatment of waste water. Communities that are not connected to the municipal systems can make use of these cost effective systems as an alternative means of disposing domestic wastewater and thus ensuring public health.

Package plant systems are also considered to be able to reduce the carbon footprint of sewage treatment systems due to the fact that not a lot of land space is required or needs to be developed for installation of such units and relatively little sludge is generated in these systems. These systems also do not run on a constant basis, thus, reducing power requirements. Sludge that is produced gets pumped back into the system and the system only needs to be cleaned every 4-5 years, thus, reducing the amount of sludge produced as well as the amount of sludge that needs to be transported via road transport to disposal sites. If these package plant systems are optimally operated, monitored and managed, their impact on the environment may be significantly decreased.

For this study, the researcher has successfully analysed and interpreted the available data and it can be concluded that the **hypothesis H0 in the context of this research study is rejected**: through sample analysis of the package plant effluent it was determined that the effluent is of poor quality containing high levels of NH_3-N, O-PO_4, COD. It can be concluded that the **hypothesis H1 in the context of this research study is rejected:** through sample analysis and habitat assessment it was determined that the effluent did not have a major impact on the surrounding aquatic environment. It can be concluded that **hypothesis H2 in the context of this research study is accepted:** through sample analysis and habitat assessment it was determined that the effluent from the package plant is of poor quality with high levels of NH_3-N, O-PO_4, COD but does not have an impact on the surrounding environment. It can be concluded that the **hypothesis H3 in the context of this research study is rejected:** through sample analysis and habitat assessments it was determined that the effluent from the package plant is not of good quality but does not have a positive impact on the surrounding aquatic environment by improving the water quality.

5.2 Recommendations

Due to the fact that the effluent from the package plant contained high levels of NH_3-N, O-PO_4, COD and chlorine, the following recommendations are made:

- A wetland should be constructed next to the plant and that the effluent should be passed through the wetland first before reaching the river. The wetland could then be used as a final filtration/treatment step of the effluent to remove some of the remaining pollutants in the effluent that could negatively impact on the river and aquatic environment. Further tests should then be conducted on the quality of the wetland water as soon as it has established itself so as to determine the quality of the final water reaching the river.

- Package plant system designs should be improved so as to meet the individual needs of buyers with regards to what the system will be used for, where the final effluent will end up, amount of people being served and volume and fluctuations in flow through the system. This will require better communications between suppliers and buyers.

- The design of the package plant should include a sensor to detect the amount of oxygen in the bioreactor tanks. As soon as the oxygen levels decrease below a certain value the sensor will detect this decrease and automatically switch on the blowers or aerators that supply oxygen to the system. As soon as the optimal level of oxygen is once again reached the sensor will switch of the blowers. This will ensure that the package plant performs at optimal level and that adequate aeration is achieved which is very important to the overall performance and efficiency of this submerged biological contactor system studied in this research project/associated with this package plant.

- A survey should be done in the Mogale City area so as to establish the exact number of package plants in use and what types of technologies are being used. This will also assist to establish a monitoring programme of these systems by local government so as to consistently gather data on these systems and determine whether they are functioning properly. Note that previous data from various other systems in the area are not consistent enough to draw proper conclusion and could thus not be included in this research study.

- Improve and clarify legislation and standards with regards to approval and licenses, instalment and effluent quality requirements.

- Further research should be done with regards to comparative analysis of package plant best practice (local and internationally) and policy documents or guidelines and compliance criteria should be drawn up specifically for package plants, owners and local government to assist in the process.
- Education and training should also be provided to owners and local communities to ensure knowledge and understanding of proper package plant operation, monitoring and maintenance of these systems.
- Future research should also be done with regards to management practices or preparing of management models to act as tools for package plant owners and municipalities.
- Research should also be done on the health of the surrounding community and animals on the research site that might be exposed to the borehole and ground water resources.

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Plant operator, August 27, 2010

Michiel Jonker, October 25, 2010

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Appendix A

Package Plant Operator Questionnaire

RESEARCH ON PACKAGE PLANTS

(MANAGER/OPERATING PERSONNEL)

FORM NUMBER | | | |

Date of interview | | | | | | |

Name: ____

Occupation: ____

Place of employment: ____

Period of employment: ____

Qualifications: ____

1) Do you have any experience in sewage treatment processes? YES/NO

If YES please indicate **what** and for **how long**:

____

____

2) Did you receive any training from the Package Plant supplier? YES/NO

If YES please indicate **what type** of training:

____

____

3) Did you receive any additional information in the form of pamphlets, instruction guides, manuals etc?

YES/NO

If YES please **specify**: ____

4) Did you receive a specifications plate from the supplier containing information such as power usage, capacity of plant etc?

YES/NO

5) Is there any communication between you and the supplier on a regular basis?

YES/NO

6) Do you monitor the system?   YES/NO

If YES please specify:

6.1) How do you monitor system:

____

6.2) Frequency of monitoring/sampling:

____

6.3) What do you do with monitoring/sampling data:

____

7) Do you have any comments/views/opinions/concerns about the system, regulations, legislation etc?

____
____
____
____
____

8) **What changes**, if any, have you made to improve system and **why**?

____
____
____
____
____

THANK YOU FOR YOUR PARTICIPATION!

Appendix B

Guideline for Utilization and Disposal of Sewage Effluent

GUIDELINE FOR UTILIZATION AND DISPOSAL OF SEWAGE EFFLUENT

(Department of National Health and Population Development, 1998)

This guide sets out the present policy of the Department and replaces all previous relevant guides. Any person intending to use treated effluent must obtain prior permission to do so from the Regional Director concerned.
This guide is applicable only to treated sewage effluent which is mainly of domestic origin and contains little or no industrial effluent

a) CLASSIFICATION OF TREATED EFFLUENTS (SEWAGE PURIFICATION WORKS)

PS - PRIMARY AND SECONDARY TREATMENT – HUMUS TANK EFFLUENT Conventional sewage purification according to accepted design criteria. This includes screening and primary settling followed by biological purification such as the biological filter bed process or activated sludge process. Secondary treatment also includes the settling or clarification after biological or alternative purification methods. **PST - PRIMARY, SECONDARY AND TERTIARY TREATMENT** **Final effluent complies with the GENERAL STANDARD*, with the *E.coli* count relaxed to a maximum of 1000 E. coli /100 mℓ** In addition to the above-mentioned primary and secondary or equivalent treatment one or more tertiary treatments, viz. land treatment, maturation pond, filtration, chlorination or other types of disinfection, etc., should be applied.	**OD – OXIDATION POND SYSTEM** **Final effluent contains a maximum of 1 000 E. coli/100mℓ** The pond system should be designed according to a recognised standard# and operated in a nuisance-free manner. The combined retention time of the primary pond and approximately 4 secondary ponds should usually be at least 45 days. This system should drain into an irrigation dam of which the reserve storage capacity during dry weather conditions is at least 12 days. Unless sufficient space is available and the ponds are sufficiently remote from built-up areas, this system is not recommended for communities with a population exceeding 5 000. Every oxidation pond system which is not able to deliver effluent of the above-mentioned quality should, for the purpose of this guide, be regarded on its merits as no more than equivalent to PS.

b) DIRECTIONS FOR THE UTILISATION OF TREATED EFFLUENTS FOR IRRIGATION

IRRIGATION OF	PS – PRIMARY AND SECONDARY	PST – PRIMARY, SECONDARY AND TERTIARY	OD – OXIDATION POND SYSTEM
LAWNS AT SWIMMING POOLS, NURSERY SCHOOLS, CHILDREN'S PLAYGROUNDS	NOT PERMISSIBLE	NOT PERMISSIBLE	NOT PERMISSIBLE
PARKS, ONLY FOR BEAUTIFYING FLOWERBEDS, TRAFFIC ISLANDS ETC. – I.E. NOT A RECREATION AREA	NO SPRINKLER IRRIGATION PERMISSIBLE NO PUBLIC DURING IRRIGATION	NO SPRINKLER IRRIGATION PERMISSIBLE NO PUBLIC DURING IRRIGATION	SPRINKLER IRRIGATION PERMISSIBLE ON ITS' MERITS NO PUBLIC DURING IRRIGATION

c) METHODS OF DISPOSAL AND DISCHARGE OF TREATED EFFLUENTS

METHODS OF DISPOSAL AND DISCHARGE OF EFFLUENTS	PS – PRIMARY AND SECONDARY	PST – PRIMARY, SECONDARY AND TERTIARY	OD – OXIDATION POND SYSTEM
DISCHARGE INTO RIVERS AND WATER COURSES, EXCLUDING ESTUARIES, DAMS AND LAGOONS	NOT PERMISSIBLE	ERMISSIBLE ON MERITS WITH DUE REGARD TO LOCAL CIRCUMSTANCES SUCH AS THE DILUTION FACTOR IN THE RIVER OR STREAM, RAINFALL ETC. THE PERMISSIBILITY OF DISCHARGE MUST BE DETERMINED WITH DUE REGARD TO THE USE OF THE RIVER WATER DOWNSTREAM	NOT PERMISSIBLE

		THE DISCHARGE POINT MUST BE DETERMINED WITH DUE REGARD TO THE POSITION OF WATER ABSTRACTION POINT(S) FOR DOMESTIC PURPOSES LOWER DOWN THE RIVER THE EFFLUENT MUST CONTAIN NO HARMFUL SUBSTANCES IN CONCENTRATIONS DANGEROUS TO HEALTH	

d) GENERAL DIRECTIONS AND PRECAUTIONARY MEASURES

• The piping used for effluent be markedly different from the piping used for drinking water in respect of colour, type of material and construction. This precaution is necessary in order to obviate accidental cross-coupling of piping.

• In order to prevent persons from unwittingly drinking effluent water or washing with it, the taps, valves and sprayers of the irrigation system must be so designed that only authorised persons can open them or bring them into operation.

• Every water point where uninformed persons could possibly drink effluent water must be provided with a notice in clearly legible English, Afrikaans and any other appropriate official languages, indicating that it is potentially dangerous to drink the water.

• All possible precautions should be taken to ensure that no surface or underground water is contaminated by the irrigation water, especially where the latter does not comply with the General Standard. Excessive irrigation must therefore be avoided and the irrigation area protected against stormwater by means of suitable contours and screening walls.

• Sprinkler irrigation shall be permitted only if no spray is blown over to areas where, such irrigation is forbidden. In this connection the quality of the effluent, the use of such adjoining area and its distance from the irrigation area must be taken into consideration before sprinkler irrigation is permitted.

• The sewage purification works must be efficiently operated by adequately trained personnel at all times and must, as far as is reasonably practicable, not be overloaded.

• The person or authority in charge of the purification works must satisfy himself that the quality of the final effluent will at all times be in accordance with the directives as set out in this guide.

• Regular control tests of representative final effluent samples must be made at least quarterly and records must be kept of such tests.

• The person or authority in charge of the works must ensure that the quality of the final effluent and the use thereof comply with the directives set out in this guide – also when such effluent is utilised by another person or body. The supply and utilisation of effluent must be terminated if the directives set out in this guide are not complied with.

• A person or body using the final sewage effluent for a purpose set out in this guide, but not undertaking the purification himself, must satisfy himself that only permissible utilisation practices are maintained and must forthwith discontinue the use thereof should he become aware of any deviation from the directive contained in this guide.

• Compliance with the requirements for the utilisation of purified sewage effluent as set out in this guide is the individual and joint responsibility of both the supplier and the user of the final effluent.

• In the case of a use qualified in this guide as permissible on merit, it will be necessary for the relevant uses and methods of use to be thoroughly motivated and investigated. The majority of such cases, stricter supervision and control of the system as well as the quality of the effluent will be required in order to prevent the development of any nuisance or conditions dangerous to health.

Appendix C

UNISA – Mogale City Memorandum of Agreement

Figure 2.20: Signing of UNISA – Mogale City MOA

Figure 2.21: Group photo of all parties present at signing ceremony

Appendix D

Consent Forms

To: Mr. Rinus Bouwer **Date:** 15 February 2010

Manager of Parks

Mogale City Council

P.O Box 94

Mogale City

1740

Dear Mr. Rinus Bouwer,

RE: Research study on quality of Package Plant effluent

As you know UNISA proposes to undertake a research study in cooperation with Mogale City, on the quality of sewage effluent from selected package plants in the Mogale City area to develop possible recommendations for guidelines on standards and policy for the discharging of domestic sewage effluents into the environment. This will be in the form of a MSc Environmental Science research study. The purpose of this letter is to inform the local council of our intended research and to work together with the City of Mogale in conducting this study.

Background:

Domestic sewage, for the purpose of this study, is defined as wastewater containing all domestic waste water/sewage that is generated mainly from the toilets and contains large amounts of fecal pollutants/contaminants. Waste water is considered to be one of the major sources of water pollution in many countries. Untreated or inadequately treated sewage effluents, often finds its way into rivers and this pose a great threat to public and environmental health. These effluent discharges contribute to oxygen demand, nutrient loading and algal blooms (eutrophication) as well as water borne diseases. Various developing countries have inadequate waste disposal systems, lack of infrastructure and capacity, and with rapid increases in population there is an increased demand for proper disposal of domestic waste, this lead to the development of package plants. Package plants were introduced to meet the ever increasing demands and needs of rural or small, isolated communities, residential areas and holiday and recreational sites. These systems are usually complete pre-assembled structures and can be in or above the ground. They are also known as alternative on-site treatment facilities or pre-engineered sewage treatment plants, and have increased in number over the last few years due to its efficiency, low cost and ease of operation.

Objectives:

The objectives of this study are to measure the physical parameters (EC, pH, temperature, DO and suspended solids) of the domestic sewage effluent that is produced and discharged by package plants. Chemical and microbial analysis will also be done on samples of the effluent to determine the concentration/levels of BOD, COD, orthophosphate, ammonia, nitrites, nitrates and coliforms.

The aim of this research will therefore be to determine the quality of the effluent that is being discharged into the environment via natural water ways or used for irrigation purposes and whether the different types of treatment plants selected for this study as well as the efficiency of operation, maintenance and monitoring have an impact on the final effluent quality.

Justification for the research:

The Mogale City council has identified that there is an opportunity for UNISA and Mogale City to work together on improving the efficiency with the monitoring of these package plants. The rapid increase in population led to an increased need for treatment and disposal of domestic sewage. There are various reasons for the importance of efficient sewage treatment such as: environmental considerations – unacceptably treated sewage can be a source of pollution. It causes oxygen depletion which leads to the death of aquatic organisms, as well as the build up of solids and eutrophication of natural water ways. Another reason for treating sewage adequately is human health. Sewage contains a large amount of disease causing pathogens that can be potentially harmful to the community.

Various research studies have been done on effluent quality, treatment system efficiencies and types of sewage treatment systems. There is however uncertainty about the number of package plants being installed in the Mogale City area or the quality of effluent they produce and discharge due to the fact that a literature search on the subject presented no results for the area. There also seems to be no real clarity regarding the standards, guidelines and monitoring requirements for these package plant effluents. Overall this study aims to improve service delivery to the community of Mogale City.

This letter thus serves to confirm the progress with the MOA between UNISA and the City of Mogale and to obtain official sanction, permission and access to certain sites for the research project. UNISA agrees to share data and to keep the City of Mogale informed throughout the course of the research project. We envisage that there will be a project/task team with representatives from Mogale City and the UNISA Research team, which will meet occasionally to review research progress. Rinus, may I suggest that, if you agree, that you facilitate the process as convenor. This study will be subject to UNISA's ethical requirements and in accordance with the law. We look forward to working together with the City council of Mogale, and hope to provide research results that will be in the interest/benefit of the community with regards to improving water quality, environmental and human health.

Please find **attached a copy of the consent form** that will be given to all property owners to sign that they agree to participate in the research study. If you require any further clarification or wish to make any suggestions, please let us know. We should be most grateful for your assistance and we look forward to working with Mogale City and to hearing from you soon.

Kind Regards

Prof. RM Hendrick

Research Supervisor – UNISA

Contact Details : 011 471 2346

Email: Rhendric@unisa.ac.za

Ms. Karin De Bruyn

Reseacher

Contact Details: 011 471 3934

Email: dbruyk@unisa.ac.za

Prof. JB Dewar

Research Co-Supervisor

UNISA Florida

Contact details: 011 471 3112

Email: dewarj@unisa.ac.za

Ms. ME Brand

Research Co-Supervisor

UNISA Florida

Contact details: 011 471 2355

Email: bbrand@unisa.ac.za

Package Plant Effluent Quality Analysis and Water Resource Quality Assessment Research Project

Dear Sir/Madam

Thank you for considering our request to participate in the above research project. The purpose of this research is to determine the quality of sewage effluent that is produced from operating package plants and whether the type of system, monitoring and maintenance have any impacts on the final effluent quality and to assess the overall water quality from the rivers, streams and boreholes in the area.

We hope that the findings of this research will greatly benefit the Mogale City community by improving service delivery, environmental and community health, as well as benefit yourselves by improving our understanding of package plants, their operation and functioning so as to make possible recommendations with regard to improving the management and monitoring of package plants as well as assisting in doing an assessment on the water quality situation in the surrounding area.

We have **attached a consent form** for your consideration and should be grateful if you could agree to complete the form so that we may commence with the project. If you require any further clarification please let us know. We should be most grateful for your assistance and participation.

Thank you.

Kind Regards

Prof. RM Hendrick

Research Supervisor – UNISA

Contact Details : 011 471 2346

Email: Rhendric@unisa.ac.za

Ms. Karin De Bruyn

Reseacher

Contact Details: 011 471 3934

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CONSENT FORM FOR OWNERS

RESEARCH ON PACKAGE PLANTS AND WATER RESOURCE QUALITY ASSESSMENT

A water resource quality assessment case study conducted in Mogale City with particular emphasis on the sewage effluent quality of a package plant.

You are being asked to participate in a **confidential** research study that is being conducted by UNISA with the help of the Mogale City Council to determine the quality of sewage effluent that is produced from operating package plants as well as an assessment of the water quality situation in the surrounding environment. It is hoped that the results of this study will gather information on the quality of effluent produced by these package plants as well as lead to possible recommendations on improving effluent quality and or provide possible standards for effluent quality and to provide recommendations with regards to the overall water quality situation in the surrounding ecosystem.

Your participation in this research study may help to provide valuable information that can be used to draw conclusions about the use of package plants and make possible suggestions towards setting up risk assessment/water safety plans for the Mogale City area which may also be used to help solve future problems in this regard.

If you sign this consent form you will agree to give us permission to enter your property once a month for a period of 12 months so as to take samples from the effluent that is being discharged from the package plant, the rivers/streams/dams as well as the boreholes on the property as well as allowing us to take photographs of certain research aspects while sampling. By signing this consent form you also give us permission to do a survey of your package plant, river, dams and boreholes that is located on your property and you and your operating personnel will be required to fill in questionnaires about the functions of the package plant. The consent form also gives us permission to use the data we obtained for the purpose of this research study.

If you agree to participate in this research the University will guarantee **confidentiality**. Any information obtained during the research or from the questionnaire will be kept **completely confidential** and that your responses to the questionnaires will not be revealed to any third party. No personal information/details about yourself or your property will be made public and only generalised results will be published thus, ensuring your privacy, anonymity and confidentiality. There are no potential risks to your property or physical, social or psychological harm to yourself or any financial costs involved if you participate in this study. This research will adhere to the UNISA's Policy on Research Ethics that states the following: UNISA is committed to undertake and promote research that will be beneficial to society and contribute to knowledge and understanding of the subject; research should respect the independence, rights, dignity, privacy and confidentiality of all participants. Your participation is voluntary. If at any time during this study you wish to withdraw from participating, you are free to do so without any consequences. If you have any questions prior or during the time of the study, feel free to contact us. A summary of the findings on completion of the study will also be available to you if you request it.

AUTHORIZATION: I have read the above and understand the nature of the study and what my participation involves. I understand that by agreeing to participate I have not waived any legal or human rights and that participation is voluntary and that I can withdraw at any time during the study. I understand that I may contact the researcher/University at any time. I agree to participate in this study.

Participant's signature: __________________________ Date: ________________

Title, name and surname:

____

Address: ____

Contact details: ____

Researcher's signature: ___________________________ Date: ________________

Please indicate times suitable for you when we can do sampling as well as where on the property you prefer we take samples:

Time:

____

Place of preferred sampling:

____

Appendix E

South African Scoring System (SASS 5)

SASS Version 5 Score Sheet

Date: / /200__

Collector:

Grid Reference: WGS-84 | Cape datum
S: ° ' " E: ° ' "

Site code:

River:...............

Site description:.......................................

Weather Condition:.......................................

Temp:..................°C pH:....................

DO:....................mg/l Cond:...........mS/m

Biotopes sampled:

SIC .... Time..................minutes
SOOC.................. Time..................minutes
Average size of stones.....................cm
Bedrock...............
Aquatic veg'n......... Dom. sp...............................
MvegIC.............. Dom. sp...............................
MvegOOC............Dom. sp...............................
Gravel................. Sand.................
Mud.......................
Hand picking/Visual observation................

Flow: Low/Medium/High/Flood
Turbidity: Low/Medium/High
Riparian land use:

Disturbance in the river: eg. sandwinning, cattle drinking point, floods etc.

Observations: eg. smell and colour of water, petroleum, dead fish, etc.

Taxon		S	Veg	GSM	TOT
PORIFERA	5				
COELENTERATA	1				
TURBELLARIA	3				
ANNELIDA					
Oligochaeta	1				
Leeches	3				
CRUSTACEA					
Amphipoda	13				
Potamonautidae*	3				
Atyidae	8				
Palaemonidae	10				
HYDRACARINA	8				
PLECOPTERA					
Notonemouridae	14				
Perlidae	12				
EPHEMEROPTERA					
Baetidae 1sp	4				
Baetidae 2 sp	6				
Baetidae > 2 sp	12				
Caenidae	6				
Ephemeridae	15				
Heptageniidae	13				
Leptophlebiidae	9				
Oligoneuridae	15				
Polymitarcyidae	10				
Prosopistomatidae	15				
Teloganodidae SWC	12				
Tricorythidae	9				
ODONATA					
Calopterygidae ST,T	10				
Chlorocyphidae	10				
Chlorolestidae	8				
Coenagrionidae	4				
Lestidae	8				
Platycnemidae	10				
Protoneuridae	8				
Aeshnidae	8				
Corduliidae	8				
Gomphidae	6				
Libellulidae	4				
LEPIDOPTERA					
Pyralidae	12				

Taxon		S	Veg	GSM	TOT
HEMIPTERA					
Belostomatidae*	3				
Corixidae*	3				
Gerridae*	5				
Hydrometridae*	6				
Naucoridae*	7				
Nepidae*	3				
Notonectidae*	3				
Pleidae*	4				
Veliidae/M...veliidae*	5				
MEGALOPTERA					
Corydalidae	8				
Sialidae	6				
TRICHOPTERA					
Dipseudopsidae	10				
Ecnomidae	8				
Hydropsychidae 1 sp	4				
Hydropsychidae 2 sp	6				
Hydropsychidae > 2 sp	12				
Philopotamidae	10				
Polycentropodidae	12				
Psychomyiidae/Xiphocen	8				
Cased caddis:					
Barbarochthonidae SWC	13				
Calamoceratidae ST	11				
Glossosomatidae SWC	11				
Hydroptilidae	6				
Hydrosalpingidae SWC	15				
Lepidostomatidae	10				
Leptoceridae	6				
Petrothrincidae SWC	11				
Pisuliidae	10				
Sericostomatidae SWC	13				
COLEOPTERA					
Dytiscidae*	5				
Elmidae/Dryopidae*	8				
Gyrinidae*	5				
Haliplidae*	5				
Helodidae	12				
Hydraenidae*	8				
Hydrophilidae*	5				
Limnichidae	10				
Psephenidae	10				

Taxon		S	Veg	GSM	TOT
DIPTERA					
Athericidae	10				
Blepharoceridae	15				
Ceratopogonidae	5				
Chironomidae	2				
Culicidae*	1				
Dixidae*	10				
Empididae	6				
Ephydridae	3				
Muscidae	1				
Psychodidae	1				
Simuliidae	5				
Syrphidae*	1				
Tabanidae	5				
Tipulidae	5				
GASTROPODA					
Ancylidae	6				
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae*	3				
Physidae*	3				
Planorbinae*	3				
Thiaridae*	3				
Viviparidae* ST	5				
PELECYPODA					
Corbiculidae	5				
Sphaeriidae	3				
Unionidae	6				
SASS Score					
No. of Taxa					
ASPT					

Sample collection effort exceeds method? .....

Other biota including juveniles:

Comments:

Procedure: 'Kick SIC & bedrock for 2 mins, max. 5 mins; Kick SOOC & bedrock for 1 min; Sweep marginal vegetation (IC & OOC) for 2m total and aquatic veg $1m^2$; Stir & sweep gravel, sand, mud for 1 min total; * = airbreathers; Hand picking & visual observation for 1 min — record in biotope where found; Score for 15 mins/biotope but stop if no new taxa seen after 5 mins; 'Estimate abundances: 1 = 1, A = 2–10, B = 10–100, C = 100–1 000, D = >1 000; S = Stone, rock & solid objects; Veg = All vegetation; GSM = Gravel, sand, mud; SWC = South Western Cape; T = Tropical; ST = Sub-tropical; Rate each biotope sampled: 1 = very poor (i.e. limited diversity), 5 = highly suitable (i.e. wide diversity)

Figure 3.3: South African Scoring System (SASS 5 sheet) (Dickens and Graham, 2002).

Appendix F

Descriptive Statistics

Table 4.1: Descriptive Statistics for sample sites LSD and LHD

Dams										
		Valid N	Mean	Confidence - -95.000%	Confidence - 95.000%	**Median**	Minimum	Maximum	Std.Dev.	Skewness
Dam LSD	EC	21	47.81	40.82	54.81	**44.30**	34.30	113.00	15.36	4.16
	pH	21	7.80	7.63	7.96	**7.86**	7.06	8.40	0.36	-0.44
	Temp	17	19.72	17.02	22.43	**22.10**	9.70	26.00	5.26	-0.76
	SS	21	20.67	15.49	25.84	**23.00**	0.00	48.00	11.37	0.20
	TDS	21	255.29	212.01	298.56	**249.00**	76.00	557.00	95.06	1.43
	DO	16	76.79	71.77	81.80	**76.25**	59.80	93.20	9.41	-0.15
	Ca	20	18.37	15.29	21.45	**15.83**	11.71	40.70	6.58	2.19
	Cl	21	10.52	8.99	12.06	**10.21**	5.66	15.76	3.37	0.24
	Mg	20	32.79	28.48	37.10	**32.77**	3.07	49.80	9.21	-1.58
	NH3-N	21	0.14	0.08	0.20	**0.11**	0.01	0.51	0.13	1.50
	NO3N	21	0.61	0.53	0.69	**0.57**	0.39	1.00	0.17	0.95
	K	20	0.88	0.68	1.08	**0.72**	0.37	1.85	0.43	1.12
	TAlk	21	234.27	206.63	261.91	**233.59**	58.71	429.70	60.72	0.50
	Na	20	6.62	3.98	9.26	**4.32**	1.81	27.00	5.64	2.84
	SO4	21	6.52	4.82	8.22	**6.00**	2.00	16.00	3.74	0.85
	COD	21	50.76	26.97	74.55	**33.00**	1.00	206.00	52.27	2.11
	O-PO4	21	0.25	0.19	0.32	**0.26**	0.00	0.54	0.15	-0.08
	Free Cl	0								
	F coli	21	337.38	30.10	644.66	**52.00**	2.00	2136.00	675.06	2.25
	E.coli	21	407.62	-57.50	872.74	**88.00**	2.00	4068.00	1021.80	3.14
	F Strep	13	185.08	-77.23	447.38	**36.00**	0.00	1564.00	434.06	3.13

Table 4.1: Descriptive Statistics for sample sites LSD and LHD continued

Dams										
		Valid N	Mean	Confidence - -95.000%	Confidence - 95.000%	**Median**	Minimum	Maximum	Std.Dev.	Skewness
Dam LHD	EC	22	18.02	17.06	18.97	**17.45**	14.60	21.70	2.15	0.46
	pH	22	7.00	6.80	7.19	**6.97**	6.19	7.89	0.44	0.19
	Temp	18	19.66	17.37	21.95	**21.15**	11.20	25.10	4.61	-0.73
	SS	22	9.27	4.22	14.33	**4.50**	0.00	42.00	11.41	1.96
	TDS	22	119.86	107.21	132.52	**117.00**	61.00	178.00	28.55	0.20
	DO	17	79.79	75.24	84.34	**79.90**	62.00	97.80	8.85	-0.04
	Ca	21	6.69	5.64	7.73	**6.01**	3.87	11.71	2.29	0.89
	Cl	22	16.99	14.97	19.01	**14.56**	7.10	23.83	4.56	-0.10
	Mg	21	7.85	6.57	9.12	**7.03**	0.78	13.06	2.80	-0.33
	NH3-N	22	0.13	0.06	0.20	**0.10**	0.01	0.79	0.16	3.54
	NO3N	22	2.53	2.20	2.87	**2.39**	1.31	4.02	0.75	0.24
	K	21	1.06	0.96	1.16	**1.06**	0.69	1.49	0.22	0.22
	TAlk	22	61.02	43.44	78.60	**51.36**	35.14	229.36	39.65	3.98
	Na	21	7.03	5.20	8.86	**6.27**	3.75	22.99	4.01	3.47
	SO4	22	10.41	8.86	11.96	**10.00**	6.00	22.00	3.49	1.61
	COD	22	42.50	30.00	55.00	**43.50**	4.00	97.00	28.20	0.26
	O-PO4	22	0.23	0.16	0.29	**0.23**	0.00	0.56	0.15	0.59
	Free Cl	0								
	F coli	22	216.45	68.41	364.50	**82.00**	4.00	1400.00	333.91	2.60
	E.coli	22	329.91	74.42	585.40	**134.00**	12.00	2260.00	576.24	2.78
	F Strep	14	231.43	-15.20	478.05	**34.00**	0.00	1400.00	427.14	2.23

Table 4.2: Descriptive Statistics for sample sites L77AB & L24JB

Boreholes										
		Valid N	Mean	Confidence 95%	Confidence 95%	**Median**	Minimum	Maximum	Std.Dev.	Skewness
BH L77AB	EC	21	62.87	57.92	67.83	**61.60**	42.60	79.30	10.89	0.05
	pH	21	7.13	6.99	7.28	**7.02**	6.75	7.98	0.31	1.30
	Temp	17	19.55	17.77	21.34	**19.90**	11.20	25.20	3.47	-0.74
	SS	0								
	TDS	21	439.81	390.88	488.74	**415.00**	275.00	714.00	107.50	0.87
	DO	16	46.74	42.56	50.91	**47.30**	30.80	59.40	7.84	-0.38
	Ca	20	7.83	5.97	9.70	**6.76**	4.28	21.72	3.99	2.58
	Cl	21	34.04	29.81	38.26	**36.23**	23.89	49.78	9.29	0.36
	Mg	20	52.08	45.36	58.79	**55.40**	4.85	72.53	14.35	-1.86
	NH3-N	21	0.04	0.02	0.07	**0.04**	0.01	0.25	0.05	3.75
	NO3N	21	8.94	6.70	11.18	**7.06**	2.82	19.71	4.91	0.73
	K	20	0.54	0.47	0.60	**0.53**	0.33	0.89	0.14	1.12
	TAlk	21	245.07	231.81	258.34	**242.56**	192.20	353.28	29.15	2.41
	Na	20	6.28	5.15	7.41	**5.80**	0.82	11.16	2.41	0.09
	SO4	21	32.52	25.11	39.94	**22.00**	15.00	63.00	16.30	0.57
	COD	21	25.43	15.42	35.44	**20.00**	5.00	84.00	21.99	1.18
	O-PO4	21	0.28	0.19	0.38	**0.24**	0.00	0.67	0.21	0.33
	Free Cl	0								
	F coli	21	72.05	-10.79	154.88	**0.00**	0.00	711.00	181.98	2.95
	E.coli	21	85.74	-13.14	184.61	**0.00**	0.00	847.50	217.22	2.94
	F Strep	13	342.92	-109.65	795.49	**10.00**	0.00	2373.00	748.92	2.32

Table 4.2: Descriptive Statistics for sample sites L77AB & L24JB continued

Boreholes										
		Valid N	Mean	Confidence 95%	Confidence 95%	**Median**	Minimum	Maximum	Std.Dev.	Skewness
BH L24JB	EC	20	60.07	54.99	65.15	**64.00**	23.80	66.20	10.85	-2.65
	pH	20	7.21	7.10	7.32	**7.17**	6.90	7.95	0.23	1.85
	Temp	17	19.42	17.24	21.61	**20.90**	11.40	25.10	4.25	-0.77
	SS	0								
	TDS	20	394.90	357.78	432.02	**403.00**	142.00	541.00	79.31	-1.48
	DO	16	60.09	52.34	67.84	**62.15**	15.00	82.10	14.55	-1.94
	Ca	19	20.21	17.12	23.30	**19.61**	9.29	35.72	6.41	0.42
	Cl	20	33.40	30.90	35.90	**33.78**	14.54	40.44	5.34	-2.36
	Mg	19	40.95	33.17	48.73	**43.20**	4.25	59.82	16.14	-1.33
	NH3-N	20	0.08	0.01	0.15	**0.03**	0.01	0.66	0.15	3.75
	NO3N	20	4.81	3.95	5.66	**4.70**	0.63	7.99	1.83	-0.48
	K	19	0.73	0.44	1.02	**0.63**	0.26	3.12	0.60	3.77
	TAlk	20	259.70	238.16	281.23	**273.63**	78.20	293.55	46.01	-3.59
	Na	19	5.35	4.80	5.89	**5.48**	1.61	7.48	1.12	-1.85
	SO4	20	13.45	11.37	15.53	**12.50**	7.00	24.00	4.45	0.84
	COD	20	29.35	14.64	44.06	**20.50**	5.00	118.00	31.43	1.70
	O-PO4	20	0.24	0.16	0.31	**0.23**	0.00	0.62	0.16	0.50
	Free Cl	0								
	F coli	20	2.75	-0.56	6.06	**0.00**	0.00	30.00	7.07	3.44
	E.coli	20	9.50	0.80	18.20	**0.50**	0.00	78.00	18.58	2.94
	F Strep	14	3.50	-1.47	8.47	**0.00**	0.00	30.00	8.60	2.78

Table 4.3: Descriptive Statistics for sample sites LRIN & LROUT

Rivers In and Out										
		Valid N	Mean	Confidence 95%	Confidence 95%	**Median**	Minimum	Maximum	Std.Dev.	Skewness
River LR In	EC	20	26.26	8.77	43.75	**17.10**	13.90	184.60	37.37	4.43
	pH	20	6.84	6.67	7.01	**6.88**	6.04	7.46	0.37	-0.56
	Temp	17	18.84	15.58	22.09	**19.40**	9.90	34.50	6.33	0.76
	SS	20	10.00	4.59	15.41	**5.50**	0.00	45.00	11.56	1.96
	TDS	20	115.20	102.28	128.12	**113.00**	75.00	194.00	27.62	1.21
	DO	16	82.66	79.18	86.13	**79.60**	76.30	96.30	6.53	0.91
	Ca	19	6.87	5.05	8.69	**5.97**	3.15	19.89	3.78	2.47
	Cl	20	17.49	15.62	19.36	**15.30**	12.86	25.78	4.00	0.55
	Mg	19	9.63	4.44	14.81	**7.52**	0.77	52.77	10.76	3.94
	NH3-N	20	0.17	0.01	0.33	**0.05**	0.02	1.53	0.34	3.81
	NO3N	20	3.15	2.57	3.74	**3.10**	1.55	5.85	1.24	0.69
	K	19	0.94	0.78	1.10	**0.91**	0.63	2.10	0.33	2.69
	TAlk	20	49.06	43.03	55.09	**45.35**	36.75	89.28	12.89	1.93
	Na	19	6.84	4.99	8.69	**6.24**	2.85	21.45	3.85	3.26
	SO4	20	10.50	8.62	12.38	**10.00**	5.00	22.00	4.02	1.42
	COD	20	34.90	22.72	47.08	**31.00**	4.00	92.00	26.02	0.61
	O-PO4	20	0.27	0.19	0.35	**0.28**	0.00	0.78	0.17	1.16
	Free Cl	11	0.01	-0.01	0.04	**0.00**	0.00	0.10	0.03	2.79
	F coli	20	235.30	28.49	442.11	**92.00**	4.00	1624.00	441.88	2.71
	E.coli	20	349.50	23.91	675.09	**110.00**	6.00	2784.00	695.69	2.99
	F Strep	12	337.67	40.00	635.34	**154.00**	24.00	1472.00	468.50	1.81

Table 4.3: Descriptive Statistics for sample sites LRIN & LROUT continued

Rivers In and Out										
		Valid N	Mean	Confidence 95%	Confidence 95%	**Median**	Minimum	Maximum	Std.Dev.	Skewness
River LR Out	EC	21	22.98	21.29	24.67	**21.70**	18.40	32.50	3.72	1.26
	pH	21	7.10	6.98	7.22	**7.10**	6.40	7.61	0.26	-0.38
	Temp	18	19.60	16.60	22.60	**20.55**	8.60	31.70	6.02	-0.17
	SS	21	12.90	8.87	16.94	**11.00**	0.00	33.00	8.87	0.91
	TDS	21	143.10	128.89	157.30	**141.00**	84.00	226.00	31.21	0.64
	DO	17	79.64	73.68	85.60	**81.40**	59.20	95.20	11.59	-0.38
	Ca	20	6.96	5.95	7.98	**6.15**	4.66	11.11	2.16	0.62
	Cl	21	16.18	14.67	17.70	**16.22**	11.26	20.70	3.33	0.03
	Mg	20	10.75	8.96	12.54	**10.71**	1.44	20.61	3.82	0.23
	NH3-N	21	0.18	0.08	0.28	**0.11**	0.02	0.87	0.22	2.43
	NO3N	21	2.04	1.72	2.37	**1.88**	1.11	3.53	0.72	0.67
	K	20	0.98	0.84	1.12	**0.98**	0.64	1.90	0.30	1.72
	TAlk	21	81.04	67.77	94.31	**68.92**	58.65	184.90	29.14	2.75
	Na	20	6.64	4.12	9.16	**5.41**	3.13	28.27	5.38	3.78
	SO4	21	11.76	10.35	13.17	**12.00**	6.00	20.00	3.10	0.93
	COD	21	33.43	16.12	50.73	**24.00**	5.00	175.00	38.02	2.80
	O-PO4	21	0.25	0.18	0.31	**0.24**	0.00	0.62	0.14	0.67
	Free Cl	19	0.13	0.08	0.17	**0.10**	0.00	0.40	0.09	1.29
	F coli	21	442.48	-2.03	886.98	**160.00**	16.00	4560.00	976.52	4.11
	E.coli	21	601.24	47.87	1154.60	**168.00**	36.00	5360.00	1215.67	3.43
	F Strep	13	471.54	97.81	845.27	**224.00**	16.00	1808.00	618.46	1.28

Table 4.4: Descriptive Statistics for sample sites RBeforePP & RAfterPP

Rivers Before vs After PP										
		Valid N	Mean	Confidence 95%	Confidence 95%	**Median**	Minimum	Maximum	Std.Dev.	Skewness
River Before PP	EC	22	41.69	39.21	44.17	**42.65**	30.30	48.80	5.60	-0.66
	pH	22	7.61	7.48	7.75	**7.65**	7.05	8.33	0.31	0.13
	Temp	19	19.25	16.52	21.98	**21.10**	8.10	26.80	5.66	-0.68
	SS	22	9.95	5.64	14.27	**7.00**	0.00	45.00	9.73	2.39
	TDS	22	213.36	191.58	235.15	**230.00**	125.00	274.00	49.14	-0.71
	DO	18	89.42	85.29	93.54	**89.75**	72.80	106.30	8.29	-0.28
	Ca	0								
	Cl	0								
	Mg	0								
	NH3-N	22	0.14	0.06	0.22	**0.08**	0.01	0.71	0.18	2.44
	NO3N	22	1.05	0.82	1.28	**0.88**	0.45	2.10	0.53	1.01
	K	0								
	TAlk	0								
	Na	0								
	SO4	0								
	COD	22	38.86	29.23	48.50	**36.00**	6.00	79.00	21.74	0.36
	O-PO4	22	0.23	0.16	0.31	**0.24**	0.00	0.78	0.17	1.39
	Free Cl	18	0.05	0.03	0.07	**0.04**	0.00	0.15	0.04	1.23
	F coli	22	284.95	69.64	500.26	**102.00**	12.00	2136.00	485.62	3.02
	E.coli	22	391.18	49.69	732.68	**152.00**	4.00	3616.00	770.22	3.84
	F Strep	14	309.64	-63.14	682.42	**38.50**	0.00	2260.00	645.63	2.64

Table 4.4: Descriptive Statistics for sample sites RBeforePP & RAfterPP continued

Rivers Before vs After PP										
		Valid N	Mean	Confidence 95%	Confidence 95%	**Median**	Minimum	Maximum	Std.Dev.	Skewness
River After PP	EC	22	25.17	21.38	28.96	**21.30**	17.20	47.60	8.55	1.62
	pH	22	7.36	7.17	7.54	**7.29**	6.54	8.31	0.41	0.43
	Temp	19	20.75	17.72	23.77	**22.20**	9.50	33.60	6.28	-0.18
	SS	22	8.59	6.02	11.16	**9.00**	0.00	23.00	5.80	0.80
	TDS	22	159.91	134.31	185.51	**146.50**	82.00	307.00	57.73	1.15
	DO	18	83.47	79.56	87.37	**82.70**	69.30	97.50	7.85	0.20
	Ca	0								
	Cl	0								
	Mg	0								
	NH3-N	22	0.38	0.12	0.64	**0.13**	0.01	1.86	0.59	1.95
	NO3N	22	2.17	1.71	2.64	**1.98**	0.59	4.21	1.04	0.55
	K	0								
	TAlk	0								
	Na	0								
	SO4	0								
	COD	22	34.32	25.46	43.18	**31.00**	3.00	73.00	19.98	0.45
	O-PO4	22	0.28	0.20	0.36	**0.24**	0.00	0.63	0.18	0.50
	Free Cl	18	0.07	0.05	0.10	**0.07**	0.02	0.15	0.05	0.36
	F coli	22	309.91	111.71	508.11	**86.00**	4.00	1360.00	447.03	1.52
	E.coli	22	448.18	94.41	801.96	**128.00**	8.00	3448.00	797.91	2.90
	F Strep	14	254.21	1.68	506.75	**26.00**	0.00	1448.00	437.38	1.88

Table 4.5: Descriptive Statistics for sample sites PPIN & PPOUT

Package Plant Before vs After										
		Valid N	Mean	Confidence 95%	Confidence 95%	**Median**	Minimum	Maximum	Std.Dev.	Skew ness
PP In	EC	19	53.00	48.00	58.00	**52.00**	38.70	78.00	10.00	1.16
	pH	19	7.00	7.00	7.00	**7.00**	6.30	8.00	0.00	0.68
	Temp	0								
	SS	19	299.00	175.00	423.00	**252.00**	2.00	870.00	257.00	0.76
	TDS	19	314.00	274.00	353.00	**291.00**	191.00	431.00	82.00	-0.03
	DO	0								
	Ca	0								
	Cl	0								
	Mg	0								
	NH3-N	19	20.00	16.00	25.00	**18.00**	6.10	39.00	9.00	0.64
	NO3N	19	3.00	1.00	4.00	**1.00**	0.60	14.00	4.00	2.60
	K	0								
	TAlk	0								
	Na	0								
	SO4	0								
	COD	19	1406.00	524.00	2288.00	**769.00**	375.00	8391.00	1829.00	3.46
	O-PO4	19	3.00	2.00	4.00	**3.00**	0.20	5.00	1.00	-0.16
	Free Cl	0								
	F coli	19	6879368.00	4007742.00	9750994.00	**5600000.00**	840000.00	18600000.00	5957921.00	1.16
	E.coli	19	7797842.00	4533403.00	11062281.00	**6700000.00**	890000.00	20850000.00	6772912.00	1.04
	F Strep	0								

Table 4.5: Descriptive Statistics for sample sites PPIN & PPOUT continued

Package Plant Before vs After										
		Valid N	Mean	Confidence 95%	Confidence 95%	**Median**	Minimum	Maximum	Std.Dev.	Skew ness
PP Out	EC	20	65.00	62.00	69.00	**65.00**	53.00	88.00	8.00	1.18
	pH	20	7.00	7.00	7.00	**7.00**	6.20	8.00	0.00	-1.85
	Temp	17	21.00	18.00	25.00	**22.00**	10.90	33.00	6.00	-0.20
	SS	20	21.00	13.00	29.00	**18.00**	0.00	68.00	17.00	1.44
	TDS	20	279.00	251.00	308.00	**289.00**	148.00	436.00	61.00	-0.16
	DO	16	38.00	31.00	45.00	**38.00**	17.40	62.00	12.00	0.28
	Ca	0								
	Cl	0								
	Mg	0								
	NH3-N	20	27.00	22.00	31.00	**28.00**	0.90	43.00	9.00	-0.98
	NO3N	20	2.00	1.00	2.00	**1.00**	0.50	7.00	2.00	2.69
	K	0								
	TAlk	0								
	Na	0								
	SO4	0								
	COD	20	152.00	119.00	184.00	**135.00**	50.00	322.00	70.00	0.80
	O-PO4	20	4.00	3.00	5.00	**4.00**	0.00	7.00	2.00	-0.28
	Free Cl	18	0.00	0.00	0.00	**0.00**	0.00	1.00	0.00	0.74
	F coli	20	457.00	16.00	898.00	**0.00**	0.00	2472.00	942.00	1.73
	E.coli	20	487.00	14.00	959.00	**0.00**	0.00	2646.00	1010.00	1.73
	F Strep	0								

Appendix G

Median Values

Table 4.6(a): Median values for physical parameters of all sample sites

Source	EC	pH	Temp	SS	TDS	DO
LSD Median	44.3	7.86	22.1	23	249	76.25
LHD Median	17.45	6.97	21.15	4.5	117	79.9
L77AB: Median	61.6	7.02	19.9		415	47.3
L24JB: Median	64	7.165	20.9		403	62.15
LR In: Median	17.1	6.88	19.4		113	79.6
LR Out: Median	21.7	7.1	20.55	11	141	81.4
RBeforePP: Median	42.65	7.645	21.1		230	89.75
RAfterPP: Median	21.3	7.29	22.2	9	146.5	82.7
PP In: Median	51.5	6.77			291	
PP Out: Median	64.95	7.325	22.4	18	289	38.45

Colour key for Tables 4.6 (a), (b), (c)	
physical parameters	
chemical mg/ℓ	**chemical** mg/ℓ
bio or microbiological parameters	
CFU/100 mℓ	

Table 4.6(b): Median values for chemical parameters of all sample sites

Source	Ca	Cl	Mg	NH_3-N	NO_3N	K	TAlk	Na	SO_4	COD	O-PO_4	Free Cl
LSD Median	15.83	10.21	32.77	0.11	0.57	0.715	233.59	4.315	6	33	0.26	
LHD Median	6.01	14.555	7.03	0.1	2.39	1.06	51.36	6.27	10	43.5	0.225	
L77AB: Median	6.755	36.23	55.395	0.04	7.06	0.53	242.56	5.8	22	20	0.24	
L24JB: Median	19.61	33.78	43.2	0.03	4.7	0.63	273.63	5.48	12.5	20.5	0.23	
LR In: Median	5.97	15.3	7.52	0.05	3.1	0.91	45.345	6.24	10	31	0.28	0
LR Out: Median	6.15	16.22	10.705	0.11	1.88	0.975	68.92	5.41	12	24	0.24	0.1
RBeforePP: Median				0.075	0.88					36	0.24	0.04
RAfterPP: Median				0.13	1.975					31	0.24	0.07
PP In: Median				18.42	1.2					769	3.03	
PP Out: Median				27.985	1.2					134.5	4.24	0.3

Table 4.6(c): Median values for biological parameters of all sample sites

Source	F coli	E.coli	F Strep
LSD Median	52	88	36
LHD Median	82	134	34
L77AB: Median	0	0	10
L24JB: Median	0	0.5	0
LR In: Median	92	110	154
LR Out: Median	160	168	224
RBeforePP: Median	102	152	38.5
RAfterPP: Median	86	128	26
PP In: Median	5,600,000	6,700,000	
PP Out: Median	0	0	

Appendix H

Statistical Tests

Table 4.7 (a): Wilcoxon Statistical Test

	Medians		River In vs Out			Medians		River Before vs After PP			Medians		PP In vs Out		
	River In	River Out	Pairs	Wilcoxon T	p	River Before PP	River After PP	Pairs	Wilcoxon T	p	PP In	PP Out	Pairs	Wilcoxon T	p
SS	5.5	11	16	23	0.019971	7.00	9.00	18	85	0.9826	252	18	19	3	0.000214
NH3-N	0.05	0.11	17	31	0.03125	0.08	0.13	22	48	0.0108	18	28	19	10	0.000625
NO3-N	3.1	1.88	19	0	0.00013	0.88	1.98	22	14	0.0003	1	1	19	39.5	0.025521
O-PO4	0.28	0.24	18	83	0.913301	0.24	0.24	21	74	0.1492	3	4	19	27	0.006211
F Coli	92	160	20	58	0.079323	102.00	86.00	20	96	0.7369	5600000	0	19	0	0.000132
E Coli	110	168	19	63	0.19783	152.00	128.00	21	113	0.9308	6700000	0	19	0	0.000132
Faecal Strep	154	224	12	34	0.69489	38.50	26.00	12	23	0.2094					

	Medians		River In vs Out			Medians		River Before vs After PP			Medians		PP In vs Out		
	River In	River Out	Pairs	Wilcoxon T	p	River Before PP	River After PP	Pairs	Wilcoxon T	p	PP In	PP Out	Pairs	Wilcoxon T	p
SS	5.5	11	16	23	*	7.00	9.00	18	85		252	18	19	3	***
NH3-N	0.05	0.11	17	31	*	0.08	0.13	22	48	*	18	28	19	10	***
NO3-N	3.1	1.88	19	0	***	0.88	1.98	22	14	***	1	1	19	39.5	*
O-PO4	0.28	0.24	18	83		0.24	0.24	21	74		3	4	19	27	**
F Coli	92	160	20	58		102.00	86.00	20	96		5600000	0	19	0	***
E Coli	110	168	19	63		152.00	128.00	21	113		6700000	0	19	0	***
Faecal Strep	154	224	12	34		38.50	26.00	12	23						

Table 4.7 (b): Sign Test

	River In vs Out			River Before vs After PP			PP In vs Out		
	Non ties	Percent < V	p	Non ties	Percent < V	p	Non ties	Percent < V	p
SS	16	81	0.02445	18	50	0.81366	19	5	0.00024
NH3-N	17	82	0.01529	0	81.82	0.00558	19	89.474	0.00132
NO3-N	19	0	0.00004	22	95.45	0.00005	19	21.053	0.02178
O-PO4	18	50	0.81366	21	61.9	0.38270	19	78.947	0.02170
F Coli	20	0	0.00002	0			0		
E Coli	20	0	0.00002	0			0		
Faecal Strep	12	17	0.04331	0			0		

	River In vs Out			River Before vs After PP			PP In vs Out		
	Non ties	Percent < V	p	Non ties	Percent < V	p	Non ties	Percent < V	p
SS	16	81	*	18	50		19	5	***
NH3-N	17	82	*	0	81.82	**	19	89.474	**
NO3-N	19	0	***	22	95.45	***	19	21.053	*
O-PO4	18	50		21	61.9		19	78.947	*
F Coli	20	0	***	0			0		
E Coli	20	0	***	0			0		
Faecal Strep	12	17	*	0			0		

Appendix I

Data for Sample Sites

Table 4.8: SS data for sample sites

mg/ℓ	**Rainfall**	**SS: Dam LSD**	**SS: Dam LHD**	**SS DWAF standards for river and dams**	SS: River LR In	**SS: River LR Out**	**SS DWAF standards for river and dams**	SS: River BeforePP	SS: River AfterPP	**SS DWAF standards for river and dams**	SS: PP In	SS: PP Out	**SS DWAF standards sewage effluent**
02-08-2010	10	23	4	25	17	15	25	6	6	25	31	0	25
16-08-2010	10	33	3	25	2	9	25	2	9	25	159	21	25
13-09-2010	10	28	2	25	6	15	25	2	9	25	159	21	25
28-09-2010	10	26	5	25	10	30	25	4	10	25			25
11-10-2010	10	48	42	25	23	33	25	21	23	25	390	54	25
25-10-2010	25	12	16	25	6	6	25	13	13	25	17	11	25
09-11-2010	25	25	4	25	45	6	25	45	6	25	91	24	25
22-11-2010	25	19	1	25	2	6	25	4	9	25	619	24	25
06-12-2010	25	7	1	25	0	9	25	3	1	25	2	1	25
17-01-2011	50	31	23	25		5	25	19	16	25	328	18	25
31-01-2011	50	23	11	25			25	8	12	25	216	15	25
14-02-2011	25	26	2	25	5	11	25	4	9	25	870	38	25
28-02-2011	25	23	4	25	9	16	25	13	7	25		14	25
15-03-2011	**100**	**32**	**17**	25	**16**	**22**	25	**5**	**20**	25	**77**	**26**	25
29-03-2011	25		37	25	32	26	25	14	9	25	446	9	25
11-04-2011	25	23	2	25	3	14	25	7	3	25	16	26	25
09-05-2011	10	15	3	25	5	5	25	9	4	25	728	18	25
24-05-2011	25	19	7	25	7	7	25	7	7	25	583	68.1	25
06-06-2011	25	6	9	25	4	19	25	14	7	25	344	8	25
20-06-2011	10	5	5	25	4	5	25	4	9	25	355	18	25
04-07-2011	10	0	0	25	0	0	25	0	0	25	252	1	25
18-07-2011	10	10	6	25	4	12	25	15	0	25			25

Table 4.9: NH_3-N data for all sample sites

Mg/ℓ as N	**Rain fall**	**NH3-N: Dam LSD**	**NH3-N: Dam LHD**	**NH3-N DWAF standards river and dams**	NH3-N: BH L77AB	NH3-N: BH L24JB	NH3-N DWAF standards for boreholes	NH3-N: River LR In	**NH3-N: River LR Out**	**NH3-N DWAF standards river and dams**	NH3-N: River BeforePP	NH3-N: River AfterPP	**NH3-N DWAF standards for river and dams**	NH3-N: PP In	NH3-N: PP Out	**NH3-N DWAF standards for sewage effluent**
02-08-2010	10	0.02	0.02	10	0.01	0.01	1	0.04	0.33	10	0.2	1.64	10	25.74	27.63	10
16-08-2010	10	0.51	0.79	10	0.04	0.13	1	0.52	0.72	10	0.57	1.86	10	29.25	28.34	10
13-09-2010	10	0.15	0.13	10	0.06	0.66	1	0.12	0.19	10	0.71	0.18	10	30.35	38.41	10
28-09-2010	10	0.12	0.09	10	0.04	0.05	1	0.06	0.13	10	0.15	0.3	10			10
11-10-2010	10	0.04	0.08	10	0.03		1	0.03	0.08	10	0.07	0.09	10	39.39	33.31	10
25-10-2010	25	0.11	0.12	10	0.06	0.06	1	0.08	0.14	10	0.08	0.89	10	24.1	24.18	10
09-11-2010	25	0.16	0.12	10	0.02		1	0.15	0.06	10	0.15	0.06	10	10.77	29.36	10
22-11-2010	25	0.08	0.12	10	0.04	0.03	1	0.04	0.08	10	0.04	0.08	10	20.07	25.74	10
06-12-2010	25	0.1	0.09	10	0.03	0.03	1	0.04	0.14	10	0.04	0.14	10	17.02	27.06	10
17-01-2011	50	0.13	0.08	10	0.04	0.03	1		0.05	10	0.12	0.19	10	18.42	18.67	10
31-01-2011	50	0.02	0.04	10	0.01	0.01	1			10	0.02	0.04	10	6.13	15.46	10
14-02-2011	25	0.06	0.32	10	0.04	0.12	1	0.05	0.1	10	0.08	0.33	10	36.1	42.52	10
28-02-2011	25	0.01	0.01	10	0.01	0.02	1	0.04	0.04	10	0.03	0.01	10		0.93	10
15-03-2011	**100**	**0.03**	**0.11**	10	**0.02**	**0.03**	1	**0.04**	**0.07**	10	**0.06**	**0.11**	10	**12.67**	**20.31**	10
29-03-2011	25		0.11	10		0.02	1	0.05	0.11	10	0.04	0.11	10	11.84	35.61	10
11-04-2011	25	0.05	0.09	10	0.02	0.02	1	0.05	0.14	10	0.03	0.21	10	13.98	30.1	10
09-05-2011	10	0.36	0.05	10	0.02	0.04	1	1.53	0.87	10	0.16	1.75	10	15.63	21.88	10
24-05-2011	25	0.18	0.11	10	0.04	0.05	1	0.1	0.07	10	0.06	0.08	10	15.13	33.23	10
06-06-2011	25	0.27	0.12	10	0.05	0.04	1	0.17	0.19	10	0.11	0.12	10	24.67	31.91	10
20-06-2011	10	0.29	0.21	10	0.07	0.2	1	0.19	0.27	10	0.28	0.19	10	18.75	29.36	10
04-07-2011	10	0.01	0.04	10	0.02	0.02	1	0.02	0.02	10	0.01	0.02	10	18.42	20.14	10
18-07-2011	10	0.17	0.02	10	0.25	0.01	1	0.03	0.03	10	0.02	0.03	10			10

Table 4.10: NO_3-N data for all sample sites

mg/ℓ as N	**Rainfall**	**NO3-N: Dam LSD**	**NO3-N: Dam LHD**	NO3-N: BH L77AB	NO3-N: BH L24JB	**NO3-N DWAF standards boreholes**	NO3-N: River LR In	**NO3-N: River LR Out**	NO3-N: River BeforePP	NO3-N: River AfterPP	NO3-N: PP In	NO3-N: PP Out
02-08-2010	10	0.48	3.02	3.8	4.22	10	2.98	1.38	0.6	0.74	1.18	0.78
16-08-2010	10	0.43	2.84	4.06	4.71	10	3.22	2.34	0.7	2.5	1.06	2.93
13-09-2010	10	0.52	3	4.49	3.51	10	3.83	2.28	0.95	2.76	1.64	1.12
28-09-2010	10	0.58	3.82	6.02	6.48	10	5.85	2.75	0.91	1.99		
11-10-2010	10	0.93	4.02	5.82		10	4.89	2.83	1.36	4.01	3.44	2.37
25-10-2010	25	0.52	2.74	4.66	4.86	10	5.37	1.26	0.73	1.14	0.79	2.73
09-11-2010	25	0.51	2.4	4.56		10	2.51	1.96	0.77	2.73	0.88	0.99
22-11-2010	25	0.58	2.29	2.82	5.64	10	3.31	1.49	0.64	1.65	2.82	1.54
06-12-2010	25	0.57	2.09	5.14	5.06	10	4.4	1.59	0.99	1.59	1.91	1.28
17-01-2011	50	0.77	2.98	6.94	6.23	10		3.25	1.24	2.89	2.36	1.94
31-01-2011	50	0.73	2.38	7.06	4.69	10			2	4.21	11	2.6
14-02-2011	25	0.61	1.87	10.77	0.63	10	2.09	1.59	0.73	1.69	0.84	0.73
28-02-2011	25	0.53	1.45	10.32	4.5	10	1.55	1.42	0.67	1.34		0.65
15-03-2011	**100**	**0.42**	**1.31**	**13.69**	**4.27**	10	**1.62**	**1.11**	**0.47**	**1.02**	**0.63**	**0.6**
29-03-2011	25		1.48		1.08	10	1.63	1.26	0.45	1.36	0.61	0.52
11-04-2011	25	0.45	1.86	15.17	4.89	10	2.27	1.65	0.63	1.82	0.81	0.77
09-05-2011	10	0.39	1.95	12.57	4.53	10	2.03	1.74	1.8	0.59	1.2	1.04
24-05-2011	25	0.83	3.1	19.71	7.93	10	3.33	2.61	0.96	2.56	1.86	1.48
06-06-2011	25	1	3.52	17.39	7.99	10	3.68	3.08	2.1	4.07	3.1	2.67
20-06-2011	10	0.84	3.17	14.47	6.69	10	3.53	3.53	2.08	3.1	13.85	7.33
04-07-2011	10	0.5	2.15	9.27	4.15	10	2.52	1.9	0.85	1.96	0.7	0.72
18-07-2011	10	0.58	2.26	8.97	4.05	10	2.48	1.88	1.45	2.11		

Table 4.11: O-PO_4 data for all sample sites

mg/ℓ as P	Rainfall	O-PO4: Dam LSD	O-PO4: Dam LHD	DWAF standards river & dams	O-PO4: BH L77AB	O-PO4: BH L24JB	O-PO4: River LR In	O-PO4: LR Out	DWAF standards for river and dams	O-PO4: River BeforePP	O-PO4: River AfterPP	DWAF standards for river and dams	O-PO4: PP In	O-PO4: PP Out	DWAF standards sewage effluent
02-08-2010	10	0	0	1	0	0	0	0	1	0	0.04	1	4.51	4.77	1
16-08-2010	10	0.31	0.32	1	0.24	0.25	0.35	0.31	1	0.35	0.31	1	4.8	7.18	1
13-09-2010	10	0.48	0.44	1	0.54	0.46	0.41	0.49	1	0.35	0.31	1	4.8	7.18	1
28-09-2010	10	0.39	0.56	1	0.39	0.3	0.44	0.35	1	0.26	0.52	1			1
11-10-2010	10	0.24	0.19	1	0.21		0.19	0.2	1	0.26	0.2	1	4.92	4.15	1
25-10-2010	25	0.32	0.26	1	0.4	0.27	0.27	0.29	1	0.24	0.32	1	2.19	2.08	1
09-11-2010	25	0.21	0.02	1	0.01		0.78	0.08	1	0.78	0.08	1	0.16	1.8	1
22-11-2010	25	0.07	0.07	1	0.04	0.08	0.02	0.01	1	0.05	0.22	1	3.96	0.03	1
06-12-2010	25	0.54	0.09	1	0.67	0.19	0.36	0.62	1	0.04	0.49	1	3.13	5.65	1
17-01-2011	50	0.05	0.17	1	0.11	0.03		0.14	1	0.08	0.14	1	1.58	2.04	1
31-01-2011	50	0	0.05	1	0	0			1	0.02	0	1	1.07	2.39	1
14-02-2011	25	0.25	0.52	1	0.12	0.34	0.09	0.24	1	0.21	0.14	1	3.24	3.15	1
28-02-2011	25	0.32	0.24	1	0.39	0.36	0.28	0.25	1	0.34	0.55	1		4.27	1
15-03-2011	**100**	**0.2**	**0.31**	1	**0.59**	**0.22**	**0.24**	**0.19**	1	**0.33**	**0.27**	1	**2.13**	**3.92**	1
29-03-2011	25		0.19	1		0.16	0.28	0.17	1	0.12	0.13	1	2.03	4.21	1
11-04-2011	25	0.17	0.22	1	0.13	0.62	0.28	0.23	1	0.37	0.58	1	2.77	4.97	1
09-05-2011	10	0.41	0.23	1	0.26	0.21	0.19	0.2	1	0.23	0.2	1	2.71	3.69	1
24-05-2011	25	0.37	0.3	1	0.59	0.2	0.28	0.29	1	0.22	0.24	1	2.3	4.35	1
06-06-2011	25	0.31	0.29	1	0.35	0.3	0.28	0.39	1	0.3	0.63	1	3.14	5.62	1
20-06-2011	10	0.26	0.2	1	0.21	0.24	0.27	0.24	1	0.24	0.24	1	3.03	4.71	1
04-07-2011	10	0.15	0.1	1	0.15	0.1	0.1	0.19	1	0.1	0.11	1	3.14	4.89	1
18-07-2011	10	0.27	0.26	1	0.52	0.45	0.3	0.3	1	0.25	0.43	1			1

Table 4.12: Faecal coliform data for all sample sites

cfu/100 mℓ	**Rainfall**	**F Coli: Dam LSD**	**F Coli: Dam LHD**	**DWAF standards for river and dams**	F Coli: BH L77AB	F Coli: BH L24JB	**DWAF standards for boreholes**	F Coli: River LR In	**F Coli: LR Out**	**DWAF standards for river and dams**	F Coli: River Before PP	F Coli: River AfterPP	**DWAF standards for river and dams**	F Coli: PP In	F Coli: PP Out	**DWAF standards sewage effluent**
02-08-2010	10	36	4	1000	0	6	0	36	72	1000	24	4	1000	840000	0	1000
16-08-2010	10	2136	20	1000	0	30	0	48	160	1000	20	20	1000	18600000	0	1000
13-09-2010	10	10	8	1000	0	0	0	336	568	1000	60	80	1000	5200000	0	1000
28-09-2010	10	116	80	1000	0	2	0	16	40	1000	216	92	1000			1000
11-10-2010	10	92	164	1000	0		0	140	276	1000	232	280	1000	7200000	2	1000
25-10-2010	25	16	476	1000	0	0	0	104	40	1000	120	20	1000	5600000	0	1000
09-11-2010	25	2136	368	1000	4		0	1624	4560	1000	196	272	1000	18600000	1648	1000
22-11-2010	25	49	28	1000	37	0	0	100	132	1000	100	132	1000	18600000	2472	1000
06-12-2010	25	16	328	1000	1	4	0	184	32	1000	48	92	1000	1800000	0	1000
17-01-2011	50	52	368	1000	81	0	0		172	1000	904	724	1000	6700000	0	1000
31-01-2011	50	44	84	1000	181	1	0			1000	104	52	1000	6200000	0	1000
14-02-2011	25	96	88	1000	474	0	0	88	288	1000	448	1360	1000	12400000	2472	1000
28-02-2011	25	540	184	1000	20	0	0	324	272	1000	864	1032	1000		0	1000
15-03-2011	**100**	**1424**	**840**	1000	**711**	**0**	0	**1360**	**904**	1000	**2136**	**1288**	1000	**4200000**	**2472**	1000
29-03-2011	25		1400	1000		0	0	108	268	1000	448	992	1000	3600000	0	1000
11-04-2011	25	60	88	1000	3	0	0	64	52	1000	84	20	1000	6100000	0	1000
09-05-2011	10	88	56	1000	0	0	0	24	64	1000	136	132	1000	7600000	0	1000
24-05-2011	25	64	16	1000	0	0	0	96	16	1000	16	16	1000	1210000	68	1000
06-06-2011	25	52	34	1000	0	0	0	4	560	1000	32	24	1000	4520000	0	1000
20-06-2011	10	16	60	1000	0	0	0	16	48	1000	16	68	1000	890000	12	1000
04-07-2011	10	2	44	1000	0	12	0	10	34	1000	12	80	1000	848000	2	1000
18-07-2011	10	40	24	1000	1	0	0	24	734	1000	53	38	1000			1000

Table 4.13: *E. coli* data for all sample sites

cfu/100 mℓ	**Rainfall**	**E Coli: Dam LSD**	**E Coli: Dam LHD**	E Coli: BH L77AB	E Coli: BH L24JB	**DWAF standards for borehole**	E Coli: River LR In	**E Coli: River LR Out**	E Coli: River BeforePP	E Coli: River AfterPP	E Coli: PP In	E Coli: PP Out
02-08-2010	10	32	20	0	16	0	24	88	24	8	890000	0
16-08-2010	10	108	28	0	23	0	84	160	12	12	20850000	0
13-09-2010	10	10	12	0	0	0	432	632	24	44	2300000	0
28-09-2010	10	152	144	0	27	0	44	88	308	120		
11-10-2010	10	116	204	0		0	288	224	272	384	8000000	4
25-10-2010	25	36	460	0	0	0	228	100	112	12	5800000	0
09-11-2010	25	4068	464	13		0	1808	5360	288	160	20850000	1764
22-11-2010	25	28	168	48	78	0	168	220	168	220	20850000	2646
06-12-2010	25	12	384	0	3	0	124	36	120	136	1000000	0
17-01-2011	50	92	432	88	1	0		232	1032	824	8800000	0
31-01-2011	50	96	140	224	0	0			188	156	9600000	0
14-02-2011	25	96	128	565	0	0	192	440	500	1544	13900000	2646
28-02-2011	25	596	288	13	0	0	416	348	904	1112		0
15-03-2011	**100**	**2712**	**2260**	**847.5**	**0**	**0**	**2784**	**2344**	**3616**	**3448**	**6700000**	**2646**
29-03-2011	25		1808		3	0	140	168	448	1116	7000000	0
11-04-2011	25	68	60	1	0	0	36	52	124	40	5200000	0
09-05-2011	10	88	28	0	0	0	52	52	160	232	7000000	0
24-05-2011	25	112	48	0	0	0	96	48	144	64	1370000	16
06-06-2011	25	84	20	0	13	0	24	640	84	30	5940000	0
20-06-2011	10	24	96	0	2	0	28	96	16	72	1120000	10
04-07-2011	10	2	52	0	24	0	16	54	4	84	989000	0
18-07-2011	10	28	14	1	0	0	6	1244	58	42		

Table 4.14: Faecal Streptococcus data for all sample sites

cfu/100 mℓ	**Rainfall**	**Faecal Strep: Dam LSD**	**Faecal Strep: Dam LHD**	**DWAF standards for river and dams**	Faecal Strep: BH L77AB	Faecal Strep: BH L24JB	**DWAF standards for boreholes**	Faecal Strep: River LR In	**Faecal Strep: River LR Out**	**DWAF standards for river and dams**	Faecal Strep: River BeforePP	Faecal Strep: River AfterPP	**DWAF standards for river and dams**
02-08-2010	10			230			230			230			230
16-08-2010	10			230			230			230			230
13-09-2010	10			230			230			230			230
28-09-2010	10			230			230			230			230
11-10-2010	10			230			230			230			230
25-10-2010	25			230			230			230			230
09-11-2010	25			230			230			230			230
22-11-2010	25			230			230			230			230
06-12-2010	25	4	384	230	42	0	230	240	24	230	0	0	230
17-01-2011	50	4	32	230	88	15	230		46	230	12	8	230
31-01-2011	50	46	30	230	340	2	230			230	12	31	230
14-02-2011	25	128	184	230	1582	0	230	544	224	230	4	648	230
28-02-2011	25	480	20	230	14	0	230	1072	904	230	1208	672	230
15-03-2011	**100**	**1564**	**984**	230	**2373**	**0**	230	**1472**	**1032**	230	**2260**	**1448**	230
29-03-2011	25		1400	230		30	230	208	280	230	384	648	230
11-04-2011	25	0	12	230	9	2	230	24	40	230	28	8	230
09-05-2011	10	88	72	230	10	0	230	24	48	230	132	28	230
24-05-2011	25	0	0	230	0	0	230	228	16	230	144	0	230
06-06-2011	25	36	36	230	0	0	230	44	1808	230	68	32	230
20-06-2011	10	4	48	230	0	0	230	100	20	230	24	24	230
04-07-2011	10	6	28	230	0	0	230	58	224	230	10	0	230
18-07-2011	10	46	10	230	0	0	230	38	1464	230	49	12	230

Table 4.15: COD data for all sample sites

mg/ℓ	**Rainfall**	**COD: Dam LSD**	**COD: Dam LHD**	**COD DWAF standards for river and dams**	COD: River LR In	**COD: River LR Out**	**DWAF standards for river and dams**	COD: River BeforePP	COD: River AfterPP	**DWAF standards for river and dams**	COD: PP In	COD: PP Out	**DWAF standards for sewage effluent**
02-08-2010	10	25	5	75	20	9	75	24	33	75	734	75	75
16-08-2010	10	180	5	75	27	5	75	38	32	75	738	134	75
13-09-2010	10	1	42	75	5	5	75	20	24	75	620	204	75
28-09-2010	10	58	58	75	73	10	75	79	73	75			75
11-10-2010	10	58	60	75	63	175	75	42	69	75	887	108	75
25-10-2010	25	35	30	75	39	5	75	34	44	75	713	76	75
09-11-2010	25	77	61	75	70	49	75	70	49	75	375	167	75
22-11-2010	25	5	46	75	32	24	75	54	30	75	1439	167	75
06-12-2010	25	5	33	75	46	45	75	53	15	75	2634	84	75
17-01-2011	50	60	27	75		67	75	24	18	75	8391	120	75
31-01-2011	50	28	97	75			75	57	54	75	739	257	75
14-02-2011	25	33	83	75	92	5	75	58	41	75	3042	50	75
28-02-2011	25	43	70	75	13	34	75	22	29	75		99	75
15-03-2011	**100**	**17**	**18**	75	**19**	**24**	75	**16**	**26**	75	**927**	**322**	75
29-03-2011	25		45	75	5	47	75	27	28	75	963	154	75
11-04-2011	25	27	28	75	4	21	75	12	23	75	492	218	75
09-05-2011	10	23	9	75	35	9	75	68	3	75	1327	135	75
24-05-2011	25	18	11	75	12	34	75	20	9	75	787	102	75
06-06-2011	25	32	4	75	30	13	75	6	5	75	710	190	75
20-06-2011	10	206	84	75	5	20	75	19	32	75	769	238	75
04-07-2011	10	71	74	75	59	69	75	71	69	75	429	132	75
18-07-2011	10	64	45	75	49	32	75	41	49	75			75

Table 4.16: Free Chlorine data for river and package plant

mg/ℓ	**Rainfall**	free Cl: River LR In	**free Cl: River LR Out**	**free Cl DWAF standards for river and dams**	free Cl: River BeforePP	free Cl: River AfterPP	**free Cl DWAF standards for river and dams**	free Cl: PP Out
02-08-2010	10		0.1	0.2	0.04	0.15	0.2	0.6
16-08-2010	10		0.04	0.2	0	0.02	0.2	0.4
13-09-2010	10		0.2	0.2	0.02	0.02	0.2	0.6
28-09-2010	10		0.1	0.2	0.06	0.02	0.2	
11-10-2010	10		0.15	0.2	0.04	0.1	0.2	0.8
25-10-2010	25		0.1	0.2	0.1	0.15	0.2	0.8
09-11-2010	25			0.2			0.2	
22-11-2010	25	0.1	0.2	0.2	0.1	0.04	0.2	0.02
06-12-2010	25		0.4	0.2	0.15	0.1	0.2	0.4
17-01-2011	50			0.2			0.2	
31-01-2011	50			0.2			0.2	0.3
14-02-2011	25	0.02	0.15	0.2	0.04	0.1	0.2	0
28-02-2011	25	0.02	0.15	0.2	0.1	0.1	0.2	0.2
15-03-2011	**100**		**0.2**	0.2	**0.04**	**0.1**	0.2	**0**
29-03-2011	25	0	0.2	0.2	0.04	0.15	0.2	0.15
11-04-2011	25	0.02	0.15	0.2	0.04	0.1	0.2	0.3
09-05-2011	10	0	0.02	0.2	0.02	0.04	0.2	0.3
24-05-2011	25	0	0.06	0.2	0.02	0.04	0.2	0.3
06-06-2011	25	0	0	0.2	0.02	0.04	0.2	0.15
20-06-2011	10	0	0.1	0.2	0.02	0.02	0.2	0.2
04-07-2011	10	0	0.04	0.2	0		0.2	0.2
18-07-2011	10	0	0.04	0.2		0.02	0.2	

Appendix J

Borehole Assessments

Sample site L24JB assessment

Table 4.17: Maximum values for borehole L24JB parameter asessment (Department of Water Affairs, Deaprtment of Health and the Water Research Commission, 1998).

Priority Class	Substance	Max.	Drinking Health	Drinking Aesthetic	Food preparation	Bathing	Laundry	Class
A	EC	66.2	Blue	Blue	Blue	Blue	Blue	Blue
A	pH	7.95	Blue	Blue	Blue	Blue	Blue	Blue
B	Nitrate	7.99	Green	Blue	Green	Blue	Blue	Green
B	Sulphate	24	Blue	Blue	Blue	Blue	Blue	Blue
A	Faecal Coliforms	30	Red	Blue	Red	Yellow	Yellow	Red
B	Chloride	40.44	Blue	Blue	Blue	Blue	Blue	Blue
D	Potassium	3.12	Blue	Blue	Blue	Blue	Blue	Blue
D	Sodium	7.48	Blue	Blue	Blue	Blue	Blue	Blue
D	Magnesium	59.82	Blue	Green	Blue	Green	Green	Green
D	Calcium	35.72	Blue	Blue	Blue	Green	Green	Green

Blue – ideal; Green – good; Yellow – marginal; Red – poor; Purple – completely unacceptable

Table 4.18: Average values for borehole L24JB parameter asessment (Department of Water Affairs, Deaprtment of Health and the Water Research Commission, 1998).

Priority Class	Substance	Average	Drinking Health	Drinking Aesthetic	Food preparation	Bathing	laundry	Class
A	EC	60.07	Blue	Blue	Blue	Blue	Blue	Blue
A	pH	7.207	Blue	Blue	Blue	Blue	Blue	Blue
B	Nitrate	4.8	Blue	Blue	Blue	Blue	Blue	Blue
B	Sulphate	13.45	Blue	Blue	Blue	Blue	Blue	Blue
A	Faecal Coliforms	2.75	Yellow	Blue	Yellow	Green	Green	Yellow
B	Chloride	33.4	Blue	Blue	Blue	Blue	Blue	Blue
D	Potassium	0.733	Blue	Blue	Blue	Blue	Blue	Blue
D	Sodium	5.34	Blue	Blue	Blue	Blue	Blue	Blue
D	Magnesium	40.94	Blue	Green	Blue	Green	Green	Green
D	Calcium	20.2	Blue	Blue	Blue	Green	Blue	Green

Blue – ideal; Green – good; Yellow – marginal; Red – poor; Purple – completely unacceptable

Table 4.19: Classification of borehole L24JB (Department of Water Affairs, Deaprtment of Health and the Water Research Commission, 1998).

	Worst substance class		
Substance	**Max.**	**Average**	**Substance class**
EC	Blue	Blue	Blue
pH	Blue	Blue	Blue
Nitrate	Green	Blue	Green
Sulphate	Blue	Blue	Blue
Faecal Coliforms	Red	Yellow	Red
Chloride	Blue	Blue	Blue
Potassium	Blue	Blue	Blue
Sodium	Blue	Blue	Blue
Magnesium	Green	Green	Green
Calcium	Green	Green	Green
Overall water class			Red

Blue – ideal; Green – good; Yellow – marginal; Red – poor; Purple – completely unacceptable

Table 4.20: Borehole L24JB sample data (Maximum and Averages)

Date	BH L24JB: EC	BH L24JB: pH	BH L24JB: Ca	BH L24JB: Cl	BH L24JB: Mg	BH L24JB: NO_3N	BH L24JB: K	BH L24JB: Na	BH L24JB: SO_4^{2-}	BH L24JB: F coli
02-08-2010	63	7.08	30	36.49	42.64	4.22	0.52	5.72	8	6
16-08-2010	49.8	7.08		36.94		4.71			13	30
13-09-2010	37.9	7.95	22.63	38.98	4.74	3.51	0.63	5.48	21	0
28-09-2010	61.9	7.37	10.54	35.24	24.16	6.48	0.26	5.82	15	2
11-10-2010										
25-10-2010	62.1	7.17	19.47	40.44	51.01	4.86	0.71	6.08	10	0
09-11-2010										
22-11-2010	63.8	7.12	15.93	35.71	42.07	5.64	0.52	5.32	12	0
06-12-2010	63.8	7.29	21.97	38.6	52.31	5.06	0.38	5.71	12	4
17-01-2011	61.2	7.53	19.61	27.73	51.1	6.23	0.52	5.86	14	0
31-01-2011	64.5	7.19	16.69	31.7	43.2	4.69	0.46	1.61	13	1
14-02-2011	60.8	7.03	19.04	33.36	40.62	0.63	0.46	4.65	20	0
28-02-2011	64.2	6.9	10.89	33.36	42.84	4.5	0.95	7.48	24	0
15-03-2011	**66.2**	**7.38**	**17.85**	**35.44**	**42**	**4.27**	**0.46**	**5.34**	**12**	**0**
29-03-2011	23.8	7.2	23.71	14.54	4.25	1.08	3.12	4.76	9	0
11-04-2011	66.2	7.1	21.32	33.9	46.95	4.89	0.81	5.86	15	0
09-05-2011	65.3	6.98	18.8	31.66	57.8	4.53	0.7	5.22	7	0
24-05-2011	65.4	7.01	35.72	31.73	59.82	7.93	0.55	5.8	11	0
06-06-2011	65.1	7.33	25.71	32.31	46.37	7.99	0.63	5.42	9	0
20-06-2011	65.4	7.18	23.12	32.31	48.97	6.69	0.91	4.84	11	0
04-07-2011	65.8	7.09	9.29	33.66	20.99	4.15	0.7	4.47	16	12
18-07-2011	65.2	7.16	21.65	33.94	56.2	4.05	0.65	6.12	17	0
Arithmetic mean	60.07	7.207	20.2074	33.402	40.9495	4.8055	0.7337	5.345263	13.45	2.75
Max	66.2	7.95	35.72	40.44	59.82	7.99	3.12	7.48	24	30

Sample site L77AB assessment

Table 4.21: Maximum values for borehole L77AB parameter asessment (Department of Water Affairs, Deaprtment of Health and the Water Research Commission, 1998).

Priority Class	Substance	Max.	Drinking Health	Drinking Aesthetic	Food preparation	Bathing	laundry	Class
A	EC	79.3	Green	Green	Green	Blue	Blue	Green
A	pH	7.98	Blue	Blue	Blue	Blue	Blue	Blue
B	Nitrate	19.71	Yellow	Blue	Yellow	Green	Blue	Yellow
B	Sulphate	63	Blue	Blue	Blue	Blue	Blue	Blue
A	Faecal Coliforms	711	Purple	Blue	Purple	Red	Red	Purple
B	Chloride	49.78	Blue	Blue	Blue	Blue	Blue	Blue
D	Potassium	0.89	Blue	Blue	Blue	Blue	Blue	Blue
D	Sodium	11.16	Blue	Blue	Blue	Blue	Blue	Blue
D	Magnesium	72.53	Green	Yellow	Green	Yellow	Yellow	Yellow
D	Calcium	21.72	Blue	Blue	Blue	Green	Blue	Green

Blue – ideal; Green – good; Yellow – marginal; Red – poor; Purple – completely unacceptable

Table 4.22: Average values for borehole L77AB parameter asessment (Department of Water Affairs, Deaprtment of Health and the Water Research Commission, 1998).

Priority Class	Substance	Average	Drinking Health	Drinking Aesthetic	Food preparation	Bathing	laundry	Class
A	EC	62.87	Blue	Blue	Blue	Blue	Blue	Blue
A	pH	7.13	Blue	Blue	Blue	Blue	Blue	Blue
B	Nitrate	8.93	Green	Blue	Green	Blue	Blue	Green
B	Sulphate	32.52	Blue	Blue	Blue	Blue	Blue	Blue
A	Faecal Coliforms	72.04	Red	Blue	Red	Yellow	Yellow	Red
B	Chloride	34.03	Blue	Blue	Blue	Blue	Blue	Blue
D	Potassium	0.53	Blue	Blue	Blue	Blue	Blue	Blue
D	Sodium	6.28	Blue	Blue	Blue	Blue	Blue	Blue
D	Magnesium	52.07	Blue	Green	Blue	Green	Green	Green
D	Calcium	7.83	Blue	Blue	Blue	Blue	Yellow	Yellow

Blue – ideal; Green – good; Yellow – marginal; Red – poor; Purple – completely unacceptable

Table 4.23: Classification of borehole L77AB (Department of Water Affairs, Deaprtment of Health and the Water Research Commission, 1998).

	Worst substance class		
Substance	**Max.**	**Average**	**Substance class**
EC	Green	Blue	Green
pH	Blue	Blue	Blue
Nitrate	Yellow	Green	Yellow
Sulphate	Blue	Blue	Blue
Faecal Coliforms	Purple	Red	Purple
Chloride	Blue	Blue	Blue
Potassium	Blue	Blue	Blue
Sodium	Blue	Blue	Blue
Magnesium	Yellow	Green	Yellow
Calcium	Green	Yellow	Yellow
Overall water class			Purple

Blue – ideal; Green – good; Yellow – marginal; Red – poor; Purple – completely unacceptable

Table 4.24: Borehole L77AB sample data (Maximum and Averages)

Date	BH L77AB: EC	BH L77AB: pH	BH L77AB: Ca	BH L77AB: Cl	BH L77AB: Mg	BH L77AB: NO_3N	BH L77AB: K	BH L77AB: Na	BH L77AB: SO_4^{2-}	BH L77AB: F coli
02-08-2010	54.4	6.75	21.72	25.01	56.75	3.8	0.4	4.31	20	0
16-08-2010	42.6	7.01		25.26		4.06			22	0
13-09-2010	52.9	7.98	4.28	26.22	4.85	4.49	0.58	4.49	24	0
28-09-2010	54.6	7.61	4.84	24.76	47.42	6.02	0.51	4.48	18	0
11-10-2010	54.8	7.64	10.71	24.5	41.32	5.82	0.39	5.77	19	0
25-10-2010	53.1	7.04	14.16	26.88	56.9	4.66	0.57	9.03	22	0
09-11-2010	52.9	7.09	5.94	25.01	43.35	4.56	0.59	7.45	21	4
22-11-2010	54.3	6.97	6.97	23.89	39.94	2.82	0.42	11.16	16	37
06-12-2010	54.4	7.29	6.54	24.96	40.18	5.14	0.33	4.85	18	1
17-01-2011	53.4	7.4	9.71	40.3	54.8	6.94	0.39	5.49	18	81
31-01-2011	61.6	6.99	6.26	26.17	60.97	7.06	0.59	4.52	22	181
14-02-2011	71.4	6.94	5.49	44.27	50.39	10.77	0.48	4.43	36	474
28-02-2011	78	7.42	5.65	49.56	55.99	10.32	0.84	7.22	40	20
15-03-2011	**79.1**	**7.09**	**7.3**	**49.78**	**60.45**	**13.69**	**0.48**	**5.83**	**63**	**711**
11-04-2011	79.3	6.83	7.9	47.44	72.53	15.17	0.54	10.29	58	3
09-05-2011	73.9	6.83	7.21	41.24	66.66	12.57	0.62	8.54	52	0
24-05-2011	72.1	7.02	7.74	39.96	60.55	19.71	0.52	7.55	50	0
06-06-2011	71.8	7.02	5.14	38.46	65.43	17.39	0.56	6.38	49	0
20-06-2011	70.1	7	6.53	38.06	60.11	14.47	0.89	5.05	48	0
04-07-2011	68.8	6.83	5	36.84	49.1	9.27	0.49	0.82	15	0
18-07-2011	66.8	7.06	7.58	36.23	53.87	8.97	0.59	8	52	1
Arithmetic mean	62.871	7.1338	7.8335	34.038	52.078	8.9381	0.539	6.283	32.524	72.048
Max	79.3	7.98	21.72	49.78	72.53	19.71	0.89	11.16	63	711

Appendix K

Habitat Assessment

Table 4.28 (a): IHI evaluation for instream habitiat integrity (Kleynhans, 1996)

EVALUATION	NONE (0)	SMALL (1-5)	MODER (6-10)	LARGE (11-15)	SERIOUS (16-20)	CRITICAL (21-25)						
SITE NAME	**U/S1**	**D/S1**	**U/S2**	**D/S2**	**U/S3**	**D/S3**	**U/S4**	**D/S4**	**U/S5**	**D/S5**	**U/S6**	**D/S6**
INSTREAM HABITAT INTEGRITY												
WATER ABSTRACTION (IMPACT 1 - 25)	0	0	5	6	5	6	5	5	5	15	5	5
FLOW MODIFICATION ((IMPACT 1 - 25)	21	21	21	25	21	25	21	21	21	21	21	21
CHANNEL MODIFICATION (IMPACT 1 - 25)	10	12	25	20	25	20	25	25	25	25	25	25
WATER QUALITY (IMPACT 1 - 25)	11	11	11	11	5	11	5	5	11	11	11	11
INUNDATION (IMPACT 1 - 25)	21	21	15	15	12	15	12	12	12	12	12	12
BED MODIFICATION (IMPACT 1 - 25)	12	12	10	16	10	16	10	10	10	10	10	10
TOTAL (OUT OF 150)	75	77	87	93	78	93	78	78	84	94	84	84
SECONDARY												
EXOTIC MACROPHYTES (IMPACT 1 - 25)	5	6	0	5	0	5	0	0	0	0	0	0
EXOTIC FAUNA (IMPACT 1 - 25)	0	20	15	25	15	25	15	15	15	15	15	15
RUBBISH DUMPING (IMPACT 1 - 25)	0	0	6	5	3	7	3	3	3	3	3	3
TOTAL (OUT OF 75)	**5**	**26**	**21**	**35**	**18**	**37**	**18**	**18**	**18**	**18**	**18**	**18**
INSTREAM HAB INTEG SCORE	**42**	**34**	**33**	**25**	**39**	**25**	**39**	**39**	**34**	**28**	**34**	**34**
INTEGRITY CLASS	**D**	**E**	**E**	**E**	**E**	**E**	**E**	**E**	**E**	**E**	**E**	**E**
	U/S1	**D/S1**	**U/S2**	**D/S2**	**U/S3**	**D/S3**	**U/S4**	**D/S4**	**U/S5**	**D/S5**	**U/S6**	**D/S6**
Instream habitat integrity %	42	34	33	25	39	25	39	39	34	28	34	34
Instream habitat integrity Class	**D**	**E**	**E**	**E**	**E**	**E**	**E**	**E**	**E**	**E**	**E**	**E**
Riparian habitat integrity %	**51**	**49**	**32**	**39**	**37**	**39**	**37**	**37**	**34**	**34**	**34**	**37**
Riparian habitat integrity Class	**D**	**D**	**E**	**E**	**E**	**E**	**E**	**E**	**E**	**E**	**E**	**E**
Over all IHI %	**46.10**	**41.57**	**32.33**	**32.12**	**37.91**	**32.01**	**37.91**	**37.91**	**33.87**	**31.03**	**33.87**	**35.50**
Over all IHI catergory	**D**	**D**	**E**	**E**	**E**	**E**	**E**	**E**	**E**	**E**	**E**	**E**

Table 4.28 (b): IHI evaluation for riperian zone habitat integiry (Kleynhans, 1996)

EVALUATION	NONE (0)	SMALL (1-5)	MODER (6-10)	LARGE (11-15)	SERIOUS (16-20)	CRITICAL (21-25)						
RIPARIAN ZONE HABITAT INTEGRITY												
SITE NAME	**U/S1**	**D/S1**	**U/S2**	**D/S2**	**U/S3**	**D/S3**	**U/S4**	**D/S4**	**U/S5**	**D/S5**	**U/S6**	**D/S6**
WATER ABSTRACTION (IMPACT 1 - 25)	0	0	15	6	5	6	5	5	5	5	5	5
FLOW MODIFICATION (IMPACT 1 - 25)	21	22	20	25	20	21	20	20	20	20	20	20
CHANNEL MODIFICATION (IMPACT 1 - 25)	10	15	25	20	25	21	25	25	25	25	25	25
WATER QUALITY (IMPACT 1 - 25)	11	11	11	6	5	5	5	5	11	11	11	5
INUNDATION (IMPACT 1 - 25)	23	21	5	5	15	5	15	15	15	15	15	15
VEGETATION REMOVAL (IMPACT 1 - 25)	5	7	16	20	15	21	15	15	15	15	15	15
EXOTIC VEGETATION (IMPACT 1 - 25)	8	5	20	20	19	17	19	19	19	19	19	19
BANK EROSION (IMPACT 1 - 25)	22	22	23	20	23	25	23	23	23	23	23	23
TOTAL (OUT OF 200)	**100**	**103**	**135**	**122**	**127**	**121**	**127**	**127**	**133**	**133**	**133**	**127**
RIPARIAN ZONE HABITAT INTEGRITY SCORE	**51**	**49**	**32**	**39**	**37**	**39**	**37**	**37**	**34**	**34**	**34**	**37**
INTEGRITY CLASS	**D**	**D**	**E**	**E**	**E**	**E**	**E**	**E**	**E**	**E**	**E**	**E**

Table 4.29: IHAS evalaution for sample sites (Dallas, 2005)

		U/S 1	D/S 1	U/S 2	D/S 2	U/S 3	D/S 3	U/S 4	D/S 4	U/S 5	D/S 5	U/S 6	D/S 6
SAMPLING HABITAT	**MAX Score**	**Score**	**Score**	**Score**	**Score**	**Score**	**Score**	**Score**	**Score**	**Score**	**Score**	**Score**	**Score**
Total length of riffle/rapid	5	4	4	5	5	5	5	5	5	4	4	2	2
Total length of submerged stones in current	4	4	4	4	4	4	4	4	4	3	3	3	3
Number of separate SIC area's kicked	4	4	4	4	4	4	4	4	4	4	4	4	3
Average stone size's kicked	4	3	3	3	3	4	4	4	3	4	3	4	3
Amount of stone surface clear of algae/sediment etc.	4	3	1	4	4	4	4	4	4	4	4	4	4
Time spent actually kicking SIC's	5	4	4	3	4	4	4	4	4	4	4	4	4
Length of marginal vegetation sampled (river banks)	5	4	2	3	4	4	2	4	1	4	3	4	3
Amount of aquatic vegetation/algae sampled (underwater)	3	1	0	0	0	0	0	0	0	2	1	1	1
Marginal vegetation sampled in or out of current	5	5	2	2	5	5	3	5	3	5	5	5	5
Type of veg	5	3	2	3	4	2	2	2	2	5	3	5	3
OTHER HABITAT/GENERAL													
Stones out of current (SOOC) sampled	4	4	3	2	2	1	2	1	2	2	3	1	3
Sand sampled	5	3	3	3	3	3	3	3	3	5	2	2	3
Mud sampled	4	3	4	2	2	2	3	2	2	4	4	4	4
Gravel sampled	3	2	1	2	3	1	2	1	3	3	2	1	3
Bedrock sampled	4	0	1	0	0	0	0	0	0	0	0	0	0
Algal presence	5	5	5	5	5	5	5	5	5	5	5	4	4
Tray identification	5	3	3	3	3	4	3	3	3	3	3	3	3
Total	**74**	55	46	48	55	52	50	51	48	61	53	51	51
	IHAS %	**74.3**	**62.2**	**65**	**74.3**	**70.3**	**68**	**69**	**65**	**82.4**	**72**	**69**	**69**
	Descript	**Good**	**Fair**	**Good**	**Good**	**Good**	**Good**	**Good**	**Good**	**V/good**	**Good**	**Good**	**Good**

Table 4.31: SASS evaluation for sample sites (Dickens and Graham, 2002)

	U/S1	D/S1	U/S2	D/S2	U/S3	D/S3	U/S4	D/S4	U/S5	D/S5	U/S6	D/S6
SASS Score	125	111	74	72	90	68	103	94	98	92	121	101
No of Taxa	22	22	17	18	17	16	22	22	16	18	20	20
ASPT	5.68	5.04	4.35	4	5.29	4.25	4.68	4.27	6.13	5.11	6.05	5.05
Category	C	D	E/F	E/F	D	E/F	D	D	B	D	B	D

Table 4.33 (a): List of species expected to find in this catchment area (Kleynhans, 2007).

		VELOCITY-DEPTH PREFERENCE				FLOW INTOLERANCE				COVER PREFERENCE				
SPECIES EXPECTED: REFERENCE (NOT INTRODUCED SPP)	**SCIENTIFIC NAMES**	**PREFERENCE: FD**	**PREFERENCE:FS**	**PREFERENCE:SD**	**PREFERENCE:SS**	**INTOLERANT: NO-FLOW (>4)**	**MODERATELY INTOLERANT: NO FLOW(>3-4)**	**MODERATELY TOLERANT: NO FLOW (>2-3)**	**TOLERANT: NO FLOW (1-2)**	**OVERHANGING VEGETATION: HIGH->VERY HIGH (>3)**	**BANK UNDERCUT: HIGH->VERY HIGH (>3)**	**SUBSTRATE: HIGH->VERY HIGH (>3)**	**AQUATIC MACROPHYTES: HIGH->VERY HIGH (>3)**	**WATER COLUMN: HIGH->VERY HIGH (>3)**
aura	**AMPHILIUS URANOSCOPUS (PFEFFER, 1889)**	4.60	4.60	FALSE	FALSE	4.80	FALSE	FALSE	FALSE	FALSE	FALSE	5.00	FALSE	FALSE
bano	**BARBUS ANOPLUS WEBER, 1897**	FALSE	FALSE	4.10	4.30	FALSE	FALSE	2.30	FALSE	4.00	FALSE	FALSE	3.20	FALSE
bmar	**LABEOBARBUS MAREQUENSIS SMITH, 1841**	4.10	4.40	4.40	3.40	FALSE	3.20	FALSE	FALSE	FALSE	FALSE	4.50	FALSE	4.10
bpau	**BARBUS PALUDINOSUS PETERS, 1852**	FALSE	FALSE	3.90	3.90	FALSE	FALSE	2.30	FALSE	4.20	FALSE	FALSE	3.60	3.50
bpol	**LABEOBARBUS POLYLEPIS BOULENGER, 1907**	3.70	4.30	4.20	FALSE	FALSE	3.30	FALSE	FALSE	FALSE	FALSE	5.00	FALSE	3.60
cpre	**CHILOGLANIS PRETORIAE VAN DER HORST, 1931**	4.30	4.90	FALSE	FALSE	4.80	FALSE	FALSE	FALSE	FALSE	FALSE	4.90	FALSE	FALSE
omos	**OREOCHROMIS MOSSAMBICUS (PETERS, 1852)**	FALSE	FALSE	4.60	3.80	FALSE	FALSE	FALSE	0.90	FALSE	FALSE	FALSE	FALSE	3.90
pphi	**PSEUDOCRENILABRUS PHILANDER (WEBER, 1897)**	FALSE	FALSE	FALSE	4.30	FALSE	FALSE	FALSE	1.00	4.50	3.20	FALSE	FALSE	FALSE
tspa	**TILAPIA SPARRMANII SMITH, 1840**	FALSE	FALSE	FALSE	4.30	FALSE	FALSE	FALSE	0.90	4.50	FALSE	FALSE	3.60	FALSE
cgar	**CLARIAS GARIEPINUS (BURCHELL, 1822)**	FALSE	FALSE	4.30	3.40	FALSE	FALSE	FALSE	1.70	FALSE	FALSE	FALSE	FALSE	FALSE

Table 4.33 (b): List of species expected to find in this catchment area continued (Kleynhans, 2007).

SPECIES EXPECTED:	SCIENTIFIC NAMES	TOLERANCE: MODIFIED PHYSICO-CHEM				MIGRATION
		INTOLERANT: MODIFIED WQ (>4)	MODERATELY INTOLERANT: MODIFIED WQ (>3-4)	MODERATELY TOLERANT (>2-3): MODIFIED WQ	TOLERANT: MODIFIED WQ (1-2)	5 -Species with requirement for catchment scale migrations 3 - Species with requirement for movement between reaches / fish habitat segments 1 - Species with requirement for movement within reaches / fish habitat segments
aura	AMPHILIUS URANOSCOPUS (PFEFFER, 1889)	4.80	FALSE	FALSE	FALSE	1.00
bano	BARBUS ANOPLUS WEBER, 1897	FALSE	FALSE	2.60	FALSE	3.00
bmar	LABEOBARBUS MAREQUENSIS SMITH, 1841	FALSE	FALSE	2.10	FALSE	3.00
bpau	BARBUS PALUDINOSUS PETERS, 1852	FALSE	FALSE	FALSE	1.80	3.00
bpol	LABEOBARBUS POLYLEPIS BOULENGER, 1907	FALSE	FALSE	2.90	FALSE	3.00
cpre	CHILOGLANIS PRETORIAE VAN DER HORST, 1931	4.50	FALSE	FALSE	FALSE	3.00
omos	OREOCHROMIS MOSSAMBICUS (PETERS, 1852)	FALSE	FALSE	FALSE	1.30	3.00
pphi	PSEUDOCRENILABRUS PHILANDER (WEBER, 1897)	FALSE	FALSE	FALSE	1.40	1.00
tspa	TILAPIA SPARRMANII SMITH, 1840	FALSE	FALSE	FALSE	1.40	3.00
cgar	CLARIAS GARIEPINUS (BURCHELL, 1822)	FALSE	FALSE	FALSE	1.00	3.00

Appendix L

Articles

A meta-analysis of South African Package Plants

De Bruyn K, Brand ME; Dewar JB and Hendrick RM

Abstract

Water has become a limiting resource as to its availability and quality. To improve water quality, and against a background of urbanisation, rapid population growth and industrial expansion, there has been a need to develop small effluent treatment plants such as package plants. A meta-analysis was conducted to compare technology, efficiency with regards to effluent quality, legislation standards and associated problems involving package plants in South Africa. Package plants have been developed to treat relatively small-scale effluent (less than 2 million litres per day). Their design is based on an activated sludge system and consists of a septic tank, an aeration tank, a clarifier tank and finally a disinfection tank. More recent developments have focused on increasing the surface area for bacterial growth within the aeration tank - by the introduction of plastic media, contactor surfaces or rotating bio discs. Package plants require skilled construction and operation, regular, effective monitoring and maintenance to contribute to good effluent quality with low toxicity. This paper also highlights the problems associated with legislative and monitoring requirements when installing a package plant. The amount of information available on package plants in South Africa is limited and therefore there is a need for research on this particular topic.

Key words: associated problems, effluent quality, legislation, monitoring requirements, package plant, technology/types of package plants.

Introduction

Freshwater resources worldwide are under severe pressure. The demand for water has increased dramatically over the years as a result of an increasing population and urbanisation. Thus, water has become a limiting resource with regards to its availability and quality (Walmsley *et al.*, 1999). Waste water is considered to be one of the major sources of water pollution in many countries (Rudel *et al.*, 1998). Treatment of waste water is a very important process in the overall management of the country's water resources, as is the measuring of the amount of pollutants that will be present in the discharged effluent that will eventually end up in rivers and streams. Thus, the influence of the treatment process will determine the potential hazard associated with the effluent to the water resources, environment and human health (Lester, 1983).

In South Africa, domestic waste water is defined by the Department of Water Affairs and Forestry as consisting of 90% of waste water by volume that arises from domestic and commercial activities and premises and may include sewage, household waste from bathing, washing and toilets (www.dwa.gov.za/Projects/WARMS/Registration/R000218/updatedwasterelatedwateruseregistration).

Untreated or inadequately treated sewage effluent often finds its way into rivers and this poses a threat to public and environmental health (Freese and Nozaic, 2004; Damafakir *et al.*, 2009). These effluent discharges contribute to oxygen demand, nutrient loading and algal blooms (eutrophication) as well as water-borne diseases (Morrison *et al.*, 2001). The term effluent is described by the Water Services Act of 1997 as human excreta, domestic sludge, domestic waste water, grey water or waste water resulting from commercial or industrial use (www.dwaf.gov.za/Documents/Notices/Water%20Services%20Act/SEC9DREG_20_April_2001.pdf).Various developing countries have inadequate waste water disposal systems, lack of infrastructure and capacity, and, together with a rapid increase in population, there is an increased demand for not only water resources but also proper disposal of domestic waste (Mahomed *et al.*, 2008; Damafakir *et al.*, 2009). A solution to this demand has been the development of package plants.

Methods

A literature study was done on all the factors and aspects of the variables and phenomena with regards to package plants (globally, in parts of Africa and South Africa) and information was gained through a secondary analysis consisting of previous and existing literature. Documentation used included journals, literature texts, reports and articles, as well as information on the internet was collected and from the catalogues of the UNISA libraries.

Search engines

The search engines used to gather the above information on the internet included: Google Scholar, Science direct and Scopus.

Key words

The key words used to conduct the information and literature search were as follows:

Package plant, package plant pollutants, package plant pollutants and environmental health, package plant pollutants and human health, package plant effluent quality, package plant effluent quality and environmental health package, plant effluent quality and human health, sewage effluent, sewage effluent pollutants, sewage effluent pollutants and environmental health, sewage effluent pollutants and human health, sewage effluent quality, sewage effluent quality and environmental health, sewage effluent quality and human health, waste water treatment plant (WWTP), waste water treatment plant pollutants, waste water treatment plant pollutants and environmental health, waste water treatment plant pollutants and human health, waste water treatment plant effluent quality, waste water treatment plant effluent quality and environmental health, waste water treatment plant effluent quality and human health.

Results and Discussion

Package plants as defined by the literature

Package plants are usually small, complete, pre-assembled or pre-fabricated structures that can be installed on-site, in or above the ground and these domestic waste water treatment systems may be privately owned, movable units (Voortman and Reddy, 1997; Department of Water Affairs, Department of Health, Water Research Commission, 2002; Laas and Botha, 2004; Gaydon *et al.*, 2007; Damafakir *et al.*, 2009). They are also known as alternative on-site treatment facilities or pre-engineered sewage treatment plants. The literature does, however, vary when it comes to size or capacity of package plants. Most recent references agree that these systems discharge less than 2000 cubic meters (equivalent to 2 million litres) per day (Laas and Botha, 2004; Gaydon *et al.*, 2007; Damafakir *et al.*, 2009) but earlier references state that package plants should discharge less than one million litres per day or even less than 500 kilo litre per day (Voortman and Reddy, 1997; Department of Water Affairs, Department of Health, Water Research Commission, 2002).

Reasons for installation of Package plants

It is clear that urbanisation, rapid population growth and expansion have impacted on the number of installed package plants (www.dwaf.gov.za). Package plants were introduced to meet the ever increasing demands and needs of rural or small, isolated communities, residential areas and holiday and recreational sites. The main reason for installation is the fact that many people are not able to connect to large conventional municipal sewage systems due to lack of infrastructure and development, poor soil structure, topography, geology or high water tables (Voortman and Reddy, 1997; Department of Water Affairs, Department of Health, Water Research Commission, 2002; Buchanan, 2004; Laas and Botha, 2004; Gaydon *et al.*, 2007; Damafakir *et al.*, 2009). Thus, with increasing rural and suburban development, there has been more interest in the installation of small, privately owned waste water treatment works.

Advantages of Package plants in comparisons with large conventional systems

There are various differences in the quality and throughput of small compared with large scale treatment systems with small systems having various advantages. Package plants are prefabricated and assembled on-site making them easier to transport, erect and install. Due to their compactness, they have a small installation footprint (Department of Water Affairs, Department of Health, Water Research Commission, 2002; Gaydon *et al.*, 2007). These systems are self contained units and are, thus, easy to maintain and operate and have reduced noise and odour when compared to larger conventional systems (Hulsman and Swartz, 1993). Package plants are a suitable alternative for small communities and are very cost effective with regards to investment and maintenance (Voortman and Reddy, 1997; www.dwaf.gov.za). These systems are highly durable and are efficient in treating effluent to high quality that can be safely discharged into streams (Hanna *et al.*, 1995; Gasparikova *et al.*, 2005).

Types of Package plant technology available

Globally, the three main technologies used in package plants are very similar to those used in conventional large scale sewage treatment plants. These involve anaerobic processes, aerobic processes or a combination of the two processes. More recently, package plants have shown improvements following the incorporation of new technologies, including: activated sludge, submerged bio-contactors, rotating bio-contactors, trickling filter plants, anaerobic systems, pond systems and constructed wetlands. (Department of Water Affairs, Department of Health, Water Research Commission, 2002; Damafakir *et al.*, 2009). A comparison between these three technologies is shown in Table 1.1 below.

In practice, these package plants consists of septic tanks, stabilization ponds, biological filtration, emergent hydrophyte systems, artificially aerated ponds, trickling filters, rotating biological contactors and activated sludge systems (Hanna *et al.*, 1995; Gasparikova *et al.*, 2005; Ra *et al.*, 2007; Odjadjare *et al.*, 2010).

Table 1.1: A comparison between different types of package plant systems.

Anaerobic systems	**Aerobic systems**	**Combined anaerobic and aerobic systems**	**Activated sludge**
Low energy consumption, simple construction, low sludge production, minimal nutrient removal.	High energy consumption, complex construction, high sludge production, very good nutrient removal, poor operational characteristics and associated maintenance failures, inconsistent and overall poor effluent quality.	High removal efficiency, low energy requirements, short detention time, biogas production, low sludge production.	Low aquatic toxicity but ineffective in removal of *Listeria*. 95% BOD removal, 90% SS removal, low land space required, good effluent quality, needs skilled construction and operation, high cost, requires monitoring and maintenance.

An analysis of currently available package plant systems indicates that the **activated sludge system is** favored in South Africa (Damafakir *et al.*, 2009). This system basically consists of a septic tank followed by an aeration tank, a clarifier tank and finally a disinfection tank. Anaerobic digestion takes place in the septic tank and from there the waste goes to an aeration tank for aerobic treatment before moving on to the clarifier tank where the sludge settles out. Finally, the effluent is treated with a disinfectant such as chlorine in a disinfection tank before being finally discharged (Hulsman and Swartz, 1993; Laas and Botha, 2004; Damafakir *et al.*, 2009). This system is indicated figure 1 below:

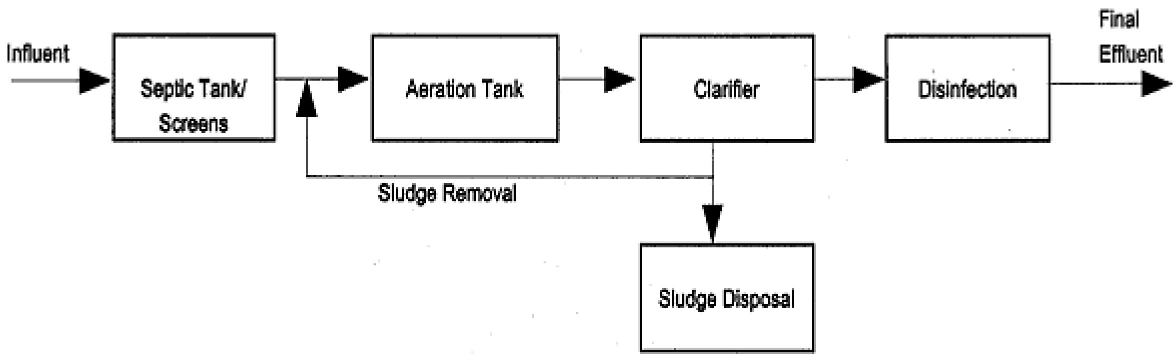

Figure 1: Activated sludge system (Laas and Botha, 2004).

A variation on this activated sludge system is called the Sequencing Batch Reactor which does not make use of a clarifier tank, per se, but instead both the biological and the clarification process occurs in the same tank or unit (Buchanan, 2004; Damafakir *et al.*, 2009). In a study done by Gaydon *et al.* (2007) these types of activated sludge systems showed 80% compliance with regards to effluent quality standards.

The **submerged biological contactor system,** shown in Figure 2, is used mostly in Cape Town and makes use of plastic media that acts as a substrate surface for microbial growth (Laas and Botha 2004). As indicated in the figure, this system consists of a septic tank with anaerobic treatment, from there the waste enters the biological contactor tank which is filled or randomly packed with plastic media and air blowers for aerobic treatment. The waste water then flows to a cone shaped clarifier tank where the solids settle out before moving on to a disinfection tank (Laas and Botha, 2004; Damafakir *et al.*, 2009). These systems have also shown 80% compliance to quality standards (Gaydon *et al.*, 2007).

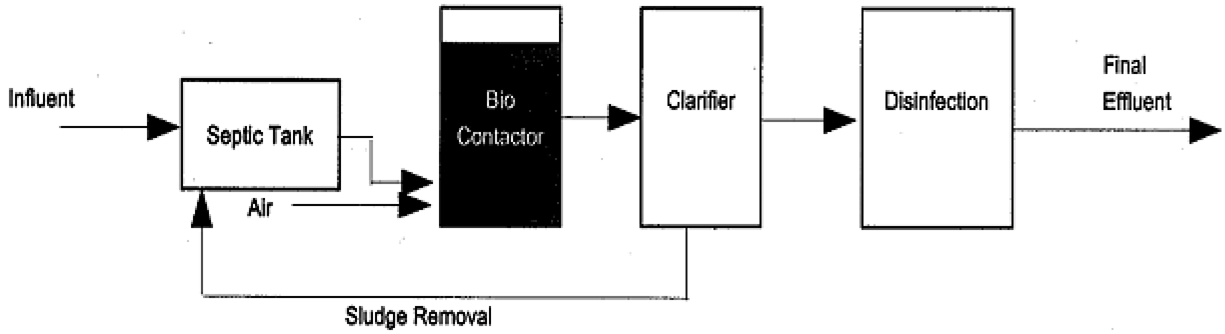

Figure 2: Submerged biological contactor system (Laas and Botha, 2004).

Another system that is favoured in South Africa and shows a standard compliance of 74% when compare with quality standards, is the **rotating biological contactor system** (Gaydon *et al.* 2007). This consists of a septic tank for anaerobic digestion from where the waste flows over a series of rotating discs placed on a horizontal shaft, as shown in Figure 3 below, that provides the aeration for aerobic treatment. Approximately 40% of the disc area must be submerged in the waste water. The system also contains a humus tank where the solids and liquids are separated by sedimentation. The liquid is then passed to the disinfection tank and discharged (Hulsman and Swartz, 1993; Laas and Botha, 2004; Damafakir *et al.*, 2009).

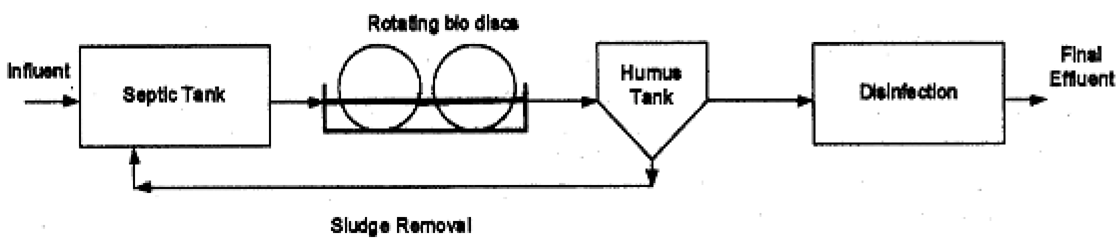

Figure 3: Rotating biological contactor system (Laas and Botha, 2004).

The **Trickling filter** package plant is also available in South Africa. These treatment plants are very similar to the submerged biological contactor systems, also consisting of a septic tank where anaerobic digestion takes place, before the waste water is sprayed over a bed of rock or synthetic media. This portion of the system is left open for ventilation and aeration. From there the waste enters the humus tank for sedimentation and then to the disinfection tank after which the final effluent is discharged (Laas and Botha, 2004; Damafakir *et al.*, 2009). A diagram of the system is shown below in figure 4.

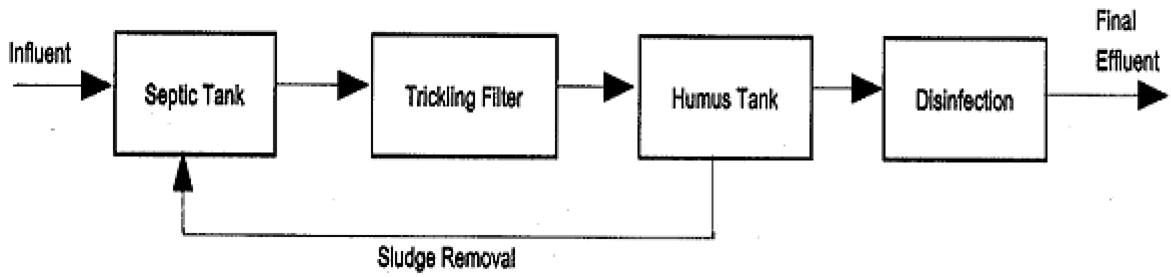

Figure 4: A diagram of a trickling filter treatment system (Laas and Botha, 2004).

Problems associated with Package plant systems and solutions offered

Throughout the literature the same types of problems are mentioned and very few researchers offer solutions, some even raise further questions about package plants and whether they are viable treatment options (Laas and Botha, 2004).

1. **Poor Plant Design and Poor Staff Training**

Although package plants are low cost and simple to operate, the main problems leading to bad odour and poor effluent quality in general that are associated with these sewage treatment systems include:

- poor design and construction linked to system/mechanical failures and ineffective/no back-up systems.
- insufficient maintenance and skilled operators combined with poor training for operators leading to technical and management problems.

2. **Challenges in monitoring, testing and analysis of effluent**

Problems in monitoring, testing and analysis of effluent are compounded by variability in influent loads. Some systems show non-compliance with regard to removal of COD, NH_3, pH, *E. coli* and suspended solids. Changes in pH are associated with excessive aeration leading to increased nitrification and thus a drop in pH. The use of soaps, detergents and fats leads to an increase in COD levels. The optimal level of oxygen is also required to convert NH_3 to nitrates, while, on the other hand, nitrate reduction has been found to be inconsistent in some systems (Hulsman and Swartz, 1993). Any changes in temperature, pH or chemicals will lead to an increase in NH_4. Problems with bacteria are due to inadequate disinfection and insufficient contact time with chlorine. High concentrations of suspended solids will also prevent chlorine from making adequate contact with the bacteria and too much NH_3 reacts with the chlorine causing insufficient disinfection (Hanna *et al.,* 1995; Laas and Botha, 2004; Gaydon *et al.,* 2007; Damafakir *et al.,* 2009; Momba *et al.,* 2009).

According to Laas and Botha (2004) studies have shown that only 89% of package plants are pH compliant, 69% are COD compliant, 25% are ammonia compliant and only 45% are *E. coli* compliant when compared to quality standards. However, in a study done by Gaydon *et al.* (2007) the three technologies (submerged bio-contactor, rotating bio-contactor and activated sludge systems) that they tested showed successful removal of COD and suspended solids with a 94% COD compliance, 31% ammonia compliance and 85% bacteria compliance. Hulsman and Swartz (1993) also stated that with the activated sludge system that they tested in their research showed no system failures and were completely COD compliant. It is, thus, clear that various types of systems have differing efficiencies but the overall literature shows that most do encounter problems, whether it is purely mechanical or a matter of operation and monitoring.

Two studies, however, did aim to provide solutions or recommendations with regards to package plants in an attempt to improve the efficiencies of these treatment systems.

The general recommendations included:

- designing of complete package plants to treat the volume load of the area they serve.
- Provision of appropriate training and education to ensure skilled operation and maintenance.
- use of effective flow equalization measures.
- ensuring efficient screening of waste water and installation of fat traps.
- installation of warning alarms for system failures.
- use of sand filters to improve effluent quality.
- Improvement in and insurance of efficient aeration.
- increasing de-sludge/cleaning frequencies and maintenance.
- insuring efficient sludge retention times.
- performing frequent, detailed sampling and analysis of effluent

They also provided recommendations towards operational and monitoring requirements, legislation and guidelines to designers (Gaydon *et al.*, 2007; Damafakir *et al.*, 2009).

Monitoring and Legislation associated with package plants

Most mention in the literature involved general water and waste water legislation in South Africa and package plant legislation appears to be somewhat neglected. Reference is made to general waste water standards (Hulsman and Swartz, 1993), general effluent quality standards as set out by the Department of Water Affairs and Forestry (Voortman and Reddy, 1997), the National Water Act (Laas and Botha, 2004), the National Environmental Management Act, Water Services Act, Local Government: Municipal Structures Act and Municipal By-Laws (Damafakir *et al.*, 2009). However, none of these references cite legislation for package plants as a separate entity and whether or not they should be considered under an entirely different set of standards or if general effluent standards should apply to all and any type of treatment facility regardless of its treatment capacity per day or if its privately or government owned (Gaydon *et al.* (2007; Damafakir *et al.* 2009).

Many authors believe a separate set of standards and requirements should apply to package plants. For example, in Cape Town specific guidelines and policies were developed specifically for package plants (Laas and Botha, 2004) which raise the questions: why is this not done in other parts of South Africa as well and why is it not included in the overall legislation of the country? If one looks at the definition of package plants it states that they have a discharge volume of less than 2000 cubic meters a day. If this definition is considered then the following monitoring requirements should be applied to package plants.

Table 1.2: Monitoring requirements (Laas and Botha, 2004; Gaydon *et al.*, 2007).

Discharge Volume per day	**Monitoring Requirements**	**Monitoring frequency**
Less than 10 cubic metres	Basic tests should include: faecal coliforms (per 100 ml) Chemical Oxygen Demand (mg/l) Ammonia as Nitrogen (mg/l) Suspended Solids (mg/l)	Annually
10 to 100 cubic metres And 100 to 1000 cubic metres	Intermediary tests should include the basic tests above, plus: pH Electrical Conductivity (rnS/m)	Monthly
1 000 to 2 000 cubic metres	Advanced tests should include the intermediary tests above, plus: Nitrate/Nitrite as Nitrogen (mg/l)	Monthly

	Free Chlorine (mg/l) Ortho-Phosphate as Phosphorous (mg/l)	

General view and conclusion drawn from available literature

Most of the literature focuses on specific technologies or types of systems and not on package plants in general, the costs involved in installing, maintaining and using a specific system nor on legislation associated with sewage treatment. However, it is clear that the number of package plants in South Africa has increased over time, although only an estimate is available on the total number of operating plants in South Africa. Thus, according to Laas and Botha (2004), the number of functioning package plants in Cape Town in September 2003 was 68 but that this increased to 600 plants throughout South Africa as was determined by a study done by Gaydon *et al*. (2007). The overall trend in these recommendations was that there was an increasing demand on small communities to treat wastewater to acceptable levels and that there should be a commensurate tightening of treated effluent standards (Hulsman and Swartz 1993; Buchanan, 2004; Laas and Botha, 2004; Gaydon *et al.*, 2007).

According to Gaydon *et al.* (2007) package plants have many weak points but that improvements can be made to these systems to improve overall efficiency and effluent quality. Naturally, if the problems are left unresolved then poor quality effluent can have environmental consequences. Some researchers believe package plants to be very effective. Hulsman and Swartz (1993) consider package plants to be a low cost, easy operating alternative that produces good quality effluent within the required standards. According to Buchanan (2004) activated sludge systems that employ sequencing batch reactors and sand filtration systems are very reliable, economical and compliant with quality standards. Damafakir *et al.* (2009) also argues that the activated sludge systems are of excellent technology, producing good effluent quality if properly designed, constructed and operated. The Department of Water Affairs and Forestry agrees that some systems such as the submerged biological contactor system is efficient in reducing waste and it exceeds national and international quality standards with regards to effluent quality (www.dwaf.gov.za).

While some types of package plant treatment systems have been shown to achieve quality standards, however, the concern lies with the majority of package plant systems that are not properly operated and maintained (Laas and Botha, 2004). Throughout the literature there are recurring themes with regards to package plants:

- lack of monitoring and managing of these systems
- lack of focus regarding problems in package plant design.

- it is clear that there is a gap in the literature about appropriate legislation and standards for package plants as separate domestic sewage treatment systems.

- Most authors or researchers only mention general waste legislation where applicable but it seems there is some confusion as to what is applicable to package plant owners and the quality of effluent that their systems produce.

- There also seems to be uncertainty about the exact number of operating plants in the country. This again links up with legislation due to the fact that these systems are not registered and government has difficulty in establishing the amount of plants installed. A survey is thus needed if possible of how many systems are operating, where they are and what type of technology they are employing.

It can thus be concluded that proper maintenance and skilled operation is absolutely essential and required to sustain a well functioning package plant. All of these factors should be considered when choosing the type of package plant as well as cost, electrical supply and backup and topography. All these will have an impact on the proper function and operation of a package plant (Voortman and Reddy, 1997; Schölzel and Bower, 1999).

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A Review of Wastewater Standards and Legislation for Package Plants in South Africa

De Bruyn K; Brand ME; Dewar JB; Hendrick RM

Abstract

A review was done on the available waste water legislation and quality standards in South Africa that has reference to package plants. Most of the legislation only refers to general waste water and do not make specific mention of package plants as a unique entity. There is however a view policies and documents that were set up with the purpose of providing guidelines for package plant owners in this country. This article will highlight and compare some of the country's requirements, standards and legislative Acts and By-Laws with regards to general waste water as well as effluents of package plants.

Key words: by-laws, effluent standards, legislative acts, package plants, waste water.

Introduction

According to Gaydon *et al.* (2007) when it comes to package plant legislation this topic is neglected. Damafakir *et al.* (2009) agrees and says that the current legislation is not aligned to dealing with package plants as a separate topic. In the literature the most mention, if any, was made towards general water and waste water legislation in South Africa. Reference was made to general waste water standards (Hulsman and Swartz, 1993), general effluent quality standards as set out by the Department of Water Affairs and Forestry (Voortman and Reddy, 1997), the National Water Act (Laas and Botha, 2004), the National Environmental Management Act, Water Services Act, Local Government: Municipal Structures Act and Municipal By-Laws (Damafakir *et al.*, 2009). But none of these explain legislation for package plants as a separate entity and whether or not they should be considered under an entirely different set of standards or if general effluent standards should apply to all and any type of treatment facility regardless of its treatment capacity per day or if its privately or government owned.

Many believe a separate set of standards and requirements should apply to package plants. For example in Durban specific guidelines and policies was developed specifically for package plants (Laas and Botha, 2004) which raises the questions: why is this not done in other parts of South Africa and why is it not included in the overall legislation of the country?

In places like Virginia permits are required for installation and use of package plants. Quarterly grab samples of the effluent are a requirement and discharge into rivers are allowed. Effluent however must comply with the following standards: BOD: >30mg/ℓ, TSS: >30mg/ℓ, Faecal coliforms: 200 per 100mℓ, pH: 6-9, DO: 5mg/ℓ (Hanna *et al.*, 1995). Norwegian regulations also permits only approved package plants and field tests are required to obtain accreditation due to past failures occurring as a result of operation and maintenance problems. The regulations also state that a service contract, maintenance service and service inspections are required (Gaydon *et al.*, 2007).

Methods

A literature study was done and information was gained through a secondary analysis consisting of previous and existing literature. Documentation used included journals, literature texts, reports and articles, as well as information on the internet was collected and from the catalogues of the UNISA libraries.

Search engines

The search engines used to gather the above information on the internet included: Google Scholar, Science direct and Scopus.

Key words

The key words used to conduct the information and literature search were as follows:

Waste water bylaws, waste water legislation, waste water standards, waste water monitoring, waste water guidelines, waste water policies, sewage effluent bylaws, sewage effluent legislation, sewage effluent standards, sewage effluent monitoring, sewage effluent guidelines, sewage effluent policies, package plant bylaws, package plant legislation, package plant effluent standards, package plant monitoring, package plant guidelines, package plant policies.

Results and Discussion

Legislative Acts in South Africa

The Water Services Act makes provision for the regulation of only general wastewater treatment works operation, setting of general wastewater standards, gathering and publishing of information and record keeping (Water Institute of South Africa, Water Research Commission and East Rand Water Care Company, 2002).

The National Water Act makes provision for all management aspects of water resources and provides general and special standards for waste water effluent. It also clearly states that anyone who discharges waste water is required to have a license (whether it is municipal or privately owned), do monthly monitoring/analysis and keep records. The Water Act also requires that acceptable maintenance is done, emergency measures and practices are in place as well as sludge removal in accordance with the requirements of the Department of National Health and Population Development (National Water Act, Act 36 of 1998; Water Institute of South Africa, Water Research Commission and East Rand Water Care Company, 2002). Damafakir *et al.* (2009) argues that according to the National Water Act, Regulation 2834 only applies to municipal treatment works and not package plants. Although the Act (National Water Act 36 0f 1998) clearly states discharge of waste water of up to 2000 cubic meters a day is allowed.

If one looks at the definition of package plants it states that they have a discharge volume of less than 2000 cubic meters a day. If this definition is considered then it would seem that the National Water Act do indeed make provision for package plants and then the following monitoring requirements (table 1.1) can be applied to package plants as well as the general and special effluent standards (table 1.2).

Table 1.1: Monitoring requirements (Laas and Botha, 2004; Gaydon *et al.*, 2007).

Discharge Volume per day	**Monitoring Requirements**	**Monitoring frequency**
Less than 10 cubic metres	Basic tests should include: faecal coliforms (per 100 ml) Chemical Oxygen Demand (mg/l) Ammonia as Nitrogen (mg/l) Suspended Solids (mg/l)	Annually
10 to 100 cubic metres And 100 to 1000 cubic metres	Intermediary tests should include the basic tests above, plus: pH Electrical Conductivity (rnS/m)	Monthly
1 000 to 2 000 cubic metres	Advanced tests should include the intermediary tests above, plus: Nitrate/Nitrite as Nitrogen (mg/l) Free Chlorine (mg/l) Ortho-Phosphate as Phosphorous (mg/l)	Monthly

Table 1.2: General and special standards for effluent (National Water Act 36 0f 1998).

Substance	**General Limit**	**Special Limit**
Faecal Coliforms (per 100 ml)	1 000	0
Chemical Oxygen Demand (mg/l)	75 *	30 *
pH	5,5-9,5	5,5-7,5
Ammonia (ionised and un-ionised) as Nitrogen (mg/l)	3	2
Nitrate/Nitrite as Nitrogen (mg/l)	15	1,5

Chlorine as Free Chlorine (mg/l)	0,25	0
Suspended Solids (mg/l)	25	10
Electrical Conductivity (mS/m)	70 mS/m above intake to a maximum of 150 mS/m	50 mS/m above background receiving water, to a maximum of 100 mS/m
Ortho-Phosphate as phosphorous (mg/l)	10	1 (median) and 2,5 (maximum)
Fluoride (mg/l)	1	1
Soap, oil or grease (mg/l)	2,5	0
Dissolved Arsenic (mg/l)	0,02	0,01
Dissolved Cadmium (mg/l)	0,005	0,001
Dissolved Chromium (Vi) (mg/l)	0,05	0,02
Dissolved Copper (mg/l)	0,01	0,002
Dissolved Cyanide (mg/l)	0,02	0,01
Dissolved Iron (mg/l)	0,3	0,3
Dissolved Lead (mg/l)	0,01	0,006
Dissolved Manganese (mg/l)	0,1	0,1
Mercury and its compounds (mg/l)	0,005	0,001
Dissolved Selenium (mg/l)	0,02	0,02
Dissolved Zinc (mg/l)	0,1	0,04
Boron (mg/l)	1	0,5

Guidelines and Policies in South Africa

The need for legislation for package plants was becoming apparent and in the City of eThekwini guideline documents was set up with regards to existing package plants and installation of new package plants. The documents (Policy Documents 8 and 12) clearly states that operation and performance monitoring of package plants must be done by the Department's Pollution division with regards to type, design and efficiency and that all package plants must comply with General limits for domestic wastewater discharge as it is stated by the National Water Act (Act 36 0f 1998). (Laas and Botha, 2004).

According to Laas and Botha (2004) inspections and sampling of package plants are done every six months by the Pollution Division and owners are required to submit analysis results on a regular basis to the local municipality. The policies also indicate that an application for permission to install a package plant must be made to the eThekwini Water and Sanitation Unit. This application must include details of the developer/engineer/manufacturer, information of the property/area/position of installation, package plant size, type, quantity, point of discharge and an environmental assessment report (EThekwini Municipality, 2005).

By-Laws in South Africa

The Ekurhuleni Metropolitan Municipality Public Health By-Laws also seem to make provision for privately owned sewage works but do not specify size or volume of these works and therefore it is difficult to establish whether it includes package plants. These By-Laws state that a permit is required for installation of any sewage works, the plant must be maintained at all times and disposal of effluent may not cause environmental or health concerns (Ekurhuleni Metropolitan Municipality Public Health By-Laws, 2009).

The Johannesburg Water Services by-laws stipulate that any person who wishes to operate any sort of sewage disposal system must have authorization by the municipality. The by-laws also states that if there is no infrastructure/connection to the municipality, owners can apply for approval to install on-site sanitation services at their own cost, in accordance with council specifications and the municipality may also specify the type of on-site system that is to be installed (City of Johannesburg Metropolitan Water Services By-Laws, 2004). Although the by-laws make provision of on-site systems, there is no mention whether it is privately owned and the capacity of the systems, again making it difficult to establish if it includes package plants.

The public health by-laws of Johannesburg City however makes mention of private sewage works and states that a permit is required for installation of these sewage works and that it must be maintained at all times (City of Johannesburg Metropolitan Water Services By-Laws, 2004). But no mention is made of the capacity of the systems.

In the West Rand District Municipal Health Services by-laws provision is also made for private sewage works and states once again that a permit is required for installation of these sewage works and that these systems must be maintained and cleaned. Private sewage works may only be installed if there is no connection to the municipal system available but do not specify the size of the systems (West Rand District Municipality: Municipal Health Services By-laws. 2010).

Summary of standards and legislation in South Africa

The following tables attempts to compare and summarize standards and legislation available in South Africa for general sewage as well as effluent from package plants.

Table 1.3: Comparison of waste water quality standards in South Africa

(National Water Act, Act 36 of 1998; Water Institute of South Africa, Water Research Commission and East Rand Water Care Company, 2002**;** Government Gazette No 399, 2004; City of Johannesburg Metropolitan Water Services By-Laws, 2004; Damafakir *et al.*, 2009; West Rand District Municipality: Municipal Health Services By-laws. 2010).

Analysis	**National Water Act**		**Government Gazette No 399**	**JHB Water Service by-laws**	**West Rand council by-laws**	**Mogale City Lab**	**WISA, ERWAT , WRC**	**Proposed standards by Damafakir *et al.*, 2009.**
	Gen. limit	**Special limit**						
Faecal Coliform (per 100 ml)	1000	0	1000	*	0	1000	*	1000
Faecal Strep per 100ml	*	*	*	*	*	230	*	*
COD (mg/l)	75	30	75	*	75	75	40 – 70	75
DO %	*	*	75	*	*	*	*	*
pH	5.5 – 9.5	5.5 – 7.5	5.5 – 9.5	*	5.5 – 9.5	5.5 – 9.5	6.5 – 8.0	5.5 – 9.5
Ammonia as Nitrogen (mg/l)	3	2	6	*	10	10	8	6
Nitrate/ Nitrite as Nitrogen (mg/l)	15	1.5	15	50	*	*	40	15
Chlorine as Free Chlorine (mg/l)	0.25	0	0.25	*	*	*	*	0.25

SS (mg/l)	25	10	25	*	25	25	5 – 25	25
TDS (mg/l)	*	*	*	*	*	1625	*	*
EC (mS/m)	70 - 150	50 – 100	70 - 150	500	*	250	*	70 - 150
Ortho-Phosphate as P (mg/l)	10	1 – 2.5	10	*		1	0.5 – 10	10
Chlorides	*	*	*	1000	*	*	*	*

Table 1.4: Comparison between laws/acts making provision for private sewage works

(National Water Act, Act 36 of 1998; City of Johannesburg Metropolitan Water Services By-Laws, 2004; Ekurhuleni Metropolitan Municipality Public Health By-Laws, 2009; West Rand District Municipality: Municipal Health Services By-laws. 2010).

	National Water Act	**JHB Water Services By-Laws**	**JHB Municipality public health By-Laws**	**West Rand District Municipality health by-laws**	**EKURHULENI health BL**
Waste water limit values/standards	√	√	x	√	x
Bylaws on domestic sewage	√	√	√	√	√
Bylaws on private sewage works	x	x	√	√	√
Capacity of sewage works	2000 cubic meters	x	x	x	x

Conclusion

It is clear from the above review that there is a gap in the literature about appropriate legislation and standards for package plants as separate domestic sewage treatment systems. Most authors or researchers only mention general waste legislation where applicable but it seems there is some confusion as to what is applicable to package plant owners and the quality of effluent that their systems produce. It is clear from the above information that there is still not absolute clarity to whether provision are made for package plants in South Africa's legislation. Where mention is made of on-site or privately owned systems no clear distinction is made of the type or capacity (whether the systems discharge more or less than 2000 cubic meters per day).

Water Service Authorities or large scale municipal treatment works are required to comply with 90% of the criteria in order to receive Green Drop status. These criteria include process controllers, waste water quality, monitoring, sample analysis, submission of results, quality compliance, management of failures etc. There are however no such criteria available for package plants which create confusion as to whether package plants falls under the same criteria compliance. If not this leaves the question of how then are package plants measured to see if they are efficient and working? (Department of Water Affairs and Forestry, 2008). There is thus a need for a single set of regulations and discharge standards that are specific to package plants and Gaydon *et al.* (2007) believe that 80% compliance is satisfactory.

When setting up standards, various factors should be considered as can be seen from a study done by Abu-Rizaiza (1999) on modification of general wastewater standards in Saudi Arabia. Standards and regulations are required with any wastewater facility so as to protect public health. But these standards also need to be realistic and obtainable, thus the country as well as the package plant owner's condition or economic and technical capabilities should be accounted for (Abu-Rizaiza, 1999).

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A case study of a package plant in Mogale City, South Africa.

De Bruyn K; Brand ME; Dewar JB and Hendrick RM

Abstract

Sewage discharge is a huge problem in South Africa. Many communities depend on surface water for their daily activities. These sources are often contaminated due to untreated or inadequately treated waste water effluents entering these surface waters and thus affecting the quality of the rivers/streams (Freese and Nozaic, 2004; Damafakir *et al.*, 2009) by contributing to oxygen demand, nutrient loading and algal blooms (eutrophication) as well as water-borne diseases (Morrison *et al.*, 2001). This can lead to the increased occurrence of disease amongst communities such as gastrointestinal and other diarrhoeal diseases which, in developing countries, could be life threatening (Igbinosa and Okoh, 2009; Omar and Barnard, 2010). A package plant in the Mogale City area was studied to determine the quality of the effluent that was produced by this on-site treatment facility. Analysis was done on coliforms, ammonia, COD and ortho-phosphate concentrations in the effluent samples. It was determined that coliform bacteria was almost completely removed due to high concentrations of chlorine used during the disinfection process but ammonia, COD and ortho-phoshate concentrations were above standard.

Key words: ammonia, coliform bacteria, effluent quality, COD, ortho-phosphate, package plant, waste water.

Introduction

There are widespread problems associated with the quantity and quality of water in South Africa. The term water quality is used to describe the chemical (phosphates and nutrients), physical (temperature, pH, conductivity) and biological (bacteria, viruses and parasites) components of water. Changes in water quality are used as indicators to establish the degree of pollution. Unmanaged human activities can cause deterioration of surface and groundwater quality (State of the Environment Report for Mogale City Local Municipality, 2003). Waste water is a global problem that has become a very important issue but is also a difficult environmental problem to solve (Rudel *et al.*, 1998; Gasparikova *et al.,* 2005). Many of South Africa's water resources have become polluted due to sewage effluent discharge (Walmsley *et al.,* 1999). The term effluent is described by the Water Services Act of 1997 as human excreta, domestic sludge, domestic waste water, grey water or waste water resulting from commercial or industrial use (www.dwaf.gov.za/Documents/Notices/Water%20Services%20Act/SEC9DREG_20_April_2001.pdf). Treatment of waste water is a very important process in the overall management of the country's water resources, as is the measuring of the amount of pollutants that will be present in the discharged effluent and eventually end up in rivers and streams. Thus, the influence of the treatment process will determine the potential hazard associated with the effluent to the water resources, environment and human health (Lester, 1983).

A number of developing countries have inadequate waste disposal systems, lack of infrastructure and capacity, and, together with a rapid increase in population, there is an increased demand for not only water resources but also proper disposal of domestic waste (Mahomed *et al.*, 2008; Damafakir *et al.*, 2009). A solution to this demand has been the development of package plants. Package plants were introduced to meet the ever increasing demands and needs of rural or small, isolated communities, residential areas and holiday and recreational sites. These systems are usually complete, pre-assembled structures and can be under- or above ground. They are also known as alternative on-site treatment facilities or pre-engineered sewage treatment plants, and have increased in number over the last few years due to its apparent efficiency, low cost and ease of operation (Department of Water Affairs, Department of Health, Water Research Commission, 2002; Goronszy, 1979). There are various types of package plants in operation in South Africa, including: activated sludge, submerged bio-contactors, rotating bio- contactors, trickling filter plants, anaerobic systems, pond systems and constructed wetlands. They operate by using a series of treatment processes that are very similar to those used in conventional large scale treatment plants (Department of Water Affairs, Department of Health, Water Research Commission, 2002; Damafakir *et al.*, 2009). Typical treatment processes in a sewage treatment plant consists of primary, secondary and tertiary treatment. Primary treatment makes use of physical processes where the organic matter is removed via settling, floatation, skimming, coagulation and flocculation with the use of rakes, grit chambers, sedimentation and clarification. Secondary treatment involves aerobic treatment where organic matter and nutrients are removed through the metabolic action of microorganisms. It also involves the use of activated sludge, trickling filters and stabilisation ponds for removal of phosphates and nitrogen through denitrification and nitrification. Tertiary treatment is the advanced treatment process that include disinfection (removal of bacteria) and sand filtration for the removal of nutrients, dissolved and or suspended solids, organics and metals (Dettrick and Gallagher, 2002; Department of Water Affairs, Department of Health, Water Research Commission, 2002; Kistemann *et al.*, 2008).

Package plants have various advantages due to the fact that they are easily assembled, low in cost and easy to operate, but there have been problems associated with these self contained, small scale units. These result mainly from variable load conditions that may result from increases in activity during certain times of the day. Often, there is also a lack of skilled supervision, monitoring, maintenance and operating personnel (Goronszy, 1979). These problems could pose serious threats to the environment and human health if effluent of a poor quality is released into the water resources (Voortman and Reddy, 1997; Dettrick and Gallagher, 2002; Department of Water Affairs, Department of Health, Water Research Commission, 2002).

It is, thus, crucial that maintenance, control and monitoring of package plants be sufficient, so as not to improve the situation regarding poor quality effluent release into waterways. Inadequately treated effluents may be a source of pathogens, nitrogen, phosphate and metals, and can, thus, deteriorate water resource quality and cause ecological and health problems in surrounding communities. The aim of this study was to determine the effluent quality by measuring the concentrations of orthophosphate, ammonia, COD and coliform bacteria that are being discharged into the river.

Package plant systems

With increasing rural and suburban development more people have become interested in small waste water treatment works. There are various differences between small and large scale treatment systems such as quality and quantity. Small systems have low investment and maintenance costs, they operate quietly, have reduced odours, simple operation, long durability and effluent can be discharged into streams (Hanna *et al.*, 1995; Gasparikova *et al.*, 2005). In the past small communities used low technology approaches to treat waste water which included only septic tanks, stabilization ponds and filtration and often these methods did not comply with the required standards. However, in recent years, package plants have increased in number and made some improvements with new technologies. The difference between large scale conventional treatment works and package plants are the fact that package plants are on-site systems with a discharge less than 2000m^3/day, they can be build/installed at low cost, can be used to treat waste of small communities, are easy to transport and install (Hulsman and Swartz, 1993; Gaydon *et al.*, 2007).

The package plant studied for this research project is based on the same technology as the submerged biological contactor systems. With the **submerged biological contactor system** (fig. 1), plastic media are used that acts as substrate for microorganism growth. This system consists of a septic tank, biological contactor tank with media and air blowers, cone shaped clarifier tank and a disinfection tank (Laas and Botha, 2004; Damafakir *et al.*, 2009).

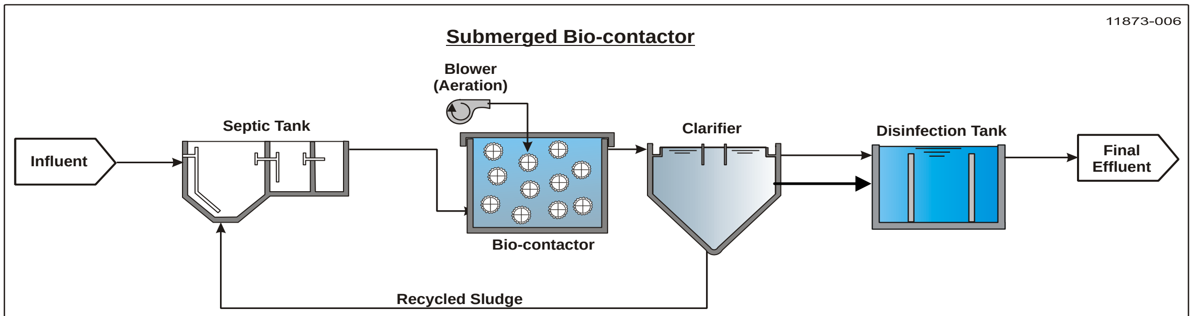

Figure 1: Submerged biological contactor system (Damafakir *et al.*, 2009).

According to the supplier website of these systems:

- were first launched in 1996

- typically consists of septic tanks, submerged bio reactor with AWW MARK 2 fixed growth media and aeration, clarifier tank to extract excess solids and disinfection with chlorine

- are easy to install and operate

- are very cost effective

- comply with requirement standards

- are odourless and silent

- can be used for small communities, villages and towns

- provide for reuse of effluent that can be used for irrigation and subsistence agriculture.

According to the Department of Water Affairs and Forestry (www.dwaf.gov.za), these domestic sewage treatment plants are:

- Small and compact, simple to install and run
- Versatile and highly efficient
- Capable of rendering toxic domestic waste clean, clear and 100% reusable
- Exceeds minimum international discharge standards as well as the Department of Water Affairs discharge limits
- Minimizes the need for chemicals
- Is a 100% odourless, almost silent AND pathogen free
- Can be re-circulated into irrigation systems, swimming pools, water features or used for flushing
- Can cope with any capacity of domestic waste water
- Does not require continuous supervision or maintenance – requires very little human input and technical knowledge, the only human input is occasional top up of chlorine for disinfection
- Its economical saving water and power

They also state that "these treatment systems renders dangerous domestic waste completely safe for discharge into natural waterways" and that "communities that take possession of these plants are taught how to maintain their plants, how to properly utilise their plants, and basic personal hygiene" (www.dwaf.gov.za). The system chosen for this research project consists of 12 tanks altogether (as well as two underground septic tanks thus total 14 tanks) as can be seen from figure 2.

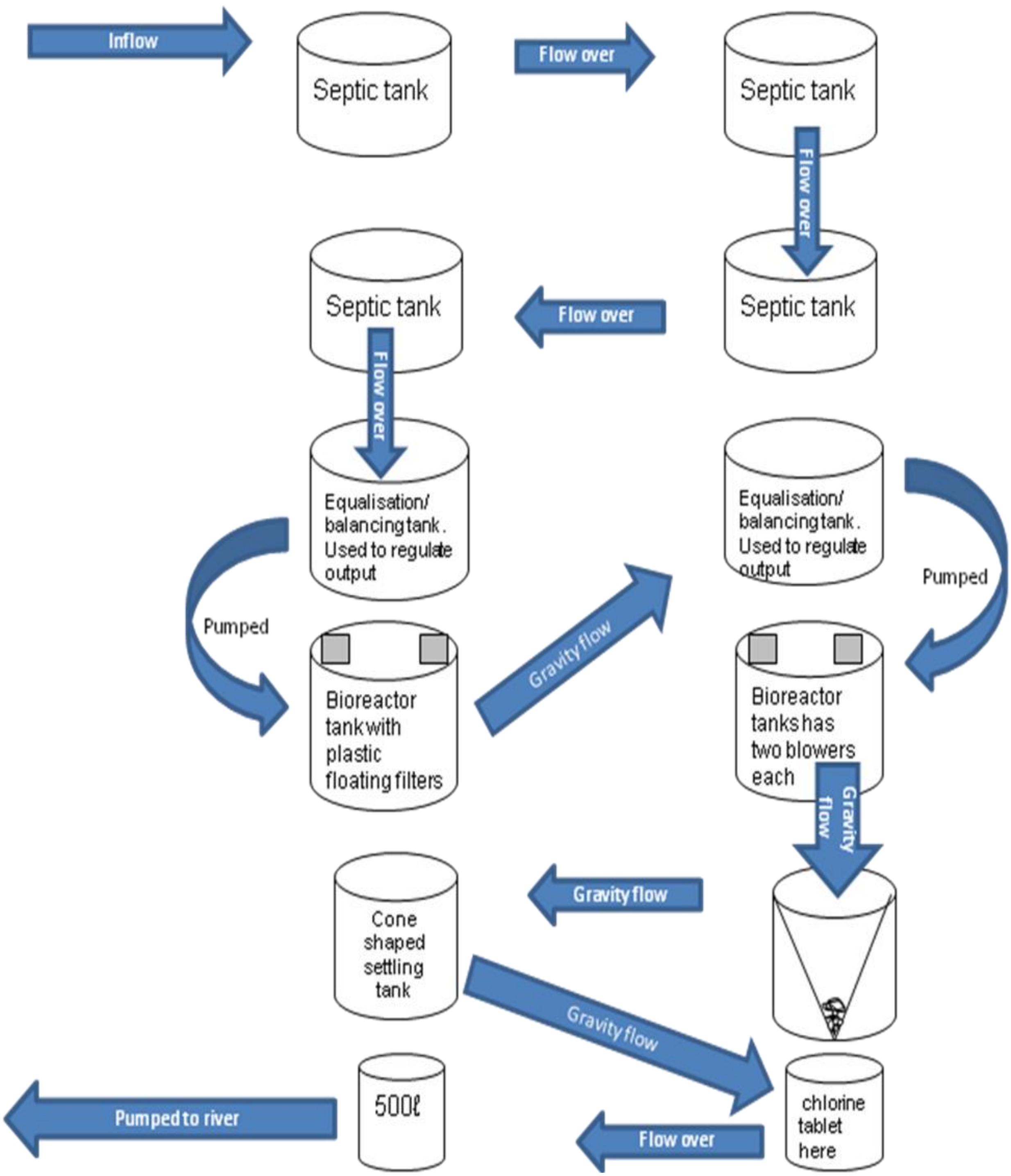

Figure 2: Diagram of selected package plant for research project.

The first four tanks are the septic tanks, from there the wastewater flows over to the equalisation tank and then it is pumped to the bioreactor tank that contains the plastic floating filters (as can be seen from figure 3 below).

Figure 3: Plastic filter media randomly packed in bioreactor tanks

The waste water then flows with the help of gravity to another equalisation tank and is again pumped to yet another bioreactor tank. These bioreactor tanks both have two sets of blowers that are responsible for pumping air into the bottom of the bio-tanks. The sewage then goes to the clarifier tanks (there are two) which is cone shaped. The solids then settle out in the bottom of the cone and are then pumped back into the system. The remaining liquid/effluent then goes to the disinfection tanks (also two of them) where it is treated with Brilliant Stabilised Chlorine Tablets with the active ingredient: Trichloroisocyanuric Acid 990g/kg. The entire system takes up land space of approximately 14.6m x 6.6m. It takes 28 days for the waste water to pass through the complete system and the effluent output is ±1000 litres per hour (personal communication: Plant operator, August 27, 2010). The specific package plant described and studied for this research project also includes a fat trap.

Thus, waste water that originates from the research site's kitchen area firstly goes through the fat trap before it reaches the treatment plant. Waste water from kitchens contains organic matter, fat, oil and grease. These oils and greases may have an influence on the waste water treatment plant by affecting aerobic and anaerobic processes (activated sludge systems), lead to high levels of BOD, clog pipes and causing an overall decrease in the system's efficiency and that is why removal of these substances prior to entering the package plant is essential (Kommalapati and Johnson, 2001; Brown, 2003). The liquid originating from the kitchens passes through these traps, usually consisting of various compartments. During retention time, the fat/oil/grease gets separated from the liquid portion and floats on the surface. There it accumulates and is then skimmed or pumped off, thus letting only the remaining liquid/waste water pass through to the waste water treatment plant (Brown, 2003). An illustration of a fat trap is shown in figure 4:

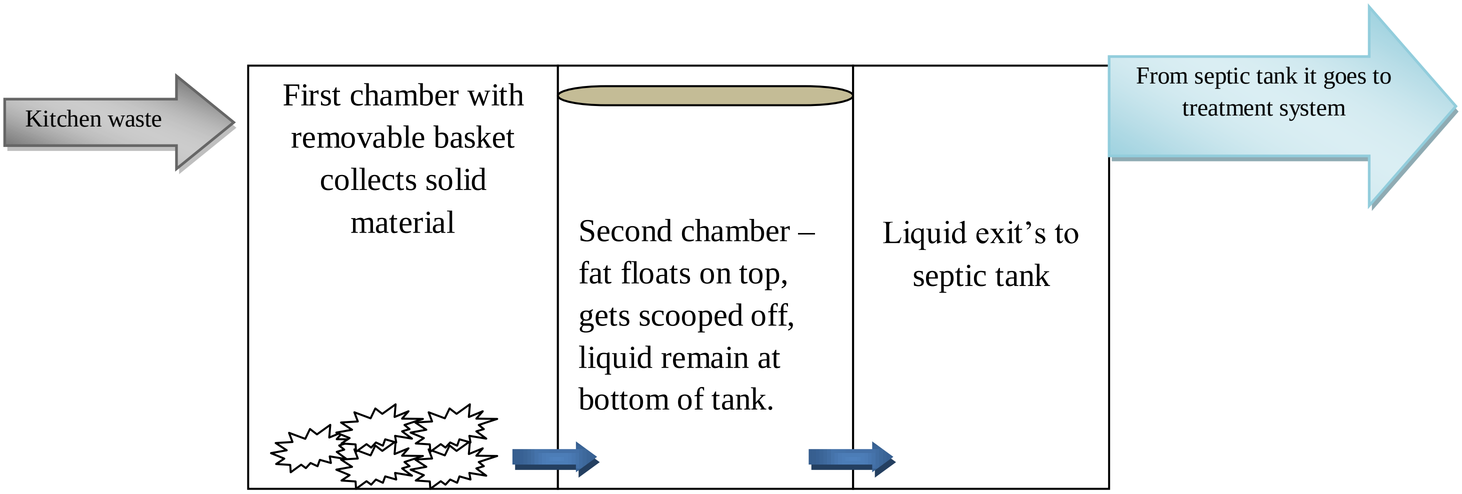

Figure 4: An illustration of a fat trap.

Problems associated with package plants

Although package plants are low cost and simple to operate alternatives to sewage treatment, there are problems associated with these treatment systems. The most common problems encountered include: bad odour, poor effluent quality, poor design and construction, system failures, lack of maintenance and skilled operators, lack of proper monitoring, technical and management problems and variable influent loads also cause problems. Some systems show non-compliance with removal of COD, NH_3, pH, *E. coli* and suspended solids. Problems associated with pH occur due to excessive aeration which in turn leads to increased nitrification and thus a drop in pH levels. COD levels are increased with the use of soaps, detergents and fats. The right amount of oxygen is also required to convert NH_3 to nitrates. Any changes in temperature, pH or chemicals will lead to an increase in NH_4. Problems with bacteria are due to inadequate disinfection and insufficient contact time with chlorine. High concentrations of suspended solids will also prevent chlorine from making adequate contact with the bacteria and too much NH_3 reacts with the chlorine causing insufficient disinfection (Hanna *et al.*, 1995; Laas and Botha, 2004; Gaydon *et al.*, 2007; Damafakir *et al.*, 2009; Momba *et al.*, 2009).

These problems can be reduced with a few solutions such as:

- designing of package plants to treat the volume load of the area they serve, thus proper designing of complete systems

- training and education to ensure skilled operation and maintenance

- the use of effective flow equalization measures

- ensure efficient screening of waste water and installation of fat traps

- installation of warning alarms for system failures

- the use of sand filters to improve effluent quality

- improve and ensure efficient aeration

- increasing de-sludge/cleaning frequencies and maintenance

- insure efficient sludge retention times

- perform frequent, detailed sampling and analysis of effluent (Gaydon *et al.,* 2007).

The Research Site

The research site chosen for this research project is situated in Mogale City and falls within the boundaries of the Cradle of Human Kind. This area is still developing and the infrastructure in certain parts of the city, are still insufficient. The specific research site chosen for this research is about 600 hectares in size and part of the property has been allowed for development. This site consists of a wide variety of natural habitats, animal and bird species as well as a river running through the site in which the effluent is being discharged.

Methodology/ Data Collection

Two sample sites within the package plant were sampled (one where sewage enters plant and one site where sewage exits plant).

Method of sample collection

Samples from the package plant influent was taken from a pipe with a valve that open and closes for easy access and is attached to the first tank (septic tank) of the system and samples from the effluent were taken from a tap that was installed on the disinfection tank to allow easy access. In both instances the waste water was allowed to run for approximately 2-3 minutes before the samples were taken. Samples were taken every second week for a time period of 12 months. This was done to ensure a representative sample. Samples were taken on approximately the same time of day. This was done to ensure consistency in sample taking and the outcome of the results due to the fact that the time of day may influence the results as a result of temperature changes. Duplicate samples were also taken – one sample was used for the biological assay and the other for the chemical assay.

Equipment used during sampling

• Protective clothing such as boots and gloves

• 500mℓ HDPE Gamma sterilised plastic bottles for all samples (chemical and microbiological samples) of package plant.

• Waterproof marker

• Cooler box with plastic ice packs

• On site data recording book/sample diary which was kept for data recording and providing information to the laboratory.

Data Analysis

The following methods listed and described below are according to the standard methods for the examination of water and wastewater (Greenberg *et al.*, 1992).

Biological analysis

Table 1: Biological analysis (Greenberg *et al.*, 1992).

Indicator organism	Analytical procedure	Growth medium	Incubation	Colony growth
E. coli *E. coli* /100 ml	Membrane filter procedure	MacConkey Agar	Incubate agar plate upside down at 44.5 °C for 20 - 22 h	Count all colonies with yellow *color*
Faecal coliform faecal coliforms /100 ml	Faecal coliform Membrane filter procedure	(m-Fc Agar)	Incubate agar plate upside down at 44.5 °C for 24h	Count all colonies with dark blue *colour*
Faecal streptococci streptococci /100 ml	Membrane filter procedure	m-Enterococcus agar	Incubate t agar plate upside down at 35 °C for 48 h	Count all colonies with dark red colour

Materials and equipment used:

Membrane filtration unit with vacuum pump, sterile forceps, culture dishes and an incubator, growth medium (Greenberg *et al.*, 1992).

Membrane filtration method:

A volume of sample was selected and a sterile filter was placed with sterile forceps over the porous plate of the receptacle. The funnel was locked on and filtered with the vacuum. The funnel was rinsed and the membrane filter was removed with the forceps. The filter was then placed on the growth medium in the petri dish and incubated (Greenberg *et al.,* 1992).

Chemical analysis

The following method was used to determine Ammonia:

Selective Electrode Method

Apparatus used:

Electrometer, ammonia selective electrode, magnetic stirrer and a beaker (Greenberg *et al.*, 1992).

Reagents used:

Ammonia free water, Sodium hydroxide (NaOH) solution, stock ammonium chloride (NH_4Cl) solution and standard ammonium chloride (NH_4Cl) solution (Greenberg *et al.*, 1992).

Selective Electrode Method:

A series of standard solutions were prepared (1000, 100, 10, 1 and 0.1mg) and placed into a beaker. The electrode was then immersed into the solution and stirred with the stirrer. 10N of NaOH was then added to the solution and the reading was taken after five minutes (Greenberg *et al.*, 1992).

Calculation:

mg NH_3 – N/L = A x B x (101 + C/101).

A = dilution factor

B = concentration of NH_3 – N/L

C = volume of added 10N NaOH

The following method was used to determine Chemical Oxygen Demand

Closed reflux, colorimetric method

Apparatus used:

Digestion vessel, heating block, oven, ampule sealer, spectrophotometer (Greenberg *et al.*, 1992).

Reagent used:

Digestion solution, sulphuric acid reagent, sulfamic acid, potassium hydrogenphthalate standard (Greenberg *et al.*, 1992).

Closed reflux, colorimetric method:

A measured volume of sample and reagent was placed into the ampule and digestion solution was added. The sulphuric acid reagent was then added down the side of the vessel. The ampule was sealed and inverted to mix properly. Time was allowed for the solids to settle and the absorbance was measured (Greenberg *et al.*, 1992).

Calculation:

COD as mg O_2/L = mg O_2 in final volume x 1000/ml sample

The following method was used to determine Ortho-phosphate:

Vanadomolybdophosphoric acid colorimetric method

Apparatus used:

Colorimetric equipment such as a spectrophotometer and a filter photometer, acid washed glassware, filtration apparatus and filter paper (Greenberg *et al.*, 1992).

Reagent used:

Phenolphthalein indicator aqueous solution, hydrochloric acid, activated carbon, vanadate-molybdate reagent, standard phosphate solution (Greenberg *et al.*, 1992).

Vanadomolybdophosphoric acid colorimetric method:

The pH of the sample was adjusted and the colour removed. 35mℓ of the sample was placed in a volumetric flask and 1.0mg of P was added. Then 10mℓ of vanadate-molybdate was added and diluted with distilled water. The sample along with a blank was inserted into the instrument and the absorbance was measured (Greenberg *et al.*, 1992).

Free chlorine determination

The analysis of free chlorine concentrations in samples was done using an on-site chlorine test kit called a Visocolor HE Chlor kit and was done according to the supplier manual instructions. A water sample was taken with a 500ml glass Schott bottle. The colour comparison disc was then placed into the comparator block. Two glass tubes were opened, rinsed with the water sample and then filled up to the mark with the water sample. One level black measuring spoon of Cl-1 was then added to the tube on the right hand side as well as 12 drops of Cl-2. The tube was then closed and shaken to mix the content. The reading was then taken immediately by turning the colour disc until both colours of both tubes match by transmitted light from above. The results are read from the mark on the front side of the comparator. These free chlorine tests were done on all river samples as well as the package plant effluent samples.

Statistical Analysis

Statistical analysis of the data was done by an external statistician. Nonparametric statistics were used to analyse the data due to the small sample size and data containing very high outliers. The methods or tests used included the Wilcoxon test and the sign test. The Wilcoxon test reflects magnitude and significant difference. Three levels of significance were used: 05, 01 and 001. The sign test focuses on direction of difference.

Means, maximum, minimum and median values were determined for all data and it was decided to use median values for the statistical analysis due to the fact that there are various outliers with extreme values within the data. This results in the mean values being pulled up by these very few high values. The median, however, are impervious to these outliers and are thus a more accurate measure. The data was also analysed and checked for serial dependence between time/sampling periods with auto correlation tests. If any correlation did occur it was extremely weak. Thus, any differences detected in the data are not correlated/related and thus be said to be independent.

Results and discussion

The following results were obtained through a sampling period that extended over 12 months: Table 2 provides data on the influent of the package plant and shows components with concentrations that are typical of raw domestic sewage with high ammonia, COD and coliform bacterial counts. Table 3 provides data on the effluent or treated waste water exiting the package plant.

Table 2: Package plant influent sample data

	PP In: NH_3-N	PP In: COD	PP In: O-PO_4	PP In: F coli	PP In: E.coli
02-08-2010	25.74	734	4.51	840000	890000
16-08-2010	29.25	738	4.8	18600000	20850000
13-09-2010	30.35	620	4.8	5200000	2300000
11-10-2010	39.39	887	4.92	7200000	8000000
25-10-2010	24.1	713	2.19	5600000	5800000
09-11-2010	10.77	375	0.16	18600000	20850000
22-11-2010	20.07	1439	3.96	18600000	20850000
06-12-2010	17.02	2634	3.13	1800000	1000000
17-01-2011	18.42	8391	1.58	6700000	8800000
31-01-2011	6.13	739	1.07	6200000	9600000
14-02-2011	36.1	3042	3.24	12400000	13900000
15-03-2011	**12.67**	**927**	**2.13**	**4200000**	**6700000**
29-03-2011	11.84	963	2.03	3600000	7000000
11-04-2011	13.98	492	2.77	6100000	5200000
09-05-2011	15.63	1327	2.71	7600000	7000000
24-05-2011	15.13	787	2.3	1210000	1370000
06-06-2011	24.67	710	3.14	4520000	5940000
20-06-2011	18.75	769	3.03	890000	1120000
04-07-2011	18.42	429	3.14	848000	989000
Arithmetic mean	20.444	1406	2.9268	6,879,368	7,797,842
Geometric mean	18.639	974.5	2.4617	4,539,365	4,946,653
Median	18.42	769	3.03	5,600,000	6,700,000
Max	39.39	8391	4.92	18,600,000	20,850,000

Table 3: Package plant effluent sample data

	PP Out: NH_3-N	PP Out: COD	PP Out: O-PO_4	PP Out: Free Cl	PP Out: F coli	PP Out: E.coli
02-08-2010	27.63	75	4.77	0.6	0	0
16-08-2010	28.34	134	7.18	0.4	0	0
13-09-2010	38.41	204	7.18	0.6	0	0
11-10-2010	33.31	108	4.15	0.8	2	4
25-10-2010	24.18	76	2.08	0.8	0	0
09-11-2010	29.36	167	1.8		1648	1764
22-11-2010	25.74	167	0.03	0.02	2472	2646
06-12-2010	27.06	84	5.65	0.4	0	0
17-01-2011	18.67	120	2.04		0	0
31-01-2011	15.46	257	2.39	0.3	0	0
14-02-2011	42.52	50	3.15	0	2472	2646
28-02-2011	0.93	99	4.27	0.2	0	0
15-03-2011	**20.31**	**322**	**3.92**	**0**	**2472**	**2646**
29-03-2011	35.61	154	4.21	0.15	0	0
11-04-2011	30.1	218	4.97	0.3	0	0
09-05-2011	21.88	135	3.69	0.3	0	0
24-05-2011	33.23	102	4.35	0.3	68	16
06-06-2011	31.91	190	5.62	0.15	0	0
20-06-2011	29.36	238	4.71	0.2	12	10
04-07-2011	20.14	132	4.89	0.2	2	0
Arithmetic mean	26.71	151.6	4.0525	0.318	457.4	486.6
Geometric mean	22.98	136.9	3.1116			
Median	27.99	134.5	4.24	0.3	0	0
Max	42.52	322	7.18	0.8	2472	2646

Microbial analysis:

Sample site PPOUT (Table 3) indicated faecal coliform bacterial counts for four of the samples were above the standard of 1000 cfu/100 ml and included counts of 1648 cfu/100 ml for one sample and 2472 cfu/100 ml for the other three samples. The faecal coliform bacteria counts for the package plant effluent (site PPOUT) are shown in the following figure 7:

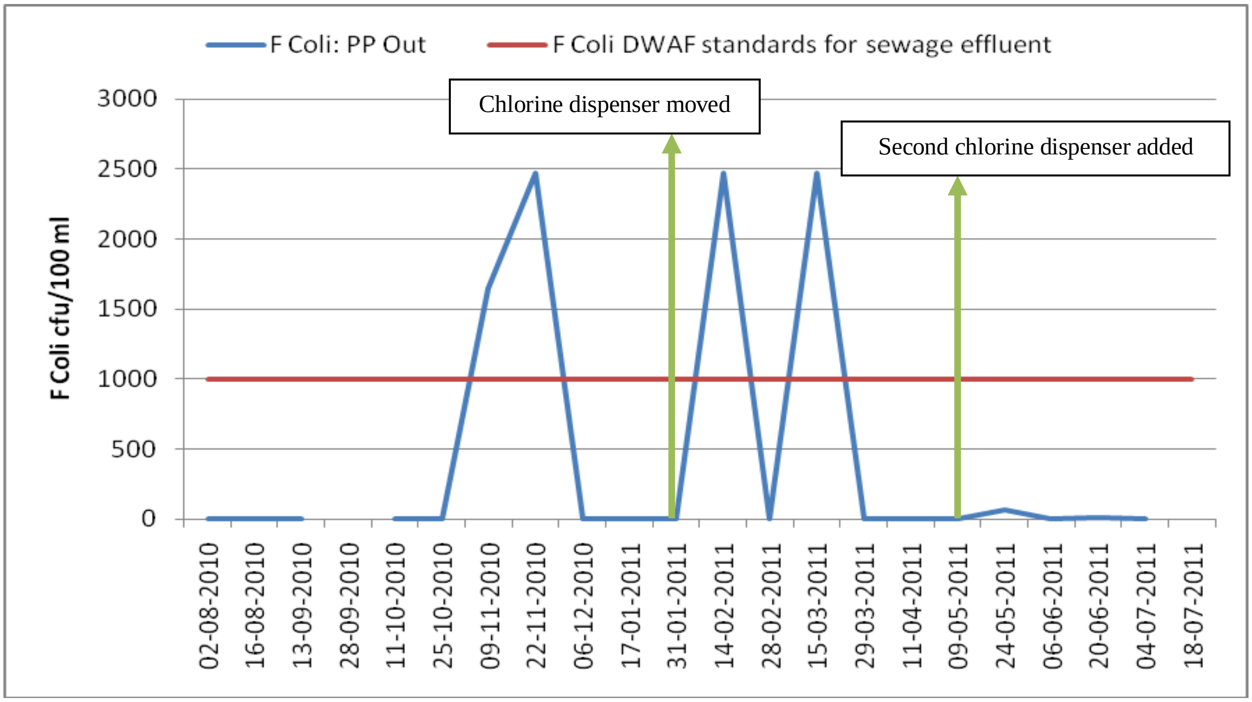

Figure 7: Faecal coliform bacteria concentrations detected in package plant effluent (PPOUT).

As can be seen from figure 7, high faecal bacterial counts were detected in three of the package plant effluent samples. The reasons for the first peak noticeable on the graph on the sample date 22/11/2010 are unclear. The chlorine dispenser was situated at the inlet of the last tank (disinfection tank) of the package plant. The position of the dispenser at this tank ensured that the bacteria counts remained low (indicating that disinfection was achieved) but unfortunately very large concentrations of chlorine was detected in the effluent being discharged into the river.

Generally chlorine is used to disinfect wastewater from treatment systems so as to protect humans against disease. Chlorine is a powerful oxidizer and highly soluble in water and can exist in various chemical forms. Toxicity of chlorine to aquatic life depends on the amount of free chlorine remaining in the water resource and can lead to fish deaths downstream from the wastewater treatment facility (Brungs, 1973). High concentrations of chlorine can be converted to other chemical forms or by-products that are toxic to human and aquatic health (Hays, 1976; Atlas, 1997; Freease and Nozaic, 2004; Botkin and Keller, 2005). The health of the river was thus of concern and, thus, in an attempt to improve the effluent quality the chlorine dispenser was moved on the 31/01/2011 to the inlet of the second last tank (clarifier tank) so as to increase chlorine contact time but not concentration.

In a study done by Gaydon *et al*. (2007) it was determined that disinfection remains a weak point in these treatment systems and that it can only be successfully achieved if the design is reviewed and monitoring is done on a constant and regular basis by the operator. Thus, constant monitoring of the chlorine tablet is required and during the period after the dispenser was moved the plant operator was unable to monitor the system himself. The chlorine dispenser was, thus, not sufficiently monitored. The result of this was extremely high counts of faecal coliform bacteria being detected in the samples taken on the 14/02/2011. This, then, indicates the importance of proper and constant monitoring by skilled operators. On the sample date 15/03/2011 the system experienced flow problems over the dispenser at the new position in the system. It was thought that the flow was too fast over the chlorine tablet resulting in insufficient contact time between the effluent and the chlorine. The result of this, as can be seen from figure 4.17, is extremely high faecal coliform bacterial counts for this sample date. The problem was detected immediately and rectified and bacteria counts decreased to 0 cfu/100 ml. Once more, this underlines the importance of operation and constant, effective monitoring of effluents as was also stated in a study done by Gaydon *et al*. (2007). On the 09/05/2011 the chlorine dispenser was moved back to its original position (at the inlet of the last tank/disinfection tank) and a second dispenser was added to the inlet of the second last tank (clarifier tank). Data indicate that this change in design of the system improved the quality of the effluent by effectively decreasing bacterial counts within the quality standard and prolonging chlorine contact time whilst decreasing the concentrations of chlorine in the final effluent discharged into the river.

When the faecal coliform bacteria and the *E. coli* counts (Table 2 and 3) within the influent (raw sewage) and the effluent (treated wastewater) are compared it would seem that the package plant is in fact decreasing the bacteria concentrations with the majority of the effluent samples containing concentrations of 0 cfu/100ml, **indicating that the package plant is capable of efficiently removing bacteria in the final effluent**. The Wilcoxon statistical tests also indicated and confirmed a high significant difference going down for Faecal coliform and *E. coli*. The samples with bacterial counts above the standard of 1000 cfu/100 ml for faecal coliform bacteria resulted from a system/design failure or from monitoring problems.

Chemical analysis:

Sample site PPOUT indicated that of all the samples analysed for NH_3-N (Table 3) only one sample (0.93 mg/l) was within the standard of 10 mg/l with the NH_3-N concentrations of the other samples ranging from 15.46 mg/l – 42.52 mg/l. The COD concentrations of samples ranged between 76 mg/l – 322 mg/l and only two samples (75 mg/l and 50 mg/l) complied with the standard of 75 mg/l. Analysis done for O-PO_4 showed only one sample (0.03 mg/l) complying with the standard of 1 mg/l, the other samples showed O-PO_4 concentrations ranging between 1.8

mg/l – 7.18 mg/l. Concentrations of NH_3-N for sample sites PPIN and PPOUT are given in the following figure 8:

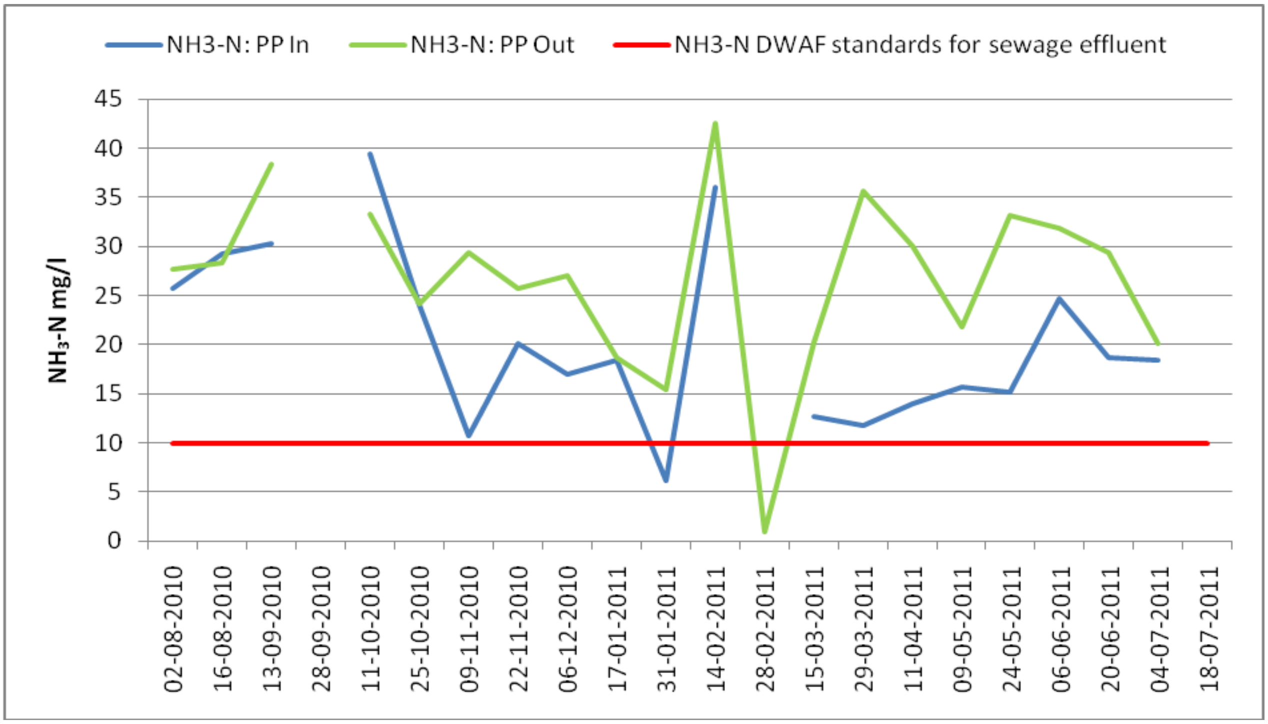

Figure 8: Concentrations of NH_3-N for sample sites PPIN and PPOUT.

From the above figure 8 it can be seen that site PPIN shows typical concentrations for raw sewage and the NH_3-N concentrations throughout the sampling period for site PPOUT remained extremely high and above the standard of 10 mg/l. Only one sample on the 28/02/2011 was below the standard with a concentration of 0.93 mg/l. **The majority of the samples had concentrations that did not comply with the standard indicating that the package plant does not sufficiently remove NH_3-N from the waste water.** Statistical analysis also confirmed this by indicating a high significant difference in the opposite direction, indicating that site PPOUT had higher concentrations than site PPIN. When the NH_3-N concentrations in the influent and effluent are compared (fig. 8) it is clear that the effluent leaving the treatment plant contains higher concentrations of NH_3-N than the influent (wastewater entering system), indicating that the NH_3-N is increasing in concentration within the treatment process instead of decreasing.

If one looks at the O-PO_4 concentrations in the effluent the same trend is seen. From figure 9 below, it can be seen that the O-PO_4 concentrations for sample site PPOUT throughout the 12 month sampling period remained high at concentrations above the standard of 1 mg/l. Once again only one sample on the 22/11/2010 had a concentration of 0.03 mg/l which is below the quality standard. **Thus the majority of the samples had concentrations that did not comply with the standard indicating that the package plant does not sufficiently remove O-PO_4 from the wastewater (a significant difference was also detected with the Wilcoxon tests).**

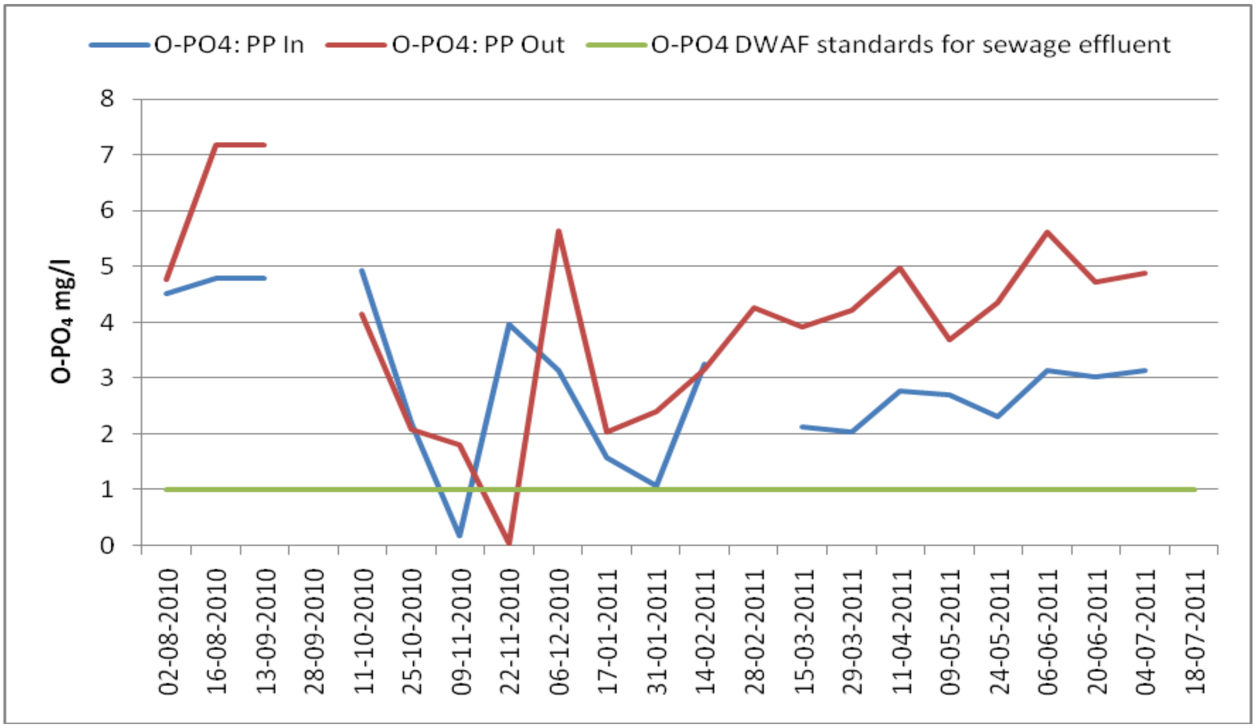

Figure 9: Concentrations of O-PO_4 for sample sites PPIN and PPOUT.

If the O-PO_4 concentrations of the incoming wastewater and that of the effluent are compared, the effluent shows higher concentrations than the influent in various samples, again, indicating that the system is not decreasing the O-PO_4 concentrations but instead increasing the levels.

Aerobic digestion takes place in the second part of the system (in the biotanks). Nitrification requires bacteria called *Nitrosomonas* and *Nitrobacter* bacteria that convert ammonia to nitrate and nitrite (Akunna et al., 1992). In the study done by Gaydon *et al*. (2007), it was determined that submerged biological contactor systems have a tendency to not successfully nitrify ammonia. Nitrification is the aerobic oxidation or biological removal of ammonia and nitrifying bacteria are considered to be the weakness of many waste water treatment plants (Wagner and Loy, 2002; Mirhossaini *et al.,* 2010). Microorganisms require oxygen to break down organic material. If more oxygen is used than produced/provided, the DO levels decrease, microorganisms weaken or die, thus, leading to improper treatment and the system becomes anaerobic (http://water.epa.gov/type/rsl/monitoring/vms52.cfm). The depth of the aerators in the bio tank also plays a role/influence the quality of the effluent. The deeper the aerator or level of wastewater in the biotank, the lower the air requirement is or the longer the contact time with oxygen bubbles is. The shallower the aerator or wastewater level in the tank, the more air is required to prolong the contact time with the oxygen bubbles. Due to diurnal problems and the fact that the system is operating at less than half of its capacity (system designed with capacity of 48kl/24 hours, currently running at 8-15kl/24 hours) the flow through the system is low and the level of wastewater in the tanks are low/shallow and, thus, more air is required to increase the contact time with the bubble path of the oxygen. Thus, there is not enough air provided and the microorganisms in the biotank weaken or die. From figure 10 below, it can be seen that the COD concentrations for various samples of site PPOUT are very high and above the standard of 75 mg/l, indicating that there is not enough oxygen in the system.

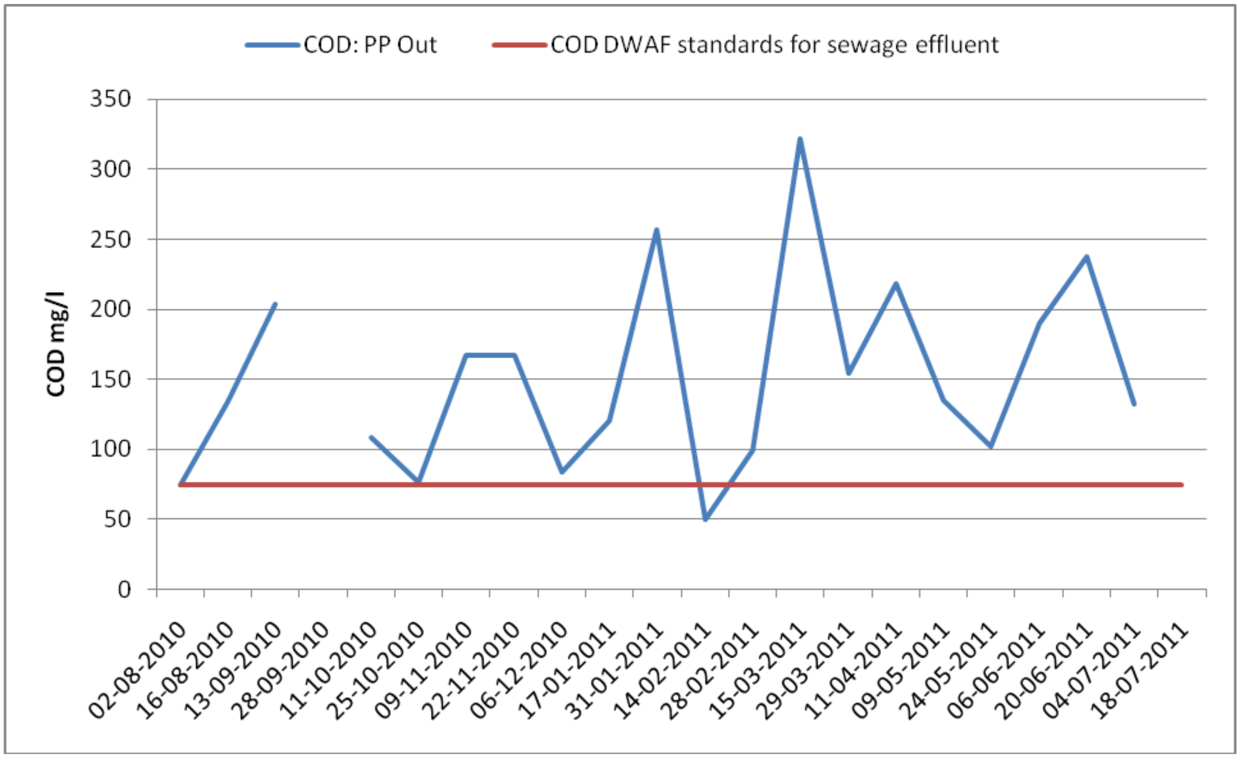

Figure 10: COD concentrations for sample site PPOUT.

This may be due to bio-film formation. Bio-film (i.e. microorganisms on the plastic filters) may detach and settles at the base of the biotank and form layers. The lower layers become anaerobic and nitrification may stop (because no oxygen is present) and denitrification may replace this process (under anoxic conditions) causing nitrates to be converted back to ammonia. This may explain the high levels of ammonia in the effluent and, in the process, also result in an increase in the COD concentrations in the effluent. Settled bio-film particles at the bottom of the tank can also leave the system with the effluent explaining the high SS concentrations in the effluent previously discussed. **Thus, adequate aeration is very important to the overall performance and efficiency of the submerged biological contactor systems** (Akunna *et al*., 1992; Isaacs and Henze, 1995; Damafakir *et al.*, 2009).

Conclusion

Package plant data highlighted a few problems with this treatment system. Previous literature indicates that package plant problems mainly occur within the design of the system as well as with poor construction, operation, maintenance and mechanical failures (Gaydon et al., 2007). The package plant studied for this research project is successfully removing the bacteria in the system/final effluent. At first there was concerns regarding large amounts of chlorine detected in the effluent and being discharged into the receiving river but after some changes was made in the design of the system (chlorine dispenser) this problem was overcome and chlorine levels were decreased whilst still maintaining bacteria concentrations below the standard. Thus the quality of the effluent with regards to the coliform bacteria concentrations are of good standard. There were only three accounts throughout the sampling period that showed spikes in coliform bacteria levels but this was due to system failure/design problems and these occurrences thus reinforces the importance of constant monitoring and maintenance of these systems so that problems can be detected immediately.

Flow/diurnals and oxygen problems seem to be the major factors affecting effluent quality. Diurnals can affect COD, nitrification, denitrification, settling and disinfection (Gaydon et al., 2007). High concentrations of ammonia, phosphate and COD were detected in the effluent. Too little flow and not enough oxygen in the bio-tanks caused nitrification (oxidation/breakdown of ammonia) to stop. Microorganisms responsible for the nitrification process die and forms layers at the bottom of the tank which then become anaerobic. The result: denitrification (production of ammonia) occurs as well as increasing COD levels in the effluent. Dead microorganisms/bio-film gets suspended in the effluent and leaves the system with the final effluent. A final polishing step such as the inclusion of a wetland can remove these remaining pollutants before the effluent is discharged into the river. Thus the effluent quality with regard to physical parameters is of good standard. The only quality concern for the package plant effluent is that of high concentrations of nutrients (ammonia and phosphate) and COD not being removed efficiently.

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