Pathogenic pollution of the Baynespruit

by

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Abstract

The status of the Baynespruit bacteriological water quality is very alarming - *E-coli* concentrations have far exceeded the allowable limit of both local and international guidelines for more than a decade, namely 2000-2010. Concentrations of indicator bacteria have been recorded as high as 2419000 cfu/100 ml, whereas guideline levels of *E-coli* for recreational contact are about 130 cfu/100 ml. In this study, statistical analyses were carried out on data from two sampling points to clarify the seasonal changes and the variability of the pollution. Cross-correlation analyses showed that there was no significant correlation between *E-coli* concentrations and rainfall in the uMsunduzi catchment. There was also only a weak correlation between the two sampling points which suggests the existence of unregulated sources of pathogenic water pollution between the sampling locations that are independent of the effect that rainfall has on dilution and dispersion of pollution. The data indicates that the population living along the Baynespruit has about a 2% risk of contracting gastrointestinal illness as a result of the pollution in the stream.

Declaration

I hereby declare that the research in this thesis, expect where otherwise indicated, is my original work. This thesis has not been submitted for any degree or examination at any other university. This thesis does not contain other persons‟ data, writings, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons. Where other written sources have been quoted, then:

- ✓ Their words have been re-written but the general information attributed to them has been referenced;
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This thesis does not contain text, graphics or tables copied and pasted from the internet, unless specifically acknowledged, with the source being detailed in the dissertation and in the references sections. This research is my original work conducted in the School of Civil Engineering, Surveying and Construction, Faculty of Engineering, University of KwaZulu-Natal, under the supervision of Prof.Dereck Stretch and Dr Kumarasamy.

Signature of student   Date

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As the candidate‟s Supervisor I agree/do not agree to the submission of this thesis.

Signature of supervisor   Date

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Prof.Dereck Stretch

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List of abbreviations

ANOVA	Analysis of Variation
BOD	Biological Oxygen Demand
CBD	Central Business District
CFU	Colony Forming Units
CO_2	Carbon dioxide
COD	Chemical Oxygen Demand
CMA	Catchment Management Agency
DUCT	Duzi-uMgeni Conservation Trust
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EPA	Environmental Protection Agency
EU	European Union
GM	Geometric Mean
MCMF	uMsunduzi Catchment Management Forum
SAGWQ	South African Guidelines for Water Quality
SEAF	Sobantu Environment and Agricultural Forum
SSL	Single Sample Limits
SSM	Single Sample Maximum
SPSS	Statistical Package for Social Science
TDS	Total Dissolved Solids
UKZN	University of KwaZulu-Natal
USEPA	United States Environmental Protection Agency
WHO	World Health Organization
WIA	Willowton Industrial Area (Pietermaritzburg)
WQ	Water Quality
WRC	Water Research Commission
WSA	Water Services Authority
WSP	Water Services Providers
WWTP	Waste Water Treatment Plant

CHAPTER 1: INTRODUCTION AND OVERVIEW

1.1 Introduction

The Baynespruit runs through the city of Pietermaritzburg, the capital of KwaZulu-Natal province in South Africa, and is the second largest city in the province. Founded in 1838, the city is a major producer of aluminum, timber and dairy products (Neysmith, 2008). Pietermaritzburg is set in the middle of the forested hills on rolling countryside in the midlands (Neysmith, 2008). With a population currently estimated at 750 845, Pietermaritzburg and its former townships together with surrounding areas were merged in 1994 to form the Msunduzi local Municipality (Neysmith, 2008). The Msunduzi local Municipality (WSA) and Umgeni Water (WSP) play important roles with regards to water pollution control and enforcement in the Baynespruit stream (Neysmith, 2008).

The Baynespruit rises in the Northdale suburb and flows through the Willowton Industrial Area (WIA). It passes through informal settlements and the Sobantu Township before it reaches its confluence with the uMsunduzi River (Neysmith, 2008). According to the results of weekly monitoring by the regional bulk water service provider (Umgeni Water) the Baynespruit is the most polluted stream in the uMsunduzi catchment. Raw sewage flows into the stream as a result of sewer overflows due to blockages, or from heavy rainfall bursting through manhole covers (Umgeni Water, 2002). Pollution also results from informal settlements in which residents have no toilet facilities and often use the stream banks as their toilets (Neysmith, 2008). Since 1990, *E-coli* levels in the Baynespruit have been above 5 000 cfu/100 ml for more than 70% of samples (Terry, 2008), and have at times been recorded as high as 610 000 cfu/100 ml (WRC, 2002). For comparison, the highest acceptable level of *E-coli* for swimming is set at 130 cfu/100 ml according to local standards guidelines (DWAF, 1996). Discharges of industrial effluent have resulted in fish kills, as well as blockages in the irrigation systems that some farmers in Sobantu use to water their vegetable gardens (Umgeni Water, 2002).

Published water pollution data in the WRC report (2002) relating to the Baynespruit stream indicate that the trends have not changed since 1990, despite the efforts that have been made to prevent pollution (Neysmith, 2008). In order to reduce pollution and improve the water quality of the Baynespruit stream, this research has to analyze the water quality data, carry out epidemiological studies and to implement mitigation measures. The present research focused on statistical analysis of pathogenic water pollution data and its effects on human health in the Baynespruit catchment.

1.2 Regulatory framework

It is necessary to understand the role of the national as well as local regulatory frameworks with respect to water quality. It is within this working environment that people dependent upon the Baynespruit water, such as small farmers and people settled along the stream, would act legally and interact with those who are responsible for stream pollution (Neysmith, 2008). Department of Water Affairs is the main policy coordinator and regulatory body, charged with implementing and administering the National Water Act of 1998. The DWA has the responsibility of overseeing both water quantity and quality planning and management, including effluent discharges (de Coning *et al.,* 2004). Under the Water Services Act of 1997, the DWA oversees the provision of drinking water and sanitation by municipalities (WSA) and their designated Water Services Providers (WSP). The DWA‟s regulations cover, *inter alia*, the control of "objectionable substances" entering storm water drains or watercourses, and the prevention of storm water from entering sewer systems (DWAF, 2002).

At the local level, Msunduzi Municipality is the main agency with jurisdiction over water-related powers and functions, including responsibility for sewer networks and industrial effluent bylaws for the city of Pietermaritzburg and its rural areas. Umgeni Water Amanzi, the regional water services provider, is a para-statal that conducts regular water quality testing, and supports the Municipality with regard to pollution monitoring and law enforcement of policies (Neysmith, 2008). While in theory this framework appears to provide comprehensive regulation of water quality, in practice, both the DWA‟s and the Municipality‟s implementation and enforcement activities have been limited by a lack of institutional capacity (Hamann and O‟Riordan, 2000; Pole, 2002). This is exacerbated by lack of coordination, poor clarification of roles among staff at the DWA, the Municipality and Umgeni Water, as well as confusion surrounding the roles of municipalities regarding enforcement and prosecution as set forth in the national legislation (Pole, 2002). It should be noted that the Umgeni Water Amanzi was the major provider of pathogenic water pollution data used in this research.

1.3 Need for research

Pathogenic water pollution has sent out an especially alarming signal due to *E-coli* concentrations that have become a chronic problem in the Baynespruit for 10 years or more (Neysmith, 2008). A number of factories spilling effluent for much of the time have repeatedly been discovered to be in violation of established discharge regulations, but prevention by legal means has been completely unsuccessful (Pole, 2002). A Catchment Management Forum for the uMsunduzi River, of which the Baynespruit is a tributary, was established in 1997. Representatives from the Sobantu Environmental and Agricultural Forum (SEAF), the Duzi-uMgeni Conservation Trust (DUCT) and regulatory agencies including DWA, Msunduzi Municipality and Umgeni Water are all represented, though there has not been regular participation from industry. The water quality status of the Baynespruit has been discussed at length by the uMsunduzi Catchment Management Forum (MCMF), but no effective action has been taken (MCMF, 2008). The state of the Baynespruit has been the subject of two research projects with respect to local water resources protection. According to Neysmith (2008), the research conducted by Pole (2002) that looked into the failure of the application of the "polluter pays principle" to industries polluting the Baynespruit was particularly informative but did not quantify pathogenic water pollution. It was then followed by Neysmith (2008) who took a step forward in pollution reduction in the Baynespruit, involving a multi-stakeholder participatory approach. But despite various awareness campaigns arising from this research to reduce pollution in the stream, and some publications in local newspapers, there has been no apparent improvement of the Baynespruit‟s water quality (Neysmith, 2008). Few research works has been done since to establish the current status of pollution in the Baynespruit. This study will provide awareness regarding pathogenic pollution and its effect on human health.

The vision guiding this research is therefore the formulation of a mitigation strategy to improve the water quality in the Baynespruit which will involve all those who use it, and those who monitor pollution, together with those who are the polluters and those affected by pollution. It is anticipated that this study will serve as a reference to anticipated future studies on the stream.

1.4 Problem statement

The current water quality status of the Baynespruit, in terms of *E-coli* concentration levels, is very alarming. It should be noted that previous initiatives, such as state prosecutions that were operating within the existing power and information structures failed to achieve lasting results (Neysmith, 2008). Instead the stream water quality has steadily declined with no sign of recovery. Due to the above, the following questions were asked:

- ✓ Can multivariate statistical analysis be used to clarify the source of pathogenic water pollution in the Baynespruit?
- ✓ How high is the health risk posed by pathogenic water pollution to those who live along the stream?

To answer these research questions, *E-coli* concentration changes were correlated with rainfall in the Baynespruit catchment. Statistical description and analysis of the stream water quality data was carried out, and the relationship between *E-coli* concentration at two sampling stations RSB001 (upstream) to and RSB002 (downstream) was investigated. Comparison of its water quality with local and international standard guidelines was carried out. Epidemiological studies to infer risks to the local population along the Baynespruit were carried out. Finally mitigation strategies for pathogenic water pollution in the Baynespruit were suggested.

1.5 Aims of the research

The overall aim of this research is to contribute towards the development of a mitigation strategy in order to improve the Baynespruit water quality. To achieve this, specific objectives were set as follows:

1. Compare the Baynespruit water quality with local and international standards water quality guidelines criteria ;
2. Investigate the health impacts of pathogenic pollution on the people that use the Baynespruit stream;
3. Assess trends in the stream pathogenic water pollution over the past decade 2000-2010;
4. Investigate the relationship between *E-coli* concentrations at two separated sampling points along the stream, and compare concentrations at the sampling points to rainfall patterns in the catchment area;
5. Propose mitigation measures to reduce or stop pathogenic water pollution in the stream.

1.6 Sequence of Chapters

- ✓ Chapter one is the introduction and overview of the research.
- ✓ Chapter two is the literature review.
- ✓ Chapter three is research design and methods.
- ✓ Chapter four is results and discussion.
- ✓ Chapter five is conclusions and recommendations.

1.7 Summary

This chapter qualitatively outlined the state of pathogenic pollution in the Baynespruit based in previous work, and described the regulatory frameworks involved in water quality planning and management. It articulated the need for studies and a problem statement, and described the aim of this research and the concepts involved.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Chapter two attempts to explain why pathogenic water pollution is a global rather than a unique problem to Pietermaritzburg‟s Baynespruit. It starts by defining pollution and reviews the general issues surrounding pathogenic water pollution. The characteristics of pathogenic water pollutants, their major sources, and factors that play roles in stream contamination are explained. This chapter explores the water quality standards guidelines applications in general, and comments on water quality assessment on a stream. Finally chapter two closes by describing water quality assessments, followed by a brief discussion and summary.

2.2 Defining pollution

In their concept definition of pollution, Chenje *et al.* (1996) stated that pollution should be considered as processes through which human beings contribute to the degradation of natural systems by adding detrimental substances such as sewage, heavy metals, pesticides and detergents etc. The above definition clearly indicates that pollution can take many forms, from the obviously visible (litter) to the less visible (organisms) that are often harmful contaminants. A simpler definition of pollution is that of Coetzee (1995), who defined pollution as the introduction of substances or energy by man into the environment. These substances or energy have the potential to cause hazards to human health or harm to living resources and ecological systems. They are also prone to damage structures or amenities and interfere with legitimate uses of the environment according to Mason (1990). Environmental pollutants exist in gaseous, solid or liquid form according to Santos (2008). He identified four general characteristics of environmental pollutants as follows:

- ✓ Pollutants are transboundary;
- ✓ Many of them are invisible pathogens or substances that cannot be degraded by living organisms and therefore may stay in the ecosphere for a long period of time;
- ✓ They destroy biota and habitat; and
- ✓ Formulation of international policy to contain them remains a big challenge due to the uncertainties about their negative effects on the environment.

High levels of pathogenic water pollution in the Baynespruit are the main reason for this case study. This type of pollution is mostly generated from sewage leaks into a natural watercourse, or disposal of fecal matter directly into the watercourse, or in exposed positions that will be later dispersed by runoff. *E-coli*, total coliforms and fecal *streptococci* counts are used in this research in order to assess pathogenic water pollution concentration in the Baynespruit.

2.3 Pathogens and indicator bacteria

Water transports, and allows, micro-organisms to survive and develop in it. *E-coli* are bacteria that originate from human or animal feces, and survive in water. They have the ability to grow in water under aerobic or anaerobic (= anoxic) conditions, for example in deep water, so are classified as facultatively anaerobic (Jones (a), 2010). This special adaptation to life in the water allows *E-coli* to freely sustain itself at any depth, unless the water is disinfected. Section 2.2 describes pollutants being trans-boundary, a characteristic well proven in the ability of *E-coli*. It does not require any means to regulate buoyancy to remain suspended in water (Jones (b), 2010). Waterborne pathogens consist of a wide range of bacteria and viruses that are not only difficult to identify but also to isolate. This has made the selection of pathogenic water pollution indicator bacteria difficult, especially nowadays where new technologies seem to challenge currently used methods of detection, and the correlation between the strength of indicator bacteria and human illness (Mass DEP, 2009). To simplify this challenge, coliform and fecal *Streptococcus* bacteria are commonly used indicators of potential pathogens in water bodies. The coliform bacteria group is composed of total coliforms, fecal coliform and *Escherichia coli* (*E-coli*).

Fecal coliform and *E-coli* bacteria are present in the intestinal tracts of animals that have warm blood. Fecal contamination of water and the possible presence of pathogens are detected by the presence of coliform bacteria (Mass DEP, 2009). The presence of fecal *Streptococcus* in the water body is also an indicator; the *Enterococcus* subgroup is more useful than fecal coliform because the *Enterococcus* die-off rate is much lower, which means that *Enterococcus* can remain in the environment for longer than fecal coliforms (Mass DEP, 2009). The groups of coliform and *Streptococcus* bacteria are given in figure 2.1. These bacteria live mostly in the intestinal tract of animals, and their presence in water is a better predictor of gastrointestinal illness infection.

In the "Ambient Water Quality Criteria for Bacteria – 1986" (USEPA, 1986), the USEPA suggests the use of *E-coli* or *Enterococcu*s as potential pathogen indicators in fresh water and *Enterococcus* in marine waters. This research will consider only fresh water and *E-coli* were selected as the main indicator of pathogenic water pollution because of the availability of data.

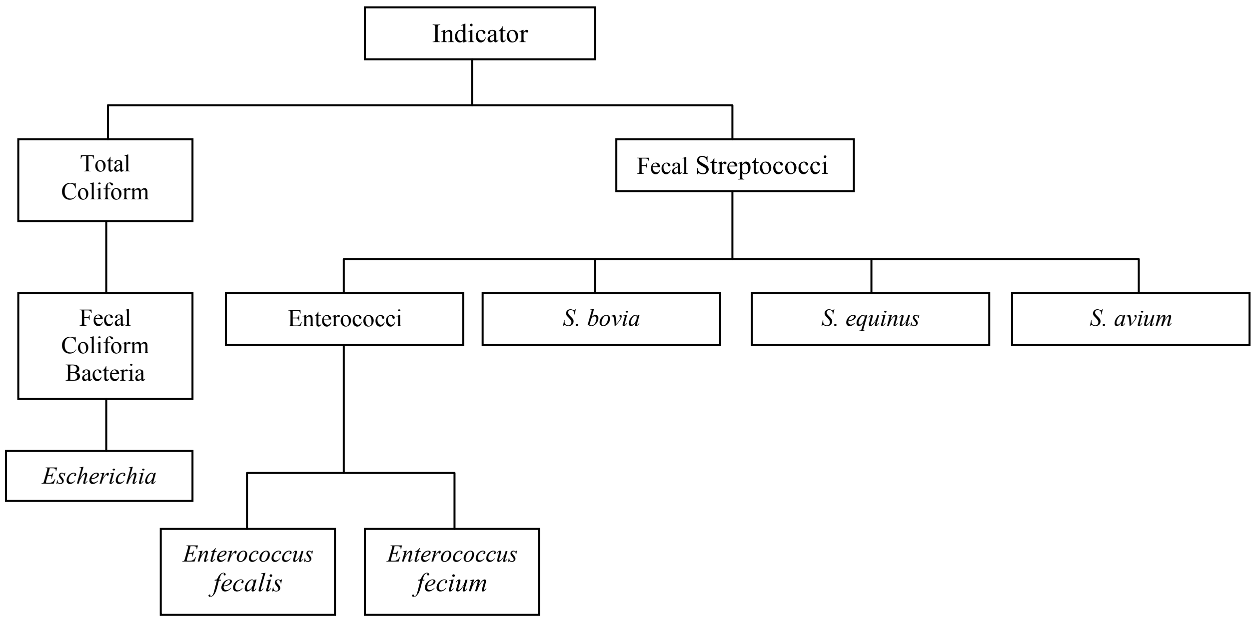

Figure 2-1 The relationship between pathogenic water pollutants indicators (USEPA, 1986)

2.4 Characteristics of pathogenic water pollutants

2.4.1 Introduction

Considering pathogen origins and behavior in general, and particularly those of *E-coli*, total coliforms and fecal *Streptococcus,* will help us understand pathogenic water pollutants in the Baynespruit. The word "pathogen" originates from Greek word "*pathos"* which means "suffering or emotion", and another "*gene"* which means "to give birth to". So pathogens are infectious agents that cause harm and diseases to human beings. Coliforms consist of a related group of bacteria (pathogens) as given in figure 2.1. They are found in two distinct situations:

- ✓ Human and animal waste (fecal in origin);
- ✓ Septic systems, sewage, animal yards, within the environment or vegetative soil, sediment, insects (Greenberg *et al.,* 1992).

Fecal *Streptococcus* originates from the intestines of warm-blooded animals. They are predominating in some excrements species, but not in others, with little to identify the source of fecal contamination (Ericksen *et al.,* 1983). Both *E-coli* and *Streptococcus* bacteria will be used in this research in order to establish the pathogenic water pollution level in the Baynespruit, and compare it with the national and international standards guidelines criteria.

2.4.2 Importance of testing for coliforms

Most studies had shown that the presence of coliforms may be associated with disease-causing organisms (Greenberg *et al.,* 1992). Two tests help to differentiate coliforms:

- ✓ The total coliform test theoretically helps to identify the presence of all coliform*s*, both vegetative and fecal in origin (Greenberg *et al.,* 1992)whereas;
- ✓ *E-coli* test indicates that the pollution is fresh from human or animal waste, and its strains may be deadly (Greenberg *et al.,* 1992).

The testing for fecal coliforms has potential to accurately locate the source of pollution in an aquifer or watershed and is used in monitoring the disinfection of treated waste water before its discharge into nature. Berg (1978) considers fecal coliforms as standard indicators of pathogenic pollution in wastewater and other waters. Fecal streptococci are indicators of pathogenic pollution in some situations also. Total coliforms, which form the core of the fecal coliforms or *E-coli*, are standard indicators of pollution in drinking water. Testing of coliforms is a major step in this research since it is a precursor to? The quantification of pathogenic pollution in the Baynespruit stream, and will help to establish the water pollution trends.

2.5 Major sources of pathogenic water pollution

2.5.1 Introduction

Pathogenic water pollutants can reach the aquatic environment when they are released into the environment, including the atmosphere and the soil, as dissolved substances or in the particulate form (Chapman, 1996). Pathogens such as *E-coli* (fecal coliforms) attach to particulate matter in order to be transported through the environment, and attachment to sediments may be the key to that process (Pegram *et al.,* 2001). The sources of pathogenic pollutants can be categorized as point sources and diffuse sources. Location of point and diffuse sources of pollution plays a key role in the mitigation of pathogenic water pollution.

2.5.2 Point sources

The major point sources of pathogenic water pollution originate from the collection and discharge of domestic wastewaters, industrial wastes, or activities such as animal husbandry (Chapman, 1996). This kind of scenario is common in the Baynespruit catchment area? Whereby a number of stakeholders, including the Municipality, might be discharging their waste (and wastewater) directly, producing plumes of pollutant into the stream.

2.5.3 Diffuse sources

Diffuse sources of pathogenic water pollution include water draining across the land or through the ground, picking up fecal matter, which can then be deposited in surface water bodies or groundwater. The water that carries diffuse-source pathogenic pollution is mostly the product of natural processes such as rainfall, or may originate from human activities such agricultural land irrigation (Harvey, 2010). This type of source is usually found spread out over a large area where it is difficult to trace the exact origins. This situation often occurs in the Baynespruit because the stream runs through almost the entire northern part of the uMsunduzi sub-catchment area where regular disposal of fresh fecally contaminated matter would be expected in drainage systems.

2.6 Loading of pathogens in stream water

2.6.1 Introduction

Pathogen loading rate in a stream describes the variation of concentrations discharged into the stream water. The assessment of pathogen loading rate is essential when comparing its water quality to local and international standards guidelines. Pathogen loading will be considered under the following headings:

- ✓ Impact of rainfall and runoff on pathogen loading in a stream;
- ✓ Importance of quantifying pathogen loading rate;
- ✓ Consequences of human activities on pathogen loading;
- ✓ Baynespruit‟s pathogen loadings analysis and;
- ✓ Pathogenic water pollution treatment options.

2.6.2 Rainfall and runoff impact on pathogen loading in a stream

Rainfall and runoff both play a major role on dilution and dispersion of pathogenic stream loading. For example, the intensity and duration of rainfall and its location dictate runoff flows and the concentration time at a catchment exit point downstream. This predicts when hygienic and microbiological examinations of watercourses are or could be carried out during or after a storm. After rainfall or snowmelt there are often high turbidity levels, reflecting shifting sediment, from flooding creeks in mountain ranges that could be interpreted as an indication of contamination due to microbes (Kistemann et *al.,* 2002). In the beginning of the rainy season, a phenomenon called" first-flush" of pollutants in the stream does occur (Stretch and Mordan). This simply means that during the dry periods pollutants do build-up in localized areas due to absence of runoff in the catchment. The above will then be flushed by runoff that occurs during rainfall events at the beginning of the rainy periods (Stretch and Mordan). The first flush conveys with it, concentrations of pollutants that have accumulated during the dry period between storms, to the stream. This can occur in one day or several months making it difficult to define accurately (Hager, 2001). The above explains why high levels of pathogenic water pollution are often observed in streams soon after the first rainfall.

2.6.3 Analysis of pathogen loading in a stream

It is necessary to quantify the different daily pathogen loadings in order to compare results with the national and international standards guidelines. Pollutant loading in a water body is expressed as either mass per time, or toxicity, or some other appropriate measure. Expressing the highest level of bacteria for a daily pathogens load is not that easy, when considering a very high number of bacteria indicators and the magnitude of the permissible load which usually depends on flow conditions (Mass DEP, 2006). In this research, *E-coli* count per volume will be used. This means that, given a particular population size of bacteria in the stream, water quality will vary with a change in flow rate. With a high flow rate, a small bacteria count may result, and fall outside the water quality standards limits (Mass DEP, 2006). With high flow rate dilution and dispersion are more likely going to take place in the stream. The difference between *E-coli* count at both points will indicate the presence of unregulated source of pollution in between the two sampling points or pollution accumulation around each sampling point.

2.6.4 Consequences of human activities on pathogen loading

USEPA (2004) states that the contamination of surface waters by fecal coliforms is most often caused by not properly managing human wastes, excrement from wild animals, including large flocks of birds, and pets, and manure applications in agricultural activities. The disposal of human and animal waste plays a major role in degrading aquatic ecosystems and has a negative impact on public health. It may even result in suspension or total closure of all health-related activities that would have benefited from the affected stream. These activities may include shellfish bed cultivation, swimming pools and drinking water supply (USEPA, 2004).

The Baynespruit has already faced the above-mentioned consequences where fishing activities are no longer practiced, swimming has been prohibited due the higher levels of *E-coli* in the stream, and the status is considered a health hazard as far as domestic use is concerned (Neysmith, 2008).

2.6.5 Baynespruit's pathogen loading analysis

Quinlan describe the Baynespruit as:" The Bayne‟s Spruit is all but dead. Industrial effluent … and human sewage regularly discharged into the stream … has killed off nearly all the life and oxygen there is. Experts have described the small tributary of the uMsunduzi River as „an open sewer" (Quinlan, 1993). The above passage shows how seriously the awareness campaign targeting sewage loading in the Baynespruit need to be carried out, and how serious pathogenic water pollution was and is still affecting the quality of its water. Neysmith (2008) also states that it is already 15 years since these words were written but no sensible change has been observed as far as sewage loading of the Baynespruit is concerned.

Neysmith‟s comments are also supported by Umgeni Water Amanzi in its weekly monitoring processes. It has found that the Baynespruit is the most pathogen-loaded stream in Pietermaritzburg. Raw sewage still flows into the stream because of sewer overflows caused by heavy rain, or blockages and breakage of sewer pipes, which run into the watercourse via manhole covers. In addition the informal settlers, lacking toilet facilities, often use the stream banks to dispose of fecal matter, and have been accused of contributing to stream loading by the WSP. Baynespruit water quality data collected has shown that the stream is extremely overloaded by pathogenic water pollutants as one of the parameters of water quality pollution indicators. For example, since 1990, *E-coli* levels in the Baynespruit have been above 5 000 cfu/100 ml, and have been recorded above 1 million cfu/100 ml on a number of occasions (Umgeni Water, 2008). This is far higher than the maximum safe level of *E-coli* for swimming which is supposed to be 130 cfu /100 ml (DWAF, 1996).

Omar *et al*. (2010) found that *E-coli* level in raw sewage was 9,690,000 cfu/100 ml and in effluent from a primary treatment unit in a conventional waste water treatment plant was 102,000 cfu/100ml. This shows that pathogenic water pollution in the stream is purely raw sewage. Umgeni Water Amanzi, alarmed by pollution in the Baynespruit, has gone as far as to publish, in 2002, that discharges of industrial effluent have resulted in fish kills, as well as blockages in the irrigation systems that some farmers in Sobantu use to water their vegetable gardens. As consequence, the stream had been considered as severely impacted with a median South African Scoring System (SASS) score below 3. This level ranked the stream as having a very poor ecosystem health rating (Terry, 2008).

2.7 Human health risk due to pathogenic pollution

Pathogenic water pollutants cause many water-borne diseases such as cholera, etc. These types of diseases are found mostly in rural areas because of the lack of sanitation facilities in most *cases,* or where the watercourses are vulnerable to fecal contamination. *E-coli* is the main indicator that is used worldwide to confirm pathogen presence in water. This indicator can only survive for short periods of time in the environment, so it is used as an indicator of recent_fecal contamination in a watercourse (Ericksen *et al.,* 1983). USEPA (2003) warns of the risk of diseases caused by these pollutants, and suggests that contact with water contaminated by them can lead to ear and skin infections or respiratory diseases. Pruss (1998) compared a number of epidemiological studies that had been carried out and found that in both marine and fresh water, a concentration of 30cfu/100ml of indicators such as *E-coli* would significantly increase the risks of gastro-intestinal infection to the water users. Harding (1993) noted also that swimmers in polluted water were exposed to significantly higher risks of contracting swimming-associated ear, eye, skin and gastro-intestinal illnesses. Nataro *et al*. (1998) on the other hand, states that *E-coli* strain was found to be a significant cause of gastro-intestinal disease in the last century and suggested that an increase of *E-coli* in surface water would increase health risks to its users. However, Harding (1993) and Nataro (1998) did not provide the rate of *E-coli* concentration to the exposed population.

It is in the USEPA guidelines that significant correlation between *E-coli* level in fresh water and the occurrence of illness related to swimming had been proven (DWAF, 1996). Being a highly selective indicator, *E-coli* cause gastrointestinal illness. This type of disease is characterized by diarrhea made of frequent and watery bowel movements, mostly caused by gastrointestinal infections. These symptoms may also come from other illnesses caused by germs, parasites, viruses, or bacteria, or from poor sanitation and hygiene, or changes in diet (DWAF, 1996). Pathogenic water pollution also renders water unsuitable for use in the irrigation of crops for consumption, and irrigation of land for dairy cow grazing (DWAF, 1996). Exposure to these bacteria has health impacts, recreational impacts and economic impacts such as potential loss of revenue, clean-up costs and medical costs (DWAF, 1996).

2.8 Application of water quality standards guidelines

2.8.1 Introduction

Water quality guidelines standards have been put in place in order to mitigate pollution. These guidelines are not only important for this research, but are very useful in our day-to-day life where water quality is concerned. The World Health Organization (2010) defines safe water as that which does not have any risk to health over a lifetime of consumption or use. In order to measure the risk level in water, the water quality standards guidelines criteria have been selected per water quality parameter, and put in place nationally and internationally as reference for any water usage. To clearly understand the impact of water quality standards guidelines, the South African and international Water Quality Guidelines will be described and applied to the Baynespruit.

2.8.2 The South African guidelines for water quality (SAGWQ)

The South African water quality standards guidelines are made for domestic, recreational, industrial and agricultural water uses; there are guidelines for the protection of the health and integrity of aquatic ecosystems as well as guidelines for the protection of the marine environment. The DWA uses these standards guidelines criteria as its main source of information and decision-making support to judge the fitness of water for use and for other water quality management purposes (DWAF, 1996). These guidelines are much the same as international ones, but adapted to local conditions. The information does not only provide the ideal water quality conditions for water uses, but also provides background information that helps users of these guidelines to make informed judgments about the water fitness. This is measured using standards criteria that provide scientific and technical information for a particular water quality constituent in the form of numerical data and/or narrative descriptions of its effects on the fitness of water for a particular use or on the health of aquatic ecosystems (DWAF, 1996).

In the Baynespruit case study, pathogenic water pollution is the key pollution type. The South Africa water quality guidelines consider only *E-coli* as an indicator of pathogenic water pollution (DWAF, 1996). More details on the use of the South African water quality standard guidelines will be provided in chapter three.

2.8.3 United States EPA water quality guidelines

The United State Environmental Protection Agency put in place the environmental assessment program in order to reduce risks caused by pathogens to human health. These guidelines focus on recreational water, coastal and health programs since 1997 (USEPA, 2003). These guidelines are very important since surveys and current scientific studies continue to prove the presence of pathogens in water, or the potential of harmful bacteria, viruses, and other types of pathogens present in local stream water, originating primarily from sewerage overflow and sometimes from storm-water runoff (USEPA, 2003).

The Baynespruit is an example, judged by counts of *E-coli* and other pathogens, that has fallen below the standards guidelines requirement since 1990, and has a level of pollution qualified as hazardous for any person who depends on the use of stream, and for communities that live along the stream. Here are the five areas that the Beach Environmental Assessment and Coastal Health (BEACH) program focuses on to improve public health and environmental protection for those who go to the beach, and provides the public with information about water quality (USEPA, 2003):

- ✓ Strengthening (BEACH) standards and testing;
- ✓ Providing faster laboratory test methods;
- ✓ Predicting pollution;
- ✓ Investing in health and methods research;
- ✓ Informing the public.

USEPA guidelines for domestic, agricultural and aquiculture waters (USEPA, 1986) state two criteria: one for fresh water and the other for marine or recreational waters. Present research on the Baynespruit focused on fresh water criteria only.

Based on a statistically sufficient number of samples (generally not less than 5 samples equally spaced over a 30-day period), the geometric mean of the indicated bacterial densities should not exceed one or the other of the following as criterion one of the USEPA:

- ✓ *E-coli* 126 per 100 ml; or
- ✓ *Enterococcus* 33 per 100 ml.

The second criterion is a single sample limit (SSL) that should not be exceeded by any sample. The SSL is set by the equation that uses the geometric limit (GM) and a factored log-standard deviation value. Based on a site-specific log standard deviation, or if site data are insufficient to establish a log standard deviation, then using 0.4 as the log standard deviation for both indicators (USEPA, 2003), no sample should exceed a one-sided confidence limit (C.L.) as detailed in chapter three.

USEPA (1986) stipulated a total fecal coliform geometric mean of 200cfu/100 ml with upper single sample fecal coliform of 400cfu/100 ml. The USEPA and the SAGWQ have nearly the same quality monitoring instructions.

2.8.4 European Union water quality directive

The EU standards guideline is one of the international water standards guidelines criteria that suit the ranking of the Baynespruit water quality together with the outcomes to the South African water quality standard guidelines when assessing the stream water quality. The European Union water quality directive considers water as a precious natural resource that has to be protected and managed with care (European Council and Parliament, 2006). The EU guideline procedure is based on the assumption that indicator concentration is log-normally distributed. The EU guidelines are consistent with the recently updated World Health Organization guidelines (WHO, 2001). Article 3 of the EU water quality guidelines specifies how important it is to monitor the bathing water quality by selecting monitoring points and a water quality parameter to be observed within the standards guideline limits. It also suggests a calendar that has to be established and carefully followed in such a manner that it will be possible and practical to track pollution. This process simply helps to quantify water pollution in general and pathogenic water pollution in particular.

2.9 Statistical analysis

Statistical analysis is a very useful tool in any type of research since it helps to describe, analyse and provide scientific interpretation of data surveyed in the environment. Mardon and Stretch (2004) used this tool in their study while comparing the Durban beaches water quality to local and international water quality standards guidelines.

Mardon and Stretch (2004) collected samples of the Durban beach water designated for full and non-full contact. They statistically analyzed Durban beach pathogenic water pollution levels, assessed and compared its water quality to the standard guidelines. Mardon and Stretch (2004) found that 8 out 10 beaches are currently poor according to international guidelines according to annual statistics. They also found the local standard guidelines to be inconsistent with the USEPA and EU guidelines because of the absence of enterococcus criteria in the local standards limits. It should be noted that this criteria plays a significant role where pollution loadings are low. Mardon and Stretch (2004) recommended that the local water quality standard guidelines should be updated.

Although steps have been taken into campaign awareness to promote the sustainability of the stream none of the research and works carried out on the Baynespruit had statistically analysed its pathogenic water pollution. For example, Pole (2002) looked at factors that prevented the “Polluter pays principle” from being successful. Neysmith (2008) on the other hand investigated non-regulatory barriers and incentives to stakeholder participation in the Baynespruit. Both pieces of research were particularly informative from a legal and social aspect but did not provide any scientific insight into preventing the stream pollution. Umgeni Water had managed to set sampling points in the uMsunduzi catchment and had carried out water quality sampling and data processing with no statistical analysis.

Since previous research on the Baynespruit was mostly qualitative, there has not been a significant volume of research generated on pathogenic water pollution mitigations in the Baynespruit using statistical tools. Thus this study will attempt to assess pathogenic water pollution using statistical analysis and SPSS software as tools.

2.10 Summary

Chapter two reviewed the relevant literature on pathogenic water pollution in the Baynespruit and national and international standard guidelines. It outlined the significance of *E-coli's* negative effects on water quality in general and on the Baynespruit in particular. It defined pathogenic water pollutant, its characteristics, sources and loading in to the stream. This chapter looked at the significance of health risks associated with *E-coli* levels in the Baynespruit and, related them to the population that depends on stream water. The literature review provided the basis for the design and methods described in chapter 3.

CHAPTER 3: RESEARCH DESIGN AND METHODS

3.1 Introduction

This chapter describes the study area in which the Baynespruit flows, the sources of data, the analysis techniques and methods used in this study to establish the mitigation measures for water pollution management. It introduces the measuring instruments and describes research procedures. It concludes with how the data interpretation and analysis will be undertaken? The research is subdivided into three sections as follows:

- ✓ The selection of water pollutants;
- ✓ The water quality standards guidelines;
- ✓ The source of data.

The following water quality guidelines are used:

- ✓ The South African water quality guidelines;
- ✓ The USEPA ambient water quality guidelines for bacteria and;
- ✓ The European Union water quality directive.

3.2 Study area

The Baynespruit is entirely located within the Pietermaritzburg city‟s urban area, as seen in Figures 3.1 and 3.2. This stream has its source in residential areas of Northdale and Raisethorpe on the northern side of Pietermaritzburg. It flows south through the Willowton Industrial Area, passing through formal and informal settlements in west Eastwood. The community of Sobantu is the last to be crossed by this stream before merging with the main uMsunduzi river (Neysmith, 2008). According to figure 3.2, there are monitoring points at nearly every uMsunduzi river tributary in the catchment area but, the Baynespruit has only two sampling points as shown in figure 3.1, RSB001 and RSB002, spaced 2 km apart. The existence of only two sampling points sets the limits to this study.

This study also refers to the Sobantu community as the most exposed to the stream‟s hazards, because they are located on the last part of the river downstream. It should be noted that the Sobantu community is a disadvantaged group of population due to poverty. The Sobantu population is dependent on the Baynespruit as a source of water for gardening or small-scale agricultural farming, sometimes fishing and some domestic use (Neysmith, 2008). This circumstance makes the Baynespruit an ideal subject when comparing its quality to standards guidelines criteria to ascertain if the stream water is fit for use. Figure 3.2 and 3.2 shows the sample sites in Pietermaritzburg including RSB001 and RSB002. Figure 3.3 shows the photo of a portion of the Baynespruit between the two sampling points revealing stagnation of water in some area of the stream. Figure 3.4 shows the confluence point between the uMsunduzi and the Baynespruit and figure 3.5 shows litter floating in the stream revealing how the Baynespruit is seriously polluted.

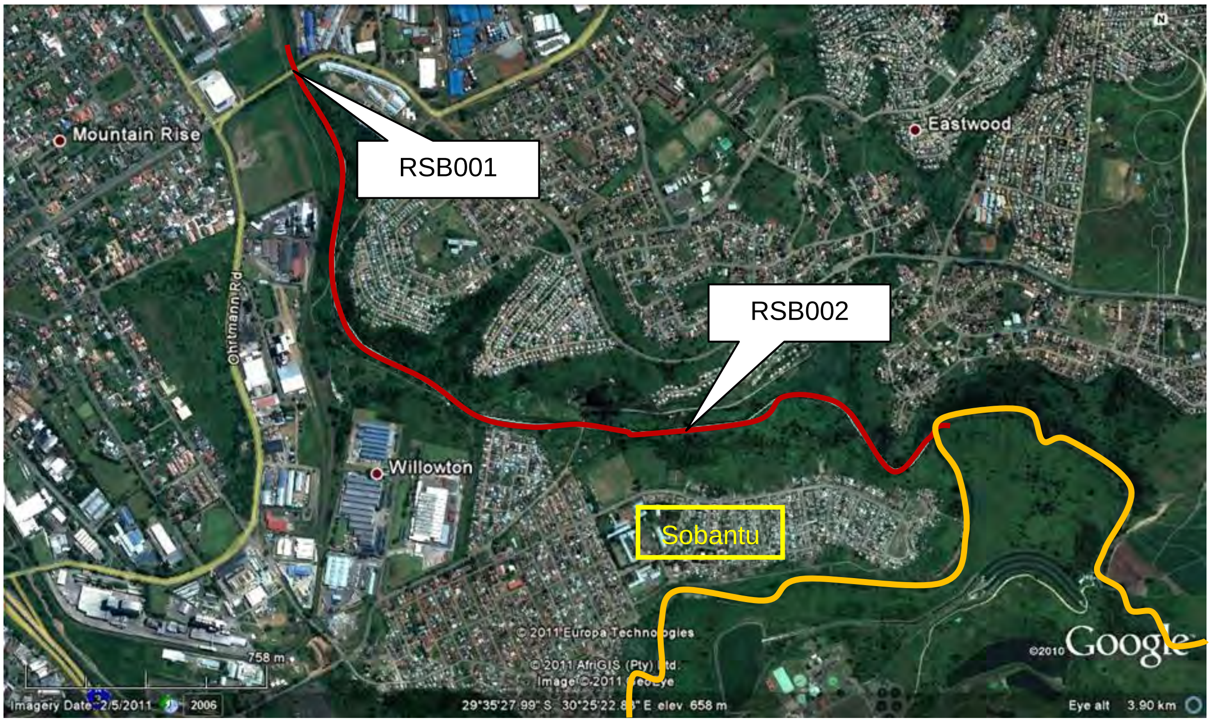

Figure 3-1 Map of the Baynespruit's catchment area with the Baynespruit in red (uMsunduzi River in yellow) Source: Google Earth (Arial photo courtesy of Msunduzi Municipality, 2011)

3.3 Demographics of the study area

The only source available for the residential population count in the Sobantu area is the South African census (Stassa, 2001), which estimated a population of 12 532 in 2001. Levels of education were projected at 54% for those residents having secondary education level, and 53% of the total of educated people were employed at that time. Nearly 8000 residents had no monthly income, and 2200 residents had a monthly income of R1600 or less. These statistics are not complete since they focus only on the lower part of the Baynespruit population distribution and thus this would be one of the short comings in this thesis and would form part of future research on the Baynespruit‟s water. Many of the Sobantu residents work in the factories from the Willowton Industrial Area (WIA), where 24 companies are located along the stream. Some are independent, and others are subsidiaries of national or even multinational operations (Neysmith, 2008).

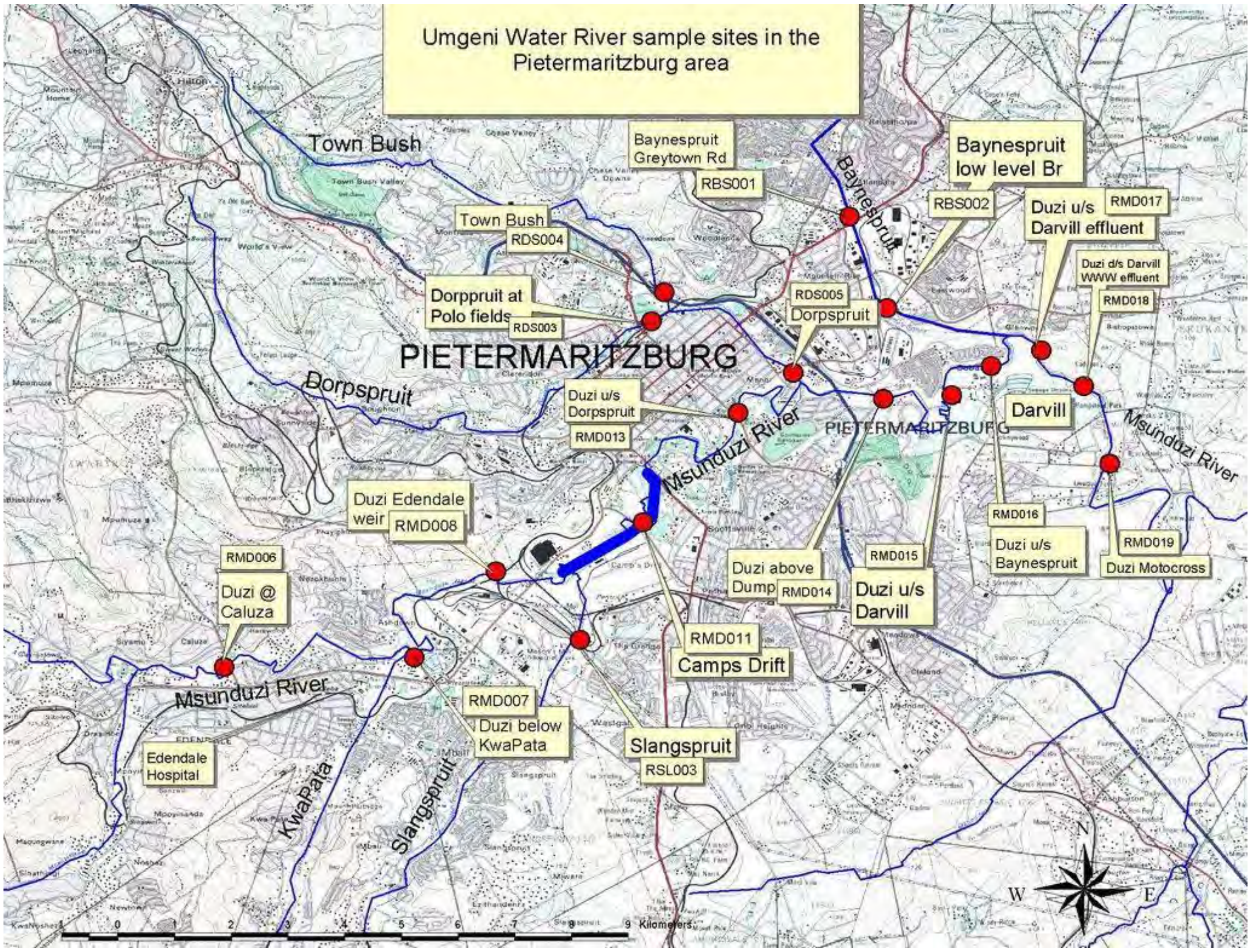

Figure 3-2 Umgeni water sample sites in Pietermaritzburg area. Source: S.Terry, Umgeni Water

3.4 Research methods

The aim of this research is to formulate a mitigation measure strategy that will be used to reduce or stop pathogenic water pollution in the Baynespruit stream, improve the water quality, and reduce risk levels to communities that use the Baynespruit. Therefore it is useful to set as dependent variables the raw water pollution, and rainfall trends in the catchment area as the independent variable in order to carry out statistical analysis. The water quality standard guidelines criteria will be used as reference points when evaluating the fitness of the Baynespruit water quality for consumption/use. Pathogenic water pollution results and their relation to rainfall will be analyzed using graphs and scatter plots.

3.4.1 Source of data

The Baynespruit water quality monitoring and assessment started in the early 1990s and is conducted by Umgeni Water Amanzi. This para-statal conducts regular water quality testing and supports the Municipality with pollution monitoring. Umgeni Water Amanzi has established a number of sampling points in the uMsunduzi catchment among which RBS001 and RBS002 sampling points were considered for this study. Most of the data used in this research were provided by the Umgeni Water Amanzi, the water services provider in the uMsunduzi sub-catchment area where the Baynespruit stream is located.

Figure 3-3 Photo of the Baynespruit taken between RSB001 and RSB002 showing that water was stagnant in some area along the stream

The raw data were collected from two sampling points RBS001 and RBS002, established by Umgeni Water Amanzi. These points are spaced 2 km from each other and play a major role in the Baynespruit‟s water quality quantification. Data were sampled from 2000 to 2010 with a frequency of four to seven sampling days per week. Other information, such as rainfall data collected over the decade, was provided by the DWA. The rainfall data were collected at three different stations in the Umgeni catchment area. The available (historical) data and literature provided here will be used to validate the reliability of the findings in order to provide the recommendations detailed in chapter five.

3.4.2 Severity of the Baynespruit's pathogenic water pollution

Most water quality guidelines manuals suggest that when pathogenic water pollution is acute then statistics analysis must be based on extreme values, like the maximum or the 95th percentile. The results must be compared to the water quality standard criteria provided in the manuals. On the other hand if the effects appear to be mostly chronic then estimates of the average, most likely the median value have to be considered (DWAF, 1996). To establish whether the effect of pathogenic water pollution was acute or chronic, the following techniques and assumptions were used in the data analysis:

- ✓ Plot the key raw data based on annual Baynespruit water quality survey against sampling dates using logarithmic scale base 10;
- ✓ Check if there was a linear or non-linear behavior of the pollution generated on daily basis when analyzing the graphs;
- ✓ If the trends appears to behave linearly then the effect is considered chronic and, estimates of the average values such as the median will be used during the statistical analysis;
- ✓ If the trends appears to behave non-linearly then the effect is considered acute and, estimate of extreme values such as the maximum or the 95th percentile will be used during the statistical analysis;

3.4.3 Water quality standards guidelines criteria

The water quality standards guidelines criteria were introduced in chapter two. These guidelines will be used in order to assess the fitness of the Baynespruit water quality. In order to clearly explain their importance in this research, the concept defined in the importance of testing coliforms will be combined with the water quality standards guidelines applications. The assessment of the Baynespruit water quality will be carried out by measuring the stream pathogenic water pollution at RBS001 and RBS002 sampling points, by processing the key raw data and comparing the results to the standards guidelines criteria set in the follows manuals:

- ✓ The South African water quality guideline (Volume 8; Field Guide) (DWAF, 1986);
- ✓ The Ambient Water Quality Guidelines for Bacteria (USEPA, 1995);
- ✓ European Union water quality directive of 2006 (European Council and Parliament, 2006).

The above methods will set the baseline of the constituent‟s effects on stream water quality as it varies from acute to chronic. The outcomes of statistical analysis will be used to classify the fitness of Baynespruit stream water uses.

3.4.3.1 The South African water quality guidelines criteria

South Africa water quality guidelines consider *E-coli* alone as an indicator of pathogenic pollution (DWAF, 1996). These guidelines have two limits for enumerated *E-coli* for full and intermediate contact or recreational waters that are specified as follows:

- ✓ Less than 20% of samples to exceed 100cfu/100 ml;
- ✓ Less than 5% of samples to exceed 2000cfu/100 ml.

Besides the above criteria, the guidelines do not set any limits for other use or the specific sampling frequency. This approach simply suggests that the South African water quality guidelines criteria can be applied to any sample set of data which is grouped on a monthly basis, seasonally or yearly. It should be noted that before applying the above mentioned criteria, the stream water quality have to be analyzed and the constituent‟s effects on stream water quality will be established according to the following assumptions:

1. In case the effect is acute then statistical analysis on an extreme value like the 95^{th} percentile should be applied and;
2. In case the effects are mostly chronic then estimates of the average will be applied as the median value;

After establishing the type of Baynespruit pathogenic water pollution constituent effects, a detailed analysis of the stream *E-coli* concentrations at RBS001 and RSB002 will be carried out using the two criteria already mentioned in this section.

3.4.3.2 The USEPA ambient water quality guidelines for bacteria

The United States Environmental Protection Agency guidelines for domestic, agricultural and aquaculture waters (USEPA, 1986) provide two criteria that apply to fresh water and marine or recreational waters. Only fresh water criteria will be used here since the Baynespruit water is mostly used for the irrigation of vegetables and micro-farming purposes. It should be noted that the geometric mean of the indicated bacterial densities will be based on a statistically sufficient number of samples and, must not exceed one or the other of the following as criterion one of the USEPA as reviewed in section 2.8.3:

- ✓ *E-coli* 126cfu/100 ml; or
- ✓ *Enterococcus* 33cfu/100 ml;

Any exceeding of these criteria will lead to the failure of the water quality standards based on the USEPA standards. The second criterion is a single sample limit (SSL) that should not be exceeded by any sample. The SSL is set by the equation below using the geometric limit (GM) and a factored log-standard deviation value.

Figure 3-4 Photo of the confluence point between the uMsunduzi and the Baynespruit

$$SSL = GM * 10^{[CL*Log\sigma]} \quad (3\text{-}1)$$

Sources: USEPA (1986)

Whereby SSL means Single sample limit;

GM is the Geometric mean of the indicated bacterial densities;

CL is the Confidence level factor;

Log σ is the Log standard deviation constant equal to 0.4;

Based on a site-specific log standard deviation, or if site data are insufficient to establish a log standard deviation, then 0.4 is used as the log standard deviation for both indicators (USEPA, 2003). No sample should exceed a one-sided confidence limit (C.L) calculated using the following confidence level factors:

- ✓ Designated bathing beach (75^{th} percentile) equal to 0.675;
- ✓ Moderate use for bathing (82^{nd} percentile) equal to 0.935;
- ✓ Light use for bathing (90^{th} percentile) equal to 1.280;
- ✓ Infrequent use for bathing (95^{th} percentile) equal to 1.650;

More details are given in appendix 2.

USEPA (1986) stipulated the total fecal coliform geometric mean of 200cfu/100 ml with upper single sample fecal coliforms of 400cfu/100 ml. The applications of statistical analysis are very critical in the USEPA guidelines and more details are provided in section 3.5.

3.4.3.3 European Union water quality directive

The EU guidelines (European Council and Parliament, 2006) specify 90^{th} or 95^{th} percentile limits for *E-coli* and *Enterococcus* in bathing waters. They require a set of data sampled in three consecutive years. Table 3-1 below gives the summary EU guidelines.

Table 3-1 Summary of the 2006 EU bathing water quality criteria

2006 EU bathing water quality criteria		
Criteria	***E-coli* standard guideline limits criteria**	***Enterococcus* standard guideline limits criteria**
Excellent "E"	95 Percentile evaluation of data should not exceed 500 cfu/100 ml	95 Percentile evaluation of data should not exceed 200 cfu/100 ml
Good quality "G"	95 Percentile evaluation of data should not exceed 1 000 cfu/100 ml	95 Percentile evaluation of data should not exceed 400 cfu/100 ml
Sufficient "S"	90 Percentile evaluation of data should not exceed 900 cfu/100 ml	90 Percentile evaluation of data should not exceed 330 cfu/100 ml
Poor quality "P"	90 Percentile evaluation of data exceeds 900 cfu/100 ml	90 Percentile evaluation of data exceeds 330 cfu/100 ml

If the bathing water is subject to short-term pollution or, last assessment period then,

- ➢ [1] "Last assessment period" means the last four bathing seasons or, when applicable, the period specified in Article 4(2) or (4) in the EU guideline manual;
- ➢ [2] Calculate the standard deviation of the log10 values (σ).The upper 90-percentile point of the data probability density function is derived from the following equation (European Council and Parliament, 2006):
- ▪ Upper 90-percentile = antilog (μ + 1,282 σ)……………………………………………........(3-2)

The upper 95-percentile point of the data probability density function is derived from the following equation (European Council and Parliament, 2006):

- Upper 95-percentile = antilog (μ + 1, 65 σ)……………………………………………….(3-3)
- [3] "Worse" means with higher concentration values expressed in cfu/100 ml;
- [4] "Better" means with lower concentration values expressed in cfu/100 ml;

Where μ is the mean of the sample and;

σ is the standard deviation;

In this study, *E-coli* is the only indicator that had a complete data set suitable to establish the Baynespruit water quality status when using the 2006 EU guidelines.

Figure 3-5 Photo showing solid waste floating on the Baynespruit surface water

3.4.4 Evaluation of *E-coli* effect on human health

The effects of *E-coli* on human health were studied and developed by the USEPA and later on used by the South African water quality standards guideline criteria to set the standard criteria guidelines as follows (DWAF, 1996):

- ✓ The range of *E-coli* counts from 0 cfu/100 ml to 130 cfu/100 ml is considered as low risk of gastrointestinal illness from contact with recreational water according to the South African standard guidelines criteria. Its effect is expected not to exceed a risk of typically less that 8 illnesses per 1000 swimmers (DWAF, 1996);
- ✓ The range of *E-coli* counts from 130 cfu/100 ml to 200 cfu/100 ml is considered slightly risky for gastrointestinal effects among bathers, and gastrointestinal illness may be expected (DWAF, 1996);
- ✓ The range of *E-coli* counts from 200 cfu/100 ml to 400 cfu/100 ml is considered as highly risky for gastrointestinal effects to swimmers, particularly if frequent. It is recommended that resampling be conducted if individual results exceed 400 cfu/100 ml (DWAF, 1996);
- ✓ The range of *E-coli* counts exceeding 400 cfu/100 ml causes health risk to increase as *E-coli* counts levels increases. Gastrointestinal illnesses are supposed to increase approximately according to the following relationship extracted from the USEPA epidemiological studies (DWAF, 1996).

$$Y = -150.5 + 423.5(\log x) \quad \text{(3-4);}$$

Where by Y means illness rate/100 000 persons and;

X means number of *E-coli*/100 ml;

Equation (3-4) will be used to interpret the observations made in section 4.7.2.More details are given in appendix 5.

3.4.5 Dilution and dispersion of the Baynespruit's *E-coli* concentrations

In establishing the sources of pathogenic water pollution in the stream the following questions were asked:

- ✓ Are there effects of dilution, dispersion, and decay processes of *E-coli* in the Baynespruit stream?
- ✓ Can these processes be used in the mitigation of pathogenic water pollution in the Baynespruit stream?

In response to the above questions, section 2.6.2 revealed that rainfall and runoff both had an influence on water pollution since both play a major role in dilution and dispersion of pathogenic water pollution. This must be allowed for when hygienic and microbiological examinations of watercourses are carried out during or after a storm. In this section data will be treated as follows:

- ✓ Rainfall data from 2000 to 2010 will be averaged, see appendix 3. This will narrow down monthly rainfall data to twelve values for each year. Then their median value will be calculated to provide one figure that will represent average rainfall data for each month in the decade 2000-2010.
- ✓ Monthly *E-coli* count at RSB001 and RSB002 will be summarized and narrowed down yearly *E-coli* count by providing to twelve values for each year. Then their values will be calculated to provide figures that will represent median and extreme *E-coli* count for each month in the decade 2000-2010.

3.5 Measuring instruments

3.5.1 Introduction

The measuring instruments were selected to suit the type of pathogenic water pollutant indicators detected in the Baynespruit stream. These indicators are coliform group, composed of some general bacteria species such as S*treptococcus* that share the same biochemical and morphological attributes including gram negative, on-spore forming rods, most of which lactose in 24-48 hours at 35^0C. The evaluation of these parameters uses the same measuring procedures and the same instruments.

3.5.2 *E-coli* results and analysis

E-coli counts from water samples collected at RSB001 and RSB002 in the Baynespruit stream were analyzed using the following general rules to calculate the *E-coli* or cfu/100 ml of sample:

- ✓ Select and count filters with number 200 target colonies per plate;
- ✓ Select and count filter with number 100 target colonies (ideally, 20-80).
- ✓ Calculate the final values using the formula:

$$E - coli = (NFC) * 100 \quad \text{(3-5);}$$

Whereby is measured in cfu/100 ml;

NFC means Number of fluorescent colonies/100 Volume of sample filtered (ml)*100;

$$E - coli = (NFC + NB) * 100 \quad \text{(3-6);}$$

Whereby NB means Number of blue, non-fluorescents colonies (if any)/volume of sample filtered (ml)

More details are provided in the USEPA Microbiology Manual, Part II, Section C, 3.5, for general counting rules and the results will be reported as *E-coli* or cfu/100 ml of drinking water (USEPA, 2003).

3.5.3 Colilert Method

Umgeni Water uses the colilert method for the *E-coli* counting. According to the American Public Health Association (2004), the colilert method requires the use of a special incubator that seals the following particular specialised tray:

- ✓ Quanti-Tray provides counts from 1 to 200 Most Probably Number /100 ml of undiluted water sample and;
- ✓ Quanti-Tray/2000 provides counts from 1 to 2,400 Most Probably Number /100 ml of undiluted water sample;

Both tests are meant to provide a wider range when diluting the sample with sterile distilled or deionized water at a ratio of 1:10 or 1:100. This method can produce *E-coli* counts up to 2 400 000 cfu/100 maximum with four significant digits (American Public Health Association, 2004).

3.6 Data interpretation and analysis

The first step in the statistical analysis processes will be to summarize the Baynespruit pathogenic water pollution and rainfall data. This step starts by organizing the data as a recording sheet in the form of tables as shown in appendix 1 from table 1 to table 20. The above mentioned step will yield to the plotting of raw data based on annual Baynespruit water quality surveys in order to establish whether the data were acute or chronic, referring to the proposed procedure in previous sections, and set the way forward to achieve the fourth specific objective of this research. The expected output from this method is that all the Baynespruit raw water data will be organized in tables in such manner that the results would be manipulated easily.

The second step is statistical description of the data as shown in table 4.1. In this step, frequencies will be established as a starting point in order to establish the probability distribution function for pathogenic pollution contents in the Baynespruit stream. Frequency was measured as follows:

$F(x) = 1/T$……………………………………………………………………………..(3-7);

And $T=1/P$……………………………………………………………………………(3-8);

Whereby $F(x)$ is the frequency function;

T is the period;

P is the probability.

The above function will be used to establish the distribution function and thus the statistical description of pathogenic water pollution summarized in tables of table 4.1. The mean will be measured as follows:

$$\mu = (\sum x)/n \qquad (3\text{-}9);$$

Whereby μ is the mean;

x is a data point;

n is the sample size.

Measuring the variation of the normal distribution will be the next step in the data analysis and description. The standard deviation will be introduced and used as follows:

$$S = \sqrt{\frac{\sum (x-\mu)^2}{n-1}} \qquad (3\text{-}10);$$

Whereby S is the standard deviation;

x is a data point;

μ is the mean of x;

n is the sample size.

Another input in the data description will be the establishment of the skew of the distribution function plotted from frequency values against their ranges. Reliability of the sample mean is one of the most important factors in the data description. Using the sample mean, it will be easier to calculate the variation of their distribution and obtain the standard deviation for the mean of means, which is the standard error of the mean. This is calculated as follows:

$$SE = \sqrt{\frac{S^2}{n}} \qquad (3\text{-}11);$$

Whereby SE is the standard error;

S is the standard deviation;

n is the sample size.

Data interpretation is the next step in the statistical analysis. In order to understand the Baynespruit pathogenic water pollution, and suggest mitigation, the following conditions will be used:

- ✓ independence of observations from each other;
- ✓ independence of observational error from potential confounding effects;
- ✓ exact or approximate normality of observations;

The third step of the statistical analysis will be hypothesis testing, the data transformation, and the choosing of a statistical test. The Baynespruit data will be used to establish null and alternative hypotheses in order to carry out statistical tests on surveyed data. The degree of freedom will then be calculated. The significance of the result from statistical tests based on the probability will also be calculated; the type of analysis will be made based on frequency or other statistical parameters previously observed. Establishing the relationship between *E-coli* data extracted from RBS001 and RBS 002 in the Baynespruit is fully explained in section 4.5.

The fourth step is the use of correlation and regression on the Baynespruit raw data in order to establish the relationship and the difference between pathogenic water pollution data collected at RSB001 and RBS002 sampling points. This step will determine if data sets collected at the two sampling points are statistically dependent or independent of rainfall trends in the catchment area. Some other statistical test would be used if the sample were proved not normally distributed. As a preliminary check of the correlation between *E-coli* counts at RSB001 as dependent variables and *E-coli* counts at RSB002 as independent variables, a scatter plot between these two variables will be carried out. This will be conducted between *E-coli* counts as the dependent variable and rainfall in the catchment area as the independent variable. This means that Spearman‟s rank correlation will be appropriate to statistically correlate variables. *E-coli* concentrations will be correlated to average rainfall of the uMsunduzi catchment. The Spearman‟s rank correlation will used as follows:

$$r_s = 1 - \frac{6\sum d^2}{n^3 - n} \quad \text{.........(3-12);}$$

Where d is the difference between the ranks within each pair of data;
n is the number of data pairs.

In some case the regression techniques will also be applied using the same assumptions as in the second step in order to reach conclusions. The data interpretation and analysis will establish the difference and relationship between *E-coli* counts on both sampling points RSB001 and RSB002 along the Baynespruit and the average monthly Rainfall in the uMsunduzi catchment. This process will be carried out using the ANOVA test as is detailed chapter 4.

The fifth step is the comparison of the Baynespruit pathogenic water pollution data to national and international standard guidelines criteria as follows:

- ✓ The median of *E-coli* counts at RSB001 and RSB002 will be compared to the South African standard guidelines criteria;

- ✓ Geometric mean (GM) and Single sample maximum (SSM) values of *E-coli* count at RSB001 and RSB002 will be compared to the USEPA standards guideline criteria and;
- ✓ Extreme values for *E-coli* count at RSB001 and RSB002 will be compared to the EU2006 standards criteria;

3.7 Data validity and reliability

Validity is interpreted as the strength resulting from observations and conclusions made during the Baynespruit pathogenic water pollution statistical analysis and their comparison to the water quality standard guidelines criteria. Reliability is the consistency between two consecutive observations made on the same sample. In this research, reliability will be established in chapter four when assessing the overall research outcomes, the key result and their interpretations.

3.8 Summary

This chapter described the study area, outlined and justifies the research methodologies used to analyze and interpret the Baynespruit water pollution data. It recommended statistical analysis and epidemiological study to be used as the main tool in this study in order to achieve the objectives.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

Chapter four starts with the assessment of the Baynespruit pathogenic water pollution in order to establish how severe pathogenic pollution is in the stream. It contains results derived from the data analysis and their discussion. The data was analyzed statistically in order to establish the relationship between *E-coli* concentration and rainfall which may describe the effects of dilution and dispersion of pollutant in the stream. The stream water quality data, represented by *E-coli* and *Streptococcus* counts, are also compared to the local and international standard guidelines criteria. Finally this chapter looks at the effect of *E-coli* concentration on human health along the Baynespruit.

4.2 Baynespruit's water quality assessment

Figure 4.1 shows the plot of monthly average *E-coli* concentration at RSB001 and RSB002 against the sampling dates. Only raw data were used in this plot.

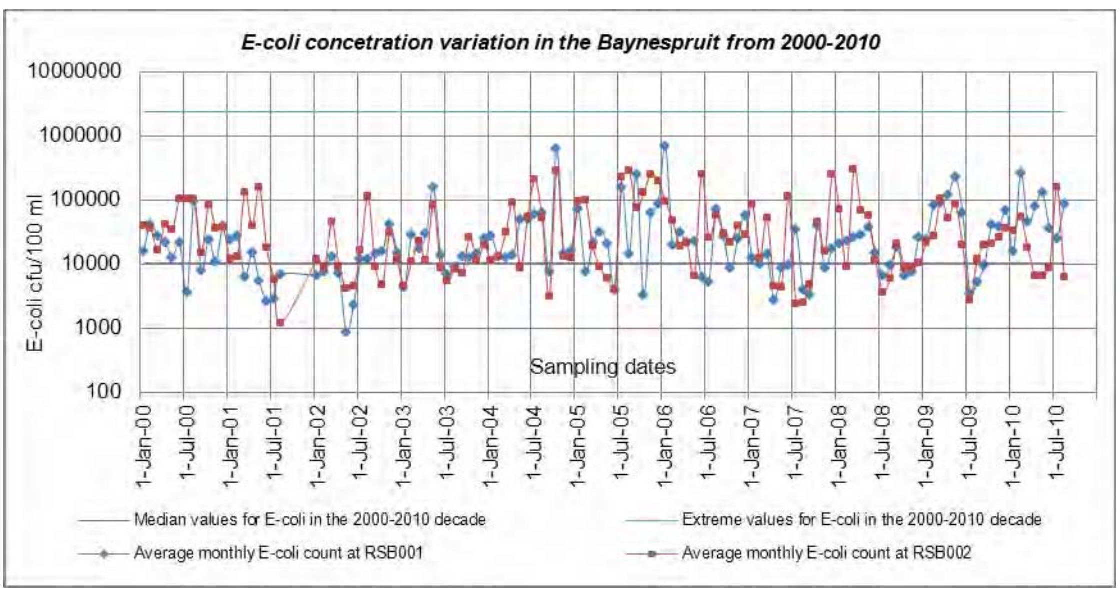

Figure 4-1 Monthly E-coli concentration in the Baynespruit stream during 2000-2010

Figure 4.1 above shows that *E-coli* contaminations in the Baynespruit had chronic effects in the decade 2000-2010. The median value for *E-coli* is estimated as 10 500 cfu/100 ml whereas the extreme value of *E-coli* is estimated as 2 419 000 cfu/100 ml. On the other hand, the allowable water quality criteria for *E-coli* count are set at 575 cfu/100 ml, according to the USEPA single sample limit (SSL) for infrequent bathing. The SSL value is far below both the median and extreme value for *E-coli* in the stream.

4.3 Dilution and dispersion in the Baynespruit

Average monthly rainfall and the median of *E-coli* concentration values was plotted against time in figure 4.2, and Monthly 95th percentiles *E-coli* concentration values in figure 4.3. The following observations are made:

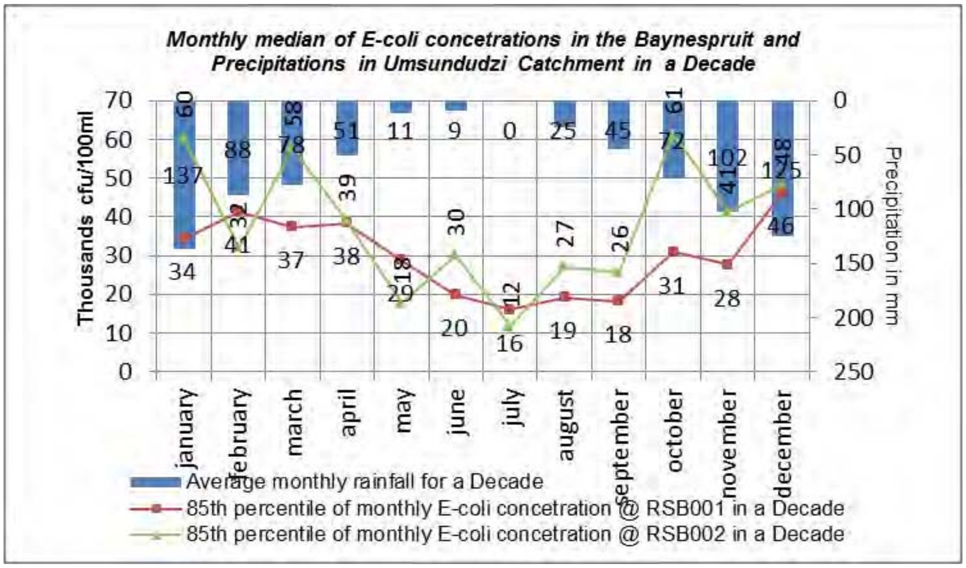

Figure 4-2 Median of monthly E-coli concentrations in the Baynespruit, and monthly average precipitation in the uMsunduzi catchment for the decade 2000-2010

1. The rainfall data shows that the month of January has the highest average rainfall, followed by December. These months represent mid-summer. The minimum rainfall occurs in July. The rainfall trend in figures 4.2 and 4.3 shows that precipitation gradually decreases from January to July, and then increases from July to December, as it is common in KwaZulu-Natal;
2. Both figures show that at the beginning of the rainy season the median values of *E-coli* levels increase. This is speculated to be caused by the first flushing of pathogenic water pollution from the entire catchment by runoff. As we approach the end of the rainy season which is March, these levels decrease. This may be caused by dilution that takes place in the entire stream, after the occurrence of first flush;
3. Comparing the maximum and minimum of *E-coli* counts at RSB001 to the ones at RSB002, the data reveals that pathogenic water pollution in the Baynespruit is highly variable;
4. *E-coli* levels at RSB001 are lower than the one at RSB002 in January. The above scenario shows that pathogenic water pollution increased at the RSB002 sampling point in this particular month. This scenario repeats in March, June, August, September, October and November with high levels of *E-coli*

observed at RSB002 compared to the observation made at RSB001.These observations support the suspicions of unregulated sources of pathogenic water pollution between the two sampling points;

5. *E-coli* counts at RSB001 are higher than those at RSB002 in February. The above scenario shows that pathogenic water pollution decreased at the RSB002 sampling point in comparison to RSB001 and this pattern repeats in April, May, July, and December with high levels of *E-coli* count observed at RSB001 compared to observation made at RSB002. These observations lead to the suspicions of pathogenic water pollution accumulation around RSB001;

Monthly 95th percentiles of *E-coli* concentration at both RSB001 and RSB002 were observed and presented in figure 4.3 as follows:

6. The data show that pathogenic water pollution in the Baynespruit is highly variable, the same as in figure 4.2;
7. *E-coli* levels in July are recorded as lower at RSB001 than at RSB002. The above scenario shows that pathogenic water pollution increased at the RSB002 sampling point and repeats in March, June, August, November and December. As in figure 4.2 , these observations lead to the suspicions of existence of unregulated sources of pathogenic water pollution between the two sampling points;

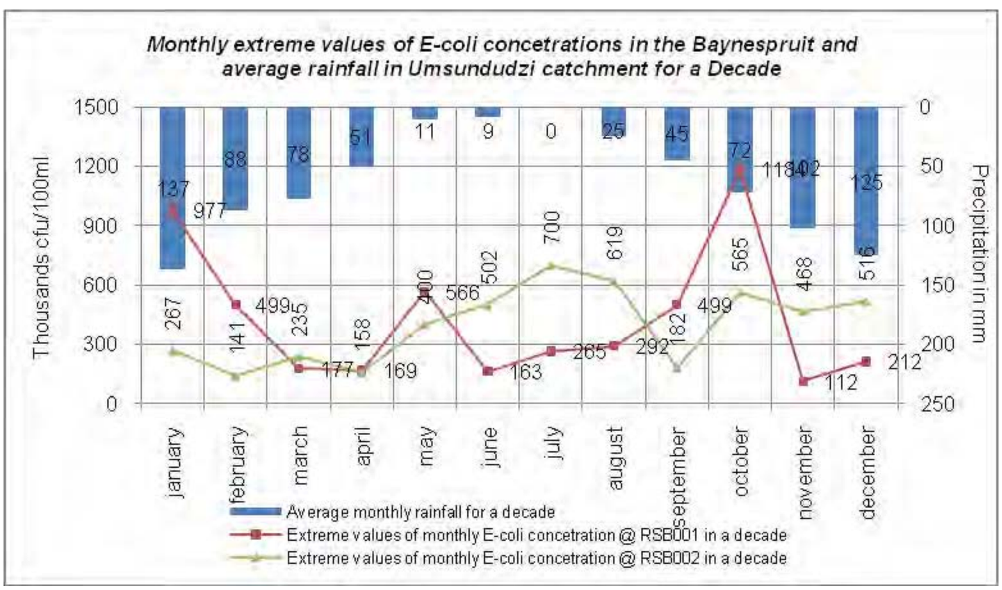

Figure 4-3 Monthly 95th percentiles of *E-coli* concentrations in the Baynespruit, and monthly average precipitation in the uMsunduzi catchment for the decade 2000-2010

8. *E-coli* counts at RSB001 are higher than those at RSB002 in February. The above scenario shows that pathogenic water pollution has decreased at RSB002 sampling point compared to RSB001, and the scenario repeats in May, September, and October with high levels of *E-coli* count observed at RSB001

compared to observations made at RSB002. As in figure 4.2, these observations lead to the suspicions of pathogenic water pollution accumulation around RSB001.

Figure 4.4 shows that *E-coli* count at RSB001 had a high standard deviation in January and October compared to RSB002 .This means that pathogenic water pollution was highly variable at this sampling point. Whereas *E-coli* count at RSB002 had a high standard deviation in June, July and August than at RSB001. This is consistent with increases in the number of high pathogenic water pollution events at each sampling point. These trends are inconsistent with those of the median values and are inversely linked to rainfall in some cases.

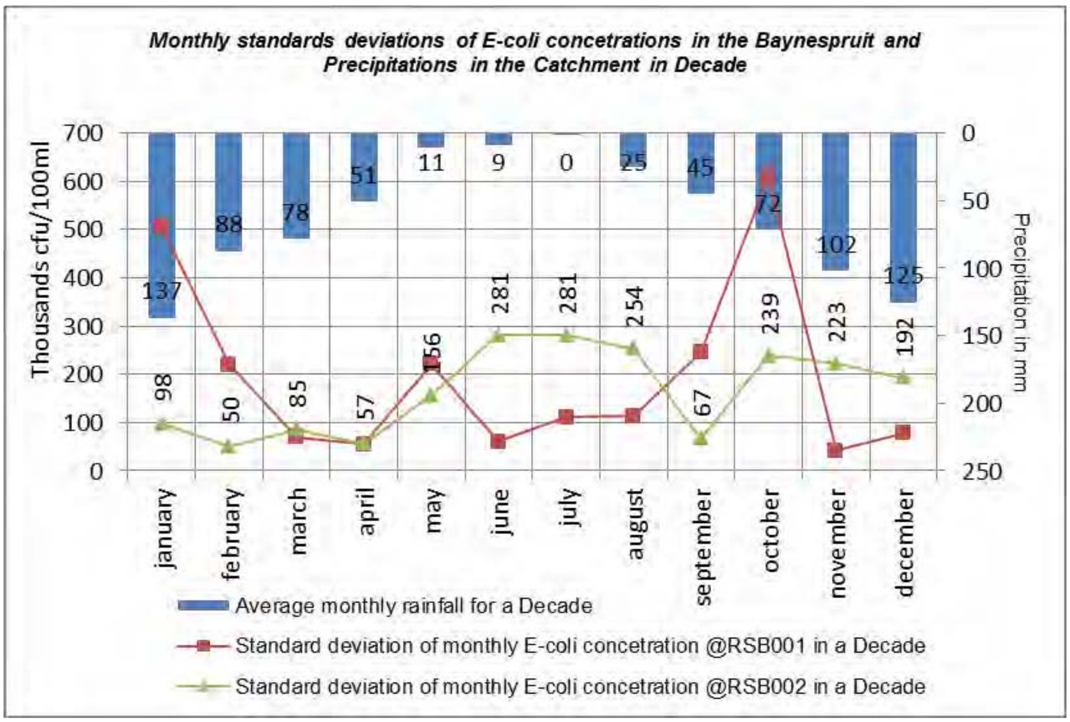

Figure 4-4 Monthly standard deviation of E-coli concentrations in the Baynespruit, and monthly average precipitation in the uMsunduzi catchment for the decade 2000-2010

In summary, observations made above reveal that, at the beginning of the rainy season, most of the pathogenic water pollution in the catchment seems to be flushed into the stream by runoff and as we approach the end of the rainy season, pathogenic water pollution concentration in the stream reduces. In the dry season *E-coli* counts were recorded as low compared to the rainy season scenario. This may be due to an absence of runoff in the catchment resulting in less pathogenic water pollution drainage in the stream. The above shows that there is a relationship between rainfall in the catchment and pollution variations in the stream. Pollution in the Baynespruit seems to accumulate around each of the sampling points during a certain period, on one hand possibly due to low flows that may be associated with the dry season. On the other hand the stream seems to be characterized by unregulated sources of *E-coli* between the two sampling points that may be due to the release of *E-coli* contaminated matter in the stream. To better understand the observations made in figure 4.2, 4.3 and 4.4 scatter plot analysis between *E-coli* counts at RSB001 against *E-coli* counts at RBS002 was carried out and is presented in the sections below.

4.4 Scatter plot of *E-coli* counts at RSB001 against *E-coli* count at RSB002

In this step, *E-coli* concentrations at RSB001 were set as independent variables and *E-coli* concentration at RSB002 set as dependent variables. These two sets were plotted in “scatter plot “as shown in figure 4.5 in order to establish the correlation between *E-coli* concentrations. The graph in figure 4.5 was subdivided into three zones as follows:

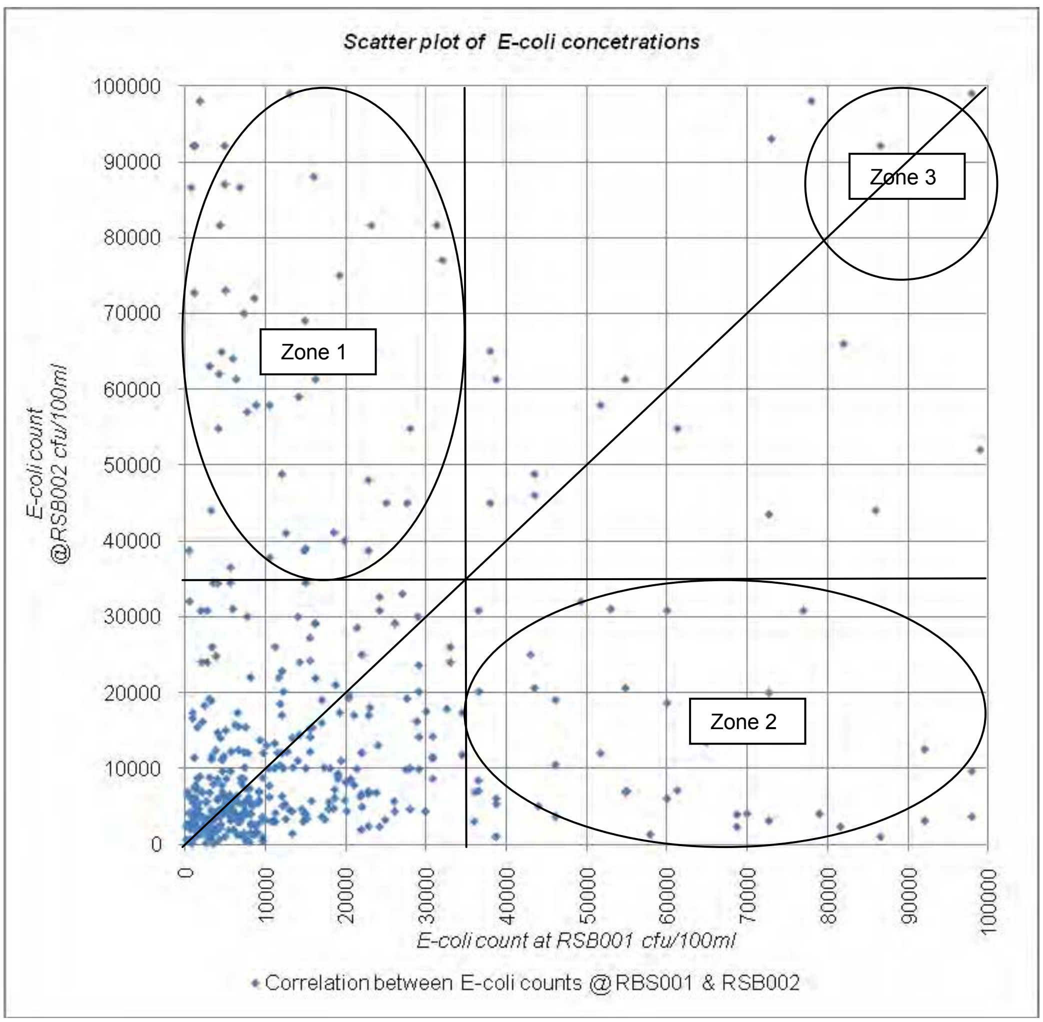

Figure 4-5 Scatter plot between *E-coli* concentrations at RS001 and RSB002

1. Zone 1 that shows a scenario whereby a high number of *E-coli* counts ranging from 0 cfu/100ml to 3000 cfu/100 ml at RSB001 seem to be negatively correlated to *E-coli* counts ranging from 4000 cfu/100 ml to 200000 cfu/100 ml at RSB002. Observation of this scenario simply reveals the existence of unregulated sources of pathogenic water pollution between the two sampling points and supports the observations made in figure 4.2 and 4.3;
2. Zone 2 shows a scenario whereby a high number of *E-coli* counts ranging from 0 cfu/100ml to 3000cfu/100ml are correlated at RSB002 seem to be negatively correlated to *E-coli* counts ranging from 5000cfu/100ml to 130000cfu/100ml at RSB001. Observation of this scenario reveals the existence of pathogenic water pollution accumulation around both sampling points and, supports the observations made in figure 4.2 and 4.3;

To clearly understand what is happening in zone 2 in figure 4.5, all the data from zone 2 were extracted and plotted in figure 4.6 as scatterplot against rainfall. Zone D of figure 4.6 shows that pathogenic water pollution may have been transferred from RSB001 to RSB002, when looking at rainfall ranges that are above 15mm. The above mentioned observations reveal that there were flows in the Baynespruit caused by high rainfall in the catchment area. On the other hand all data correlated to rainfall that ranges from 0 mm to 10 mm in zone two shows that there is accumulation around sampling points.

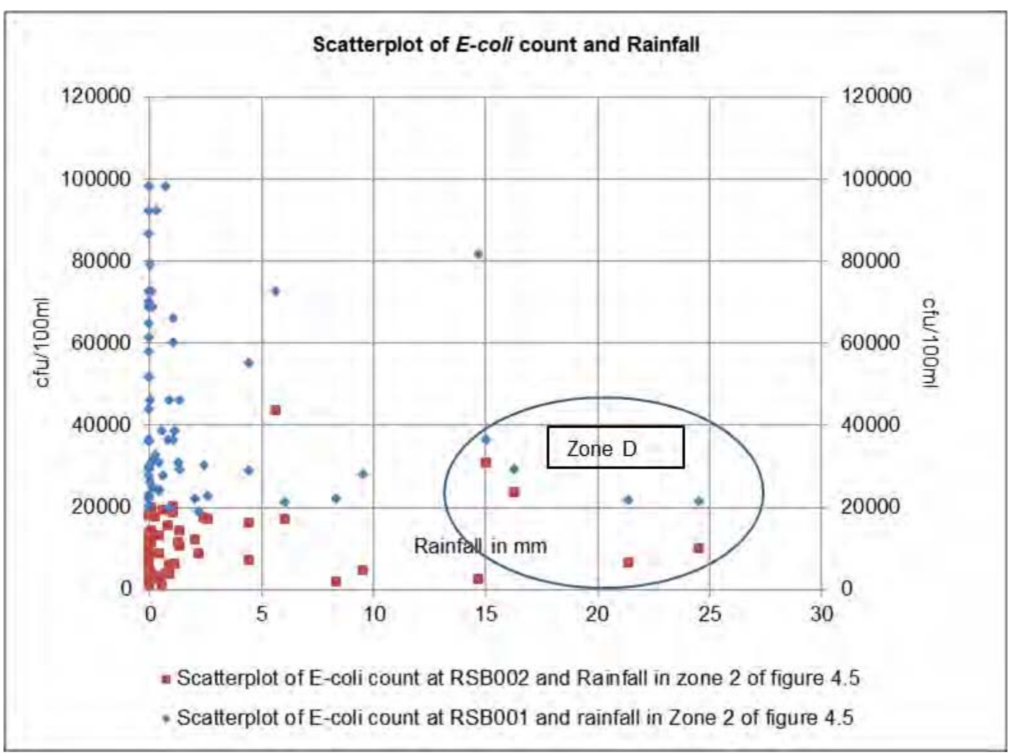

Figure 4-6 Scatterplot of *E-coli* counts from zone 2 in figure 4.5 correlated to daily rainfall in mm

3. Zone 3 shows a scenario whereby a small number of *E-coli* counts ranging from 70000 cfu/100ml to 98000 cfu/100 ml at RSB001 seem to be positively correlated to *E-coli* counts ranging from 87000 cfu/100 ml to 90000 cfu/100 ml at RSB002. Observation of this scenario simply reveals that the flush of pathogenic water pollution in the stream just after the beginning of the rainy season supports the observations made in figure 4.2 and 4.3;

In summary, observations of figure 4.5 supports interpretations made earlier in figure 4.2, 4.3 and 4.4. Negative correlation may mean the existence of unregulated source of pathogenic water pollution between both sampling points, at the same time negative correlation may means accumulation of pathogenic water pollution around the RSB001 sampling point. Positive correlation reveals the first flush of pathogenic water pollution in the stream due to runoff.

4.6 Scatter plot of *E-coli* counts at both sampling points against rainfall in the catchment

The scatter plot in figure 4.7 shows three scenarios as follows:

1. High rainfall is related to a low level of pathogenic water pollution in the stream according to zone 2. This may be due to dilution that would have occurred in the entire catchment during the rainy season after the first flush. The above observation matches with figure 4.2 and 4.3 and;
2. Some scatter points whereby lower rainfall related to high level pollution in the stream according to zone 1. This may be due to unregulated sources of pathogenic water pollution that may have been occurred. This again matches the data in figures 4.2 and 4.3 and;
3. High rainfall is related to a high level of pathogenic water pollution in the stream according to zone 3. This is due to first flushing that may have occurred in the entire catchment during the rainy season. The above observation matches the data in figure 4.2 and 4.3 and;
4. Low rainfall is related to a low level of pathogenic water pollution in the stream according to zone 4. This may be as a result of no flushing occurring in the entire catchment during the low rainfall.

These observations show that rainfall did have a direct effect on pathogenic water pollution in some cases through flushing of pollution from the catchment into the stream. This occurs at the beginning of the rainy season and supports findings and observations of the data in figures 4.2, 4.3, 4.4 and 4.5 which suggest that higher level of pathogenic water pollution may also be linked to the lack of proper sanitation in the area on one hand and, pathogenic water pollution accumulation around sampling points resulting from low flows in the dry season on the other hand.

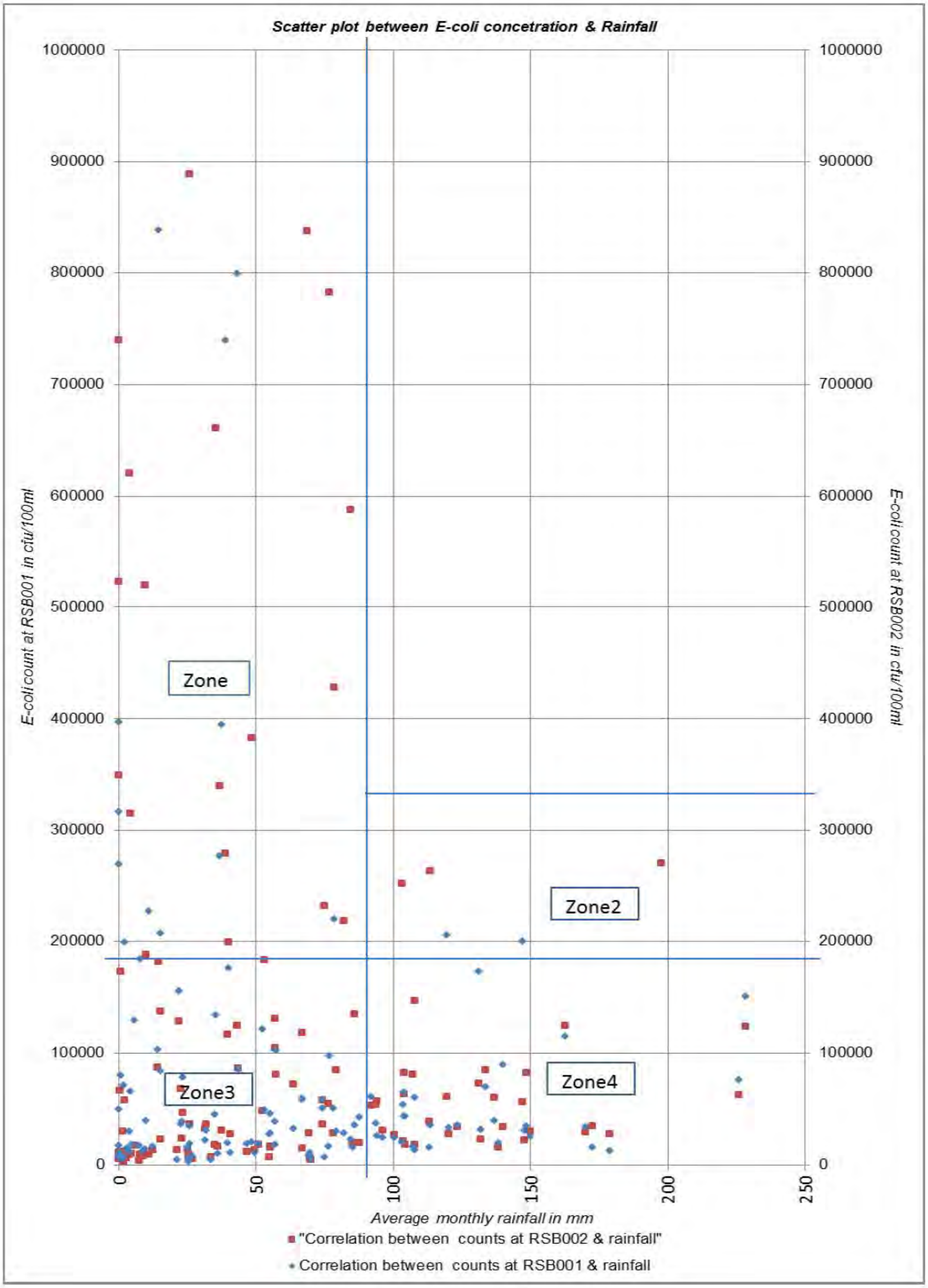

Figure 4-7 Scatter plot between *E-coli* concentrations at both sampling points and average monthly rainfall

4.7 Baynespruit's water quality statistical description

Statistically describing the Baynespruit"s pathogenic water pollution is an important milestone for the analysis process and the data presentation in the thesis. Section 2.3 shows that the coliform bacteria groups are commonly used as indicators of potential pathogens. In this research and particularly this section, *E-coli,* Total coliforms *and Streptococcus* are used as indicators of pathogenic water pollution. Details of pathogenic water pollution statistical analysis are given in table 4.1. It contains rows representing the following: sample size; missing data; mean; median, mode, standard deviation, variance, skewness, and standards error of skewness, kurtosis; standard error of kurtosis, range, maximum and minimum, sum and finally the percentiles. Comments were only made on the mean, standard error of the mean, standard deviation, maximum and minimum as already indicated in section 3.6.

Table 4-1 Summary table of statistical analysis and results

Table1:Statistical description of pathogenic water pollution in the Baynespruit and average rainfall in Umsunduzi catchment area									
Parameters	**Monthly average rainfall in mm**	**Monthly 95th percentile *E-coli* @ RBS001**	**Monthly 95th percentile *E-coli* @ RBS002**	**Seasonal average rainfall in mm**	**Seasonal 95th percentile *E-coli* @ RBS001**	**Seasonal 95th percentile *E-coli* @ RBS002**	**Annual average rainfall in mm**	**Annual 95th percentile *E-coli* @ RBS001**	**Annual 95th percentile *E-coli* @ RBS002**
Valid	128	128	128	43	43	43	11	11	11
Mean	64	106681	114300	192	106395	114057	749	317407	385728
Std. Error of Mean	5	23677	16141	20	24042	18762	61	97400	69573
Median	55	33603	36015	185	51807	62925	820	183501	330767
Std. Deviation	54	267879	182617	126	157655	123027	201	323038	230747
Skewness	0.77	5.55	2.57	0.26	2.79	1.63	-2.0	1.28	0.81
Std. Error of Skewness	0.21	0.21	0.21	0.36	0.36	0.36	0.7	0.66	0.66
Kurtosis	0.05	34.70	6.41	-0.84	7.91	2.53	4.40	0.99	0.38
Std. Error of Kurtosis	0.42	0.42	0.42	0.71	0.71	0.71	1.28	1.28	1.28
Range	228	2060499	888999	464	700886	545546	676	984913	780025
Minimum	0	1	1	4	1	1	228	55871	50565
Maximum	228	2060500	889000	468	700887	545547	903	1040784	830590
Sum	8235	13655164	14630418	8236	4574996	4904456	8236	3491481	4243006

In summary it can be seen that in almost all cases, either seasonally or annually, *E-coli* concentration arithmetical mean for the Baynespruit far exceeded local and international standards guidelines criteria. The mean standard error of all data ranged between 0% and 30%, indicating the level of accuracy of the computed statistics.

4.8 Statistical relationship between *E-coli* at RSB001, RSB002 and rainfall

Correlation and regression were used to establish the relationship between pathogenic water pollution variations and rainfall trends in the uMsunduzi catchment. The correlation coefficient was established in order to measure the strength or weakness of the relationship between rainfall trends and *E-coli* counts at both sampling points in the stream using the Spearman‟s rank correlation coefficient approach in section 4.8.1. Regression was also used to establish the relationship that may exist between *E-coli* counts and rainfall in the Baynespruit in section 4.8.2.

4.8.1 Correlation between *E-coli* counts at RSB001, RSB002 and rainfall

Table 4.2 shows the Spearman‟s rank correlation coefficient (r_s) between *E-coli* at RSB001 and RSB002 is 0.51. The correlation between *E-coli* at RSB001 and monthly average rainfall is estimated at 0.04 whereas the correlation between RSB002 and monthly rainfall is 0.12 with the degree of freedom (df) = 126 (or 150 on probability distribution function tables). Consulting the statistical table on Spearmen‟s rank correlation, the following was concluded:

- ✓ There is a correlation between *E-coli* level at RSB002 and RSB001 whereby r is 0.51 and greater than $P_{0.01}$ = 0.22. Therefore there is significant positive correlation between *E-coli* level at both sampling points;
- ✓ There is a no significant correlation between *E-coli* level at RSB002 and RSB001 and rainfall whereby both correlation coefficients are (0.04 and 0.12) smaller than $P_{0.01}$ = 0.22;

Referring to the statistical analysis made above, these observations reveal that *E-coli* concentration at RSB002 were directly influenced by *E-coli* concentration at RSB001. *E-coli* counts at both RSB001 and RSB002 sampling points had been influenced by pathogenic water pollution flushed into the stream through runoff. Other factors such as unregulated sources of pathogenic water pollution between RSB001 and RSB002 sampling points may be involved in the process together with pathogenic water pollution accumulation around RSB001 sampling points that may be caused by low flows during the dry season.

Table 4-2 Spearman's rank correlation coefficient between *E-coli* and rainfall

Correlation coefficients (r)			Rainfall	*E-coli* at RSB001	*E-coli* at RSB002
Spearman's rho	Rainfall	Correlation Coefficient	1.00	0.04	0.12
		Sig. (2-tailed)	.	0.63	0.19
		N	128	128	128
	E-coli at RSB001	Correlation Coefficient	0.04	1.00	0.51
		Sig. (2-tailed)	0.63	.	0.00
		N	128	128	128
	E-coli at RSB002	Correlation Coefficient	0.12	0.51	1.00
		Sig. (2-tailed)	0.19	0.00	.
		N	128	128	128

4.8.2 Regression between *E-coli* counts and rainfall

Regression was used in this analysis to establish a relationship that could exist between *E-coli* counts and rainfall in the catchment area as discussed below in section 4.8.2.1 and 4.8.2.2.

4.8.2.1 Regression between *E-coli* counts at RSB001 and rainfall

In table 4.3 below, the regression gradient and the interceptor are established in order to define the linear relationship between rainfall and *E-coli* counts at RSB001.

Table 4-3 ANOVA table of *E-coli* counts at RSB001 and rainfall

	Degree of freedom	Sum of squares (ss)	Mean squares (ms)	F value	P value	Regression gradient (b)	Interceptor (a)
Regression	1	3.68E+10	3.68E+10	0.51	P > 0.01	1.00	284.62
Residual	126	9.08E+12	7.20E+10				
Total	127	9.11E+12					
Coefficient of determination in %	0.40						

The statistic test (F) is estimated at 0.51 as seen in table 4.3 whereas the critical value of F-distribution for (P = 0.05) and (P = 0.01) in table A.3 (appendix 4) are 3.06 and 4.75 respectively. Since 0.51 the calculated value of F-distribution was smaller than (P = 0.05) and (P = 0.01), the alternative hypothesis was considered and concluded that there is no significant variation of *E-coli* counts at RSB001 related to rainfall in the catchment area. The coefficient of determination $r^2 = 0.40$ %.

4.8.2.2 Regression between *E-coli* counts at RSB002 and rainfall

In table 4.4 below, the regression gradient and the interceptor are established in order to define the linear relationship between rainfall and *E-coli* counts at RSB002 as introduced in previous section.

Table 4-4 ANOVA table of *E-coli* at RSB002 and rainfall

	Degree of freedom	Sum of squares (ss)	Mean squares (ms)	F value	P value	Regression gradient (b)	Interceptor (a)
Regression	1	5.11E+10	5.11E+10	1.54	P > 0.01	1.00	252.82
Residual	126	4.18E+12	3.32E+10				
Total	127	4.24E+12					
Coefficient of determination in %	1.2						

Again a statistical test (F) was carried out in order to establish the linear relationship between *E-coli* at RSB002 and rainfall in the catchment area. (F) is 1.54 as indicated in table 4.4, whereas in table A.2 (appendix 4), the critical value of (F) for (P = 0.05) and (P = 0.01) is 3.06 and 4.75 respectively. Since the calculated value of (F) is 1.54 and in this case is lower than (P = 0.05) and (P = 0.01), the alternative hypothesis is considered, valid and concluded that there is no significant variation between *E-coli* counts at RSB001 and rainfall in the catchment area. The coefficient of determination $r^2 = 1.21$ %.

In summary, the scatter plot between *E-coli* concentrations at RSB001 and RSB002 in figure 4.2, 4.3, 4.4, 4.5, 4.6 and, 4.7 reveal the existence of unregulated sources of pathogenic water pollution between the two sampling points. It shows again that at the beginning of the rainy season flushing of pathogenic water pollution followed by dilution in the entire catchment usually occurs in the Baynespruit. At the same time these figures show that there may be pathogenic water pollution accumulation around sampling points cause by low flows during dry season. Tables 4.3 and 4.4 showed that there is no significant correlation between *E-coli* concentration in the stream and rainfall trends in the catchment area.

4.9 Baynespruit's water quality compared with local and international guidelines

Local and international water quality standards guidelines were used to assess the status of the Baynespruit, using *E-coli*, total coliforms and S*treptococcus* as the main indicators of pathogenic water pollution in the stream.

4.9.1 South African water quality guidelines

The South African water quality guidelines are used in this section in order to assess the levels of *E-coli* as pathogenic water pollution in the Baynespruit. The following criteria were considered (DWAF, 1996):

1. Less than 20% of samples to exceed 100 cfu/100 ml;
2. Less than 5% of samples to exceed 2 000 cfu/100 ml;

Table 4.5 and 4.6 below illustrate the comparison of the stream water quality to the South African standard guidelines criteria.

Table 4-5 SA Water quality guidelines, criteria 2, for *E-coli* concentrations at RSB001 during 2000-2010 decade stating that only 5% of samples should be greater than 2000cfu/100ml

SA WQ Guidelines Criteria 2 for *E-coli* concentration at RSB001 from 2000 to 2005 Maximum 5% (5th Percentile) of the samples greater than 2000cfu/100ml						
Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Summer	100%	100%	100%	88%	90%	85%
Autumn	100%	100%	75%	100%	60%	83%
Winter	86%	62%	50%	80%	100%	64%
Spring	83%	100%	82%	92%	85%	62%
Annual	92%	83%	75%	90%	83%	75%
SA WQ Guidelines Criteria 2 for *E-coli* concentration at RSB001 from 2006 to 2010 Maximum 5% (5th Percentile) of samples greater than 2000cfu/100ml						
Year	**2006**	**2007**	**2008**	**2009**	**2010**	
Summer	92%	85%	100%	100%	92%	
Autumn	92%	92%	100%	100%	100%	
Winter	100%	92%	100%	85%	100%	
Spring	77%	79%	92%	85%	100%	
Annual	86%	90%	98%	90%	94%	

Since pathogenic water pollution has such a chronic effect in the Baynespruit according to section 4.2, the South African water quality standards guidelines recommends the median of the data to be used to compare the stream water quality to the above mentioned standards guidelines.

Table 4-6 SA water quality guidelines, criteria 2, for *E-coli* concentrations at RSB002 during 2000-2010 decade stating that only 5% of samples should be greater than 2000cfu/100ml

SA WQ Guidelines Criteria 2 for *E-coli* concentration at RSB002 from 2000 to 2005 Maximum 5% (5th Percentile) of samples greater than 2000cfu/100ml						
Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Summer	100%	100%	67%	75%	100%	100%
Autumn	100%	100%	82%	100%	100%	100%
Winter	79%	92%	42%	100%	100%	91%
Spring	91%	67%	100%	100%	85%	92%
Annual	92%	93%	75%	98%	98%	96%
SA WQ Guidelines Criteria 2 for *E-coli* concentration at RSB002 from 2006 to 2010 Maximum 5% (5th Percentile) of samples greater than 2000cfu/100ml						
Year	**2006**	**2007**	**2008**	**2009**	**2010**	
Summer	100%	100%	100%	92%	100%	
Autumn	85%	92%	100%	100%	100%	
Winter	75%	75%	54%	85%	92%	
Spring	100%	71%	100%	100%	100%	
Annual	90%	84%	87%	94%	94%	

Observations in table 4.5 and 4.6 show that; *E-coli* concentration in the stream had far exceeded the South African guidelines criteria in all seasons. These observations show that 54 % to 100 % of the samples respectively as minimum and maximum of *E-coli* data analyzed, were higher than 2 000 cfu /100 ml seasonally.

4.9.2 USEPA ambient water quality guidelines for bacteria

The USEPA criteria were used to assess stream water quality and the health risks associated with the Baynespruit water quality status. In this section *E-coli* and *Enterococcus* are used to as pathogenic water pollution indicators of the USEPA water quality standards guidelines criteria which were reviewed in section 2.8.3 and 3.4.3.2. Tables 4.7 and 4.8 compared the single sample maxima (SSM) to the analyzed stream water quality data for each year in the decade 2000-2010 and, provided the percentage of the samples that had failed to meet the USEPA standards. The SSM criteria as listed below:

a. *Enterococcus (Streptococcus)*

   A. Designated bathing 75% CL or 61 cfu/100 ml,

   B. Moderately used for bathing 82% CL or 78 cfu/100 ml,

   C. Lightly used for bathing 90% CL or 107 cfu/100 ml,

   D. Infrequently used for bathing 95% CL or 151 cfu/100 ml,

b. *E-coli*

   E. Designated bathing 75% CL or 235 cfu/100 ml,

   F. Moderately used for bathing 82% CL or 298 cfu/100 ml,

   G. Lightly used for bathing 90% CL or 409 cfu/100 ml,

   H. Infrequently used for bathing 95% CL or 575 cfu/100 ml,

Detailed calculations are provided in appendix 2.

Table 4-7 Percentage of samples that exceeded the USEPA single sample maximum at RSB001

Percentages of samples that failed to meet Single Sample Maximum criteria at RS001								
Year	***E-coli***				***Streptococci***			
	E	**F**	**G**	**H**	**A**	**B**	**C**	**D**
2000	100%	100%	100%	100%	100%	100%	100%	100%
2001	100%	100%	100%	96%	100%	100%	100%	100%
2002	98%	98%	98%	90%	-	-	-	-
2003	100%	98%	98%	98%	-	-	-	-
2004	100%	100%	98%	96%	-	-	-	-
2005	98%	98%	98%	98%	-	-	-	-
2006	100%	100%	100%	100%	-	-	-	-
2007	98%	98%	98%	98%	-	-	-	-
2008	100%	100%	100%	100%	-	-	-	-
2009	98%	98%	98%	98%	-	-	-	-
2010	100%	100%	100%	100%	-	-	-	-

Table 4-8 Percentages of samples that exceeded the USEPA single sample maximum at RSB002

Percentages of samples that failed to meet Single Sample Maximum criteria at RS002								
Year	***E-coli***				***Streptococci***			
	E	**F**	**G**	**H**	**A**	**B**	**C**	**D**
2000	98%	98%	98%	96%	100%	100%	100%	100%
2001	97%	97%	97%	97%	100%	100%	100%	100%
2002	100%	98%	98%	98%	-	-	-	-
2003	100%	100%	100%	100%	-	-	-	-
2004	100%	100%	98%	98%	-	-	-	-
2005	100%	100%	100%	100%	-	-	-	-
2006	100%	100%	98%	98%	-	-	-	-
2007	96%	96%	96%	96%	-	-	-	-
2008	100%	100%	100%	100%	-	-	-	-
2009	100%	100%	100%	100%	-	-	-	-
2010	100%	100%	100%	100%	-	-	-	-

It can be seen that for every year in the decade 2000-2010, *E-coli* concentrations exceeded the single sample limits by nearly 100%. The same applies to *Streptococcus*. This means that all samples tested for *E-coli* and *Enterococcus* exceeded the geometric means of 126 cfu/100 ml and 33 cfu/100 ml respectively. At the same time all samples again exceeded the SSM limits given in sections 4.5.2, meaning that the Baynespruit water quality failed to meet the standard guideline criteria set by the USEPA.

4.9.3 European Union water quality directive of 2006

Introduced in section 3.3.4.3, the EU guidelines specify 90^{th} and 95^{th} percentile limits for *E-coli* as well as *Enterococcus* in bathing waters. A three-year period is required in order to carry out the water quality assessment. In the present research *E-coli* data were sampled over ten years, three times the proposed sampling calendar of the EU standards guidelines. The available data for *Streptococcus* (*Enterococcus*) were sampled in two consecutive years only, 2000 to 2002; this had not fulfilled the requirement of the EU guidelines.

The number preceding the “P” entry indicates the magnitude of the calculated 90^{th} percentile value as a multiple of the poor quality limit. This means for example that 797P of *E-coli* represents the 90^{th} percentile for poor quality 797 times higher than the limit, which is 900 cfu/100 ml in table 4.9 and 4.10.

Table 4-9 Summary of categorized E-coli and Interococcus for 90^{th} percentile values according to 2006 EU bathing water quality criteria at RSB001 (the number preceding the "P" entry indicates the magnitude or a multiple of the poor water quality)

Categorization summary of *E-coli* and *Enterococcus* for 90^{th} percentile values at RSB001												
Year	**2000**		**2001**		**2002**		**2003**		**2004**		**2005**	
	W.Q Indicator		W.Q Indicator		W.Q Indicator		W.Q Indicator		W.Q Indicator		W.Q Indicator	
Summer	39P	33P	98P	21P	6P		56P		36P		115P	
Autumn	59P	36P	35P	57P	23P		49P		36P		40P	
Winter	19P	12P	5P	8P	16P		68P		115P		193P	
Spring	57P	29P	18P	11P	31P		33P		221P		41P	
Annual	56P	33P	24P	34P	29P		41P		104P		179P	
Year	**2006**		**2007**		**2008**		**2009**		**2010**			
Summer	797P		71P		28P		37P		138P			
Autumn	57P		25P		71P		243P		198P			
Winter	39P		60P		47P		220P		161P			
Spring	105P		32P		29P		73P		253P			
Annual	81P		33P		51P		180P		211P			

Table 4-10 Summary of categorized *E-coli* and *Enterococcus* for 90th percentile values according to 2006 EU bathing water quality at RSB002 (the number preceding the "P" entry indicates the magnitude a multiple of the poor quality limit)

Categorization summary of *E-coli* and *Enterococcus* for 90th percentile values at RSB002												
Year	**2000**		**2001**		**2002**		**2003**		**2004**		**2005**	
	W.Q Indicator		W.Q Indicator		W.Q Indicator		W.Q Indicator		W.Q Indicator		W.Q Indicator	
Summer	69P	33P	98P	21P	29P		61P		33P		113P	
Autumn	71P	36P	64P	57P	27P		32P		152P		107P	
Winter	114P	12P	33P	8P	16P		41P		99P		27P	
Spring	222P	29P	4P	11P	44P		17P		169P		286P	
Annual	99P	33P	38P	34P	42P		32P		150P		275P	
Year	**2006**		**2007**		**2008**		**2009**		**2010**			
Summer	495P		100P		343P		29P		67P			
Autumn	68P		64P		132P		157P		56P			
Winter	250P		7P		28P		65P		20P			
Spring	102P		49P		27P		38P		12P			
Annual	110P		102P		72P		69P		59P			

The letter "F" stands for "Failed" in table 4.11 whereby stream water quality was summarized and compared to the three standard guidelines criteria. Table 4.11 shows in detail that the Baynespruit had never met any standard criteria locally or internationally in the last decade 2000-2010.

Table 4-11 Summary of the Baynespruit water assessment based on local and international water quality standards guidelines criteria (The letter "F" stands for" Failed").

Summary of water quality guideline assessments referring the Baynespruit stream																		
Period	**2000**			**2001**			**2002**			**2003**			**2004**			**2005**		
WQG	**SA**	**USEPA**	**EU2006**	**SA**	**USEPA**	**EU2006**	**SA**	**USEPA**	**EU2006**	**SA**	**USEPA**	**EU2006**	**SA**	**USEPA**	**EU2006**	**SA**	**USEPA**	**EU2006**
Summer	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F
Autumn	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F
Winter	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F
Spring	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F
Annual	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F
Period	**2006**			**2007**			**2008**			**2009**			**2010**					
WQG	**SA**	**USEPA**	**EU2006**	**SA**	**USEPA**	**EU2006**	**SA**	**USEPA**	**EU2006**	**SA**	**USEPA**	**EU2006**	**SA**	**USEPA**	**EU2006**			
Summer	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F			
Autumn	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F			
Winter	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F			
Spring	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F			
Annual	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F	F/F	F	F			

It should be noted that the Baynespruit water is also used for primary activities. In this case the bathing guidelines criteria were used to assess the stream pollution risks posed to the users. After comparing the data to the EU standards criteria guidelines as shown in both tables, it can be seen that all samples had exceed the requirements provided in table 3.1 and thus had failed. The "P" entry in both tables 4.9 and 4.10 implies that the Baynespruit water quality was ranked as "Poor" with the lowest magnitude of 5 and the highest 797. This clearly shows how highly the Baynespruit is highly polluted.

4.10 *E-coli* effect on human health in the Baynespruit catchment area

E-coli levels in fresh water are directly correlated to the occurrence of gastrointestinal illnesses to swimmers and bathers. Figure 4.8 indicates how hazardous the Baynespruit is to communities settled along the stream, and to the uMsunduzi River itself. With the current *E-coli* level in Baynespruit, the stream is a major point source of pathogenic water pollution to the uMsunduzi River. Using equation 4, the danger posed by high *E-coli* level in the Baynespruit was estimated by establishing expected ratio of illness per 1000 swimmers or bathers as stated in section 3.4.4.

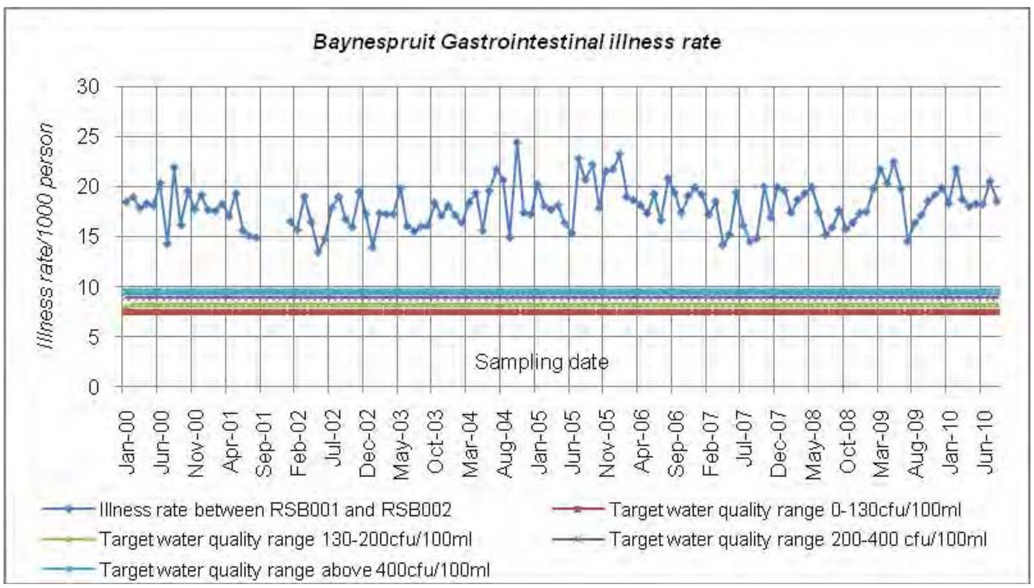

Figure 4-8 Baynespruit gastrointestinal illness rate per 1000 persons

According to figure 4.8, the minimum risk of being affected by gastrointestinal illness (GI) was 14 illnesses/1000 swimmers, or approximately 208 people affected monthly. The maximum risk of being affected by GI illness was 25 illnesses/1000 swimmers, or approximately 328 people affected every month. Both these figures exceeded the target water quality range set by the SAGWQ for expected illness that would occur, with an *E-coli* level of 130 cfu/100 ml, which is 8 illnesses/1000 swimmers or, approximately 103 people affected. Figure 4.9 shows estimations of 2% to 2.4 % of the population that live along the Baynespruit between RSB001 and RSB002 sampling points being at risk of infection by gastrointestinal illness each month if they swam in the stream. This would be disastrous if the communities who used the Baynespruit water for primary purposes such as irrigation of vegetables, car washing, and sometimes fishing at the confluence of the Baynespruit and uMsunduzi River. Appendix 5 provides a detailed calculation of risks of being infected by gastrointestinal illness to stream water users.

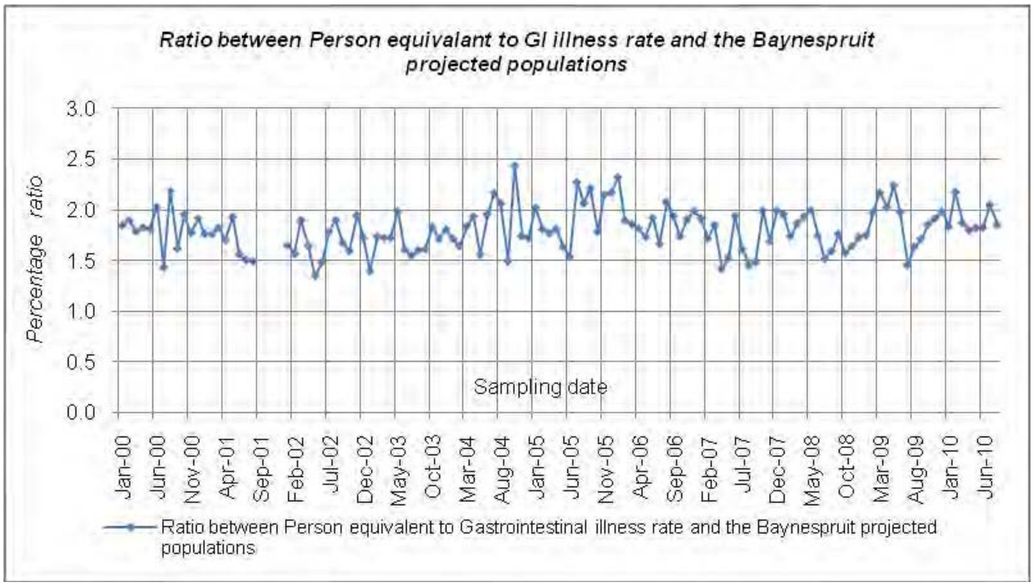

Figure 4-9 Ratio between person equivalents to gastrointestinal illness rate and the Baynespruit projected population

4.11 Discussion

The Baynespruit‛s pathogenic water pollution assessment in figure 4.1 highlights a chronic effect in the stream for the 2000-2010 decade whereby *E-coli* concentration had always been above the allowable *E-coli* level set by the local and international standards guidelines. The test for dilution and dispersion of *E-coli* concentrations in the Baynespruit analysis presented in figures 4.2 and 4.3 revealed that there have been first flushes of pathogenic water pollution in the stream soon after the beginning of the rainy season. This is followed by dilution effects characterized by low levels of *E-coli* in the stream that may be caused by more rain that continues to occur in the catchment. Observations made on figures 4.2 and 4.3 also revealed the existence of unregulated sources of *E-coli* between the RSB001 and RSB002 sampling points. These unregulated sources of pathogenic water pollution between the two sampling points have had a negative impact on the statistical analysis when trying to correlate *E-coli* counts at both sampling points to rainfall.

Figure 4.6 shows that accumulation of pathogenic water pollution occurred around the sampling points, suggesting this to be due to low flow in the catchment area during the dry season as previously revealed in figure 4.5 and 4.6. Zone A of figure 4.6 shows that pathogenic water pollution had been transferred from RSB001 to RSB002 when considering rainfall ranges that are above 15mm. The above mentioned observation reveals that there were flows in the Baynespruit caused by high rainfall in the catchment area. In order to establish the level of accuracy of the computed statistics, the data was statistically described and validity error ranged between 0 and 30%.

The next stage in the data analysis was to establish the strength of the correlation and statistical relationship between *E-coli* count at both sampling points using scatter plot in figure 4.5, figure 4.7 and Spearman"s rank correlation coefficient in table 4.2, ANOVA in table 4.3 and 4.4. Figure 4.5 revealed three zones of data set indicating the existence of unregulated sources of pathogenic water pollution between the sampling points, accumulation of pollution around each sampling point that may result from low flow in the stream during the dry season and, first flush of pollution that may be caused by high runoff in catchment. Table 4.2 showed that there was a significant correlation between *E-coli* count at RSB001 and RSB002 but no significant correlation between *E-coli* count at both sampling points and rainfall.

Figure 4.6 and ANOVA in tables 4.3 and 4.4 were used to establish the direct relationship between rainfall and *E-coli* concentrations at both sampling points. Figure 4.6 revealed again the existence of unregulated sources between the two sampling points that may be due to the direct discharge of sewage into the stream, the accumulation of pathogenic water pollution at both sampling points that may be due to low flows in the river during the dry season and the first flush that may be caused by high runoff during the rainy season. The ANOVA in tables 4.3 and, 4.4 show that there was no significant correlation between rainfall and *E-coli* concentration in the Baynespruit. In summary, statistical analysis carried out on *E-coli* counts for both sampling points and rainfall shows that *E-coli* concentrations in the river were not correlated to rainfall in the uMsunduzi catchment according to tables 4.3 and 4.4.

At the same time a significant correlation between *E-coli* count at both sampling points was observed referring to Spearman"s rank correlation coefficient. The comparison of the Baynespruit water quality, the local and international standards guideline criteria in summary in table 4.11 shows that the Baynespruit water is unfit for use and poses a high health hazard to the population settled along the stream or anyone who may come in contact with the stream water. A simple epidemiological study carried on the stream shows that 2% to 2.5 % of the population settled along the Baynespruit are at risk of being affected by gastrointestinal illness as indicated in figure 4.9.

4.12 Summary

In this chapter, the Baynespruit‟s water quality assessment and pathogenic water pollution propagation processes were explored. The stream water quality was statistically described and the statistical relationship between *E-coli* and rainfall in the uMsunduzi catchment were examined. The results strongly suggested that there is existence of unregulated pathogenic water pollution sources between the RSB001 and RSB002 sampling points. *E-coli* effects on human health along the stream were established. Chapter four presented the applications of the research methodologies designed in chapter three and, opened the doors to the conclusions and recommendations provided in chapter five.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The main objective of this research was to make a contribution towards the development of a mitigation strategy in order to improve the Baynespruit water quality. The research question relating to the main objective was: "can multivariate statistical analysis be used to clarify the source of pathogenic water pollution in the Baynespruit?" and "How high is the health risk posed by pathogenic water pollution to those who live along the stream?" To answer these questions, a summary of key results presented in chapter four are here reviewed and evaluated against the literature.

5.2 History of pathogenic water pollution in the Baynespruit

Raw sewage has been flowing into the Baynespruit for years as a result of sewer overflows through manhole covers due to blockages or heavy rainfall. Sewage discharges also originate from informal settlements where residents have no sanitation facilities and often use the stream banks instead (Neysmith, 2008). Terry (2002) recorded *E-coli* concentrations above 5000 cfu/100 ml, in 70-90% of the water samples, between 1990 and the present time. These records in most cases are higher than 610 000 cfu/100 ml (Terry, 2002), compared with the acceptable level of *E-coli* for swimming of 130 cfu/100 ml (DWAF, 1996). *E-coli* concentration variations ranged between 10 500cfu/100 ml and 2 190 000 cfu/100 ml, way above the level required by local and international water quality standards guidelines criteria. Discharges have resulted in fish deaths and blockages in the irrigation systems which farmers in Sobantu use to irrigate their gardens and small scale farm lands (WRC, 2002). Pathogenic water pollution trends in the Baynespruit show that *E-coli* concentration had changed significantly for the 2000-2010 decade.

5.3 Summary of key results

5.3.1 Dilution and dispersion in the Baynespruit

The results show that the Baynespruit has been severely affected by *E-coli* or pathogenic water pollution in the 2000-2010 decade. Figure 4.1 present readings of *E-coli* count ranging between 10500 cfu/100ml and 2419000 cfu/100 ml and, led to the conclusion that the stream has a chronic effect of *E-coli* contamination in the 2000-2010 decade.

Table 5.1 summarizes results observed in figure 4.2, 4.3, 4.4, 4.5 and 4.6 whereby average rainfall, median and extreme *E-coli* values were plotted against sampling date. Interpretations of the results in table 5.1 led to conclusions that unregulated sources of pathogenic water pollution are being drained in the stream during dry or the winter period and thus cause high levels of *E-coli* in the stream. At the same time high levels of *E-coli* may be flushed from the entire catchment area by stormwater drainages during rainy seasons. These figures point to the existence of pathogenic water accumulation around both sampling points that may be occurring in the dry season.

Table 5-1 Summary of key results

Indicators	**Summary of Key results**			
	January	**March**	**July**	**October**
Monthly average Rainfall in mm	137	78	0.3	72
Median Key values of *E-coli* counts according to figure 4.2				
***E-coli* at RSB001 cfu/100ml**	34420	37465	**16104**	30890
***E-coli* at RSB002 cfu/100ml**	**60450**	**57940**	11700	**61423**
Extreme Key values of *E-coli* counts according to figure 4.2				
***E-coli* at RSB001 cfu/100ml**	**976825**	176800	264843	**1184494**
***E-coli* at RSB002 cfu/100ml**	267437	**235350**	**700414**	564690

5.3.2 Statistical relationship between *E-coli* and rainfall

The relationship between *E-coli* concentrations and average rainfall was analyzed in order to confirm observations made in section 5.3.1. Two techniques used in the statistical analysis were correlation and regression, with the support of statistical tables in appendix 4. The hypotheses were as follows:

- ✓ Null hypothesis: "There is a significant relationship between independent and dependent variables;
- ✓ Alternative hypothesis: "There is no significant relationship between independent and dependent variables";

Independent variables considered in section 4.6.2.1 were *E-coli* concentration at RSB001 and rainfall; rainfall was considered as the independent variable alone in section 4.6.2.2. Dependent variables were considered as *E-coli* concentration in section 4.6.2.2, and *E-coli* concentrations at RSB001 and RSB002. The degree of freedom =126 and the sample population size was n=128. In appendix 4 of this research, the degree of freedom was set as 150. The key results were observed as follows:

- ✓ Spearman‟s rank correlation coefficient between RSB001 (independent variables) and RSB002 (dependent variables) was r = 0.51. The interpretation is that there is a significant correlation between *E-coli* concentration at RSB001 and RSB002 where r = 0.51, degree of freedom = 150 and, $P < 0.01$;
- ✓ Spearman‟s rank correlation coefficient between rainfall (independent variable), and *E-coli* concentration at RSB001 and RSB002 (dependent variables) was r = 0.04 and r = 0.12. Thus there is an insignificant correlation between *E-coli* concentration at RSB001 and RSB002, where r = 0.04 and 0.12, degree of freedom = 126 or 130, and $P > 0.01$;

It should be noted that both observations in this section support interpretations of key results from previous sections whereby *E-coli* concentrations at RSB001 compared to those at RSB002 were significantly correlated. This validated conclusions drawn from section 5.3.1 and 5.3.2 confirming the existence of unregulated sources of pathogenic water pollution along the stream.

5.3.3 Baynespruit water quality compared with local and international standards

At the local level, the Baynespruit water quality was compared to the SAGWQ. The key results from the comparison of the Baynespruit water quality to local and international standards guidelines criteria were as follows:

- ✓ The Baynespruit pathogenic water pollution showed unchanged trends at both sampling points when plotting the raw data against sampling dates. This suggested that pollution in the stream was chronic. In such a case the use of the median or averaged data was the most appropriate for comparison of the stream water quality to the SAGWQ;
- ✓ 100% of samples at both sampling points exceeded the first criterion of the SAGWQ, less than 20% of samples to exceed 100 cfu/100 ml: and 60-100% of these samples exceeded the second criterion of the SAGWQ; that the maximum 5% of the samples should be greater than 2000 cfu/100 ml;
- ✓ At the international level Baynespruit water quality was compared with the USEPA. The GM criterion was used in order to find out the SSM (SSL) in section 4.9.2 and appendix 2. The key results shows that the GM of the sample exceeded the standard guideline criterion 100% of time for each season in the decade 2000-2010 whereas the SSM to exceed allowable densities of *E-coli* and *Streptococcus* per 100ml by 95% to 100% at both sampling points RBS001 and RSB002;
- ✓ The 2006EU standard guidelines were used as international standard guidelines and were compared with the Baynespruit water quality. They required that 90^{th} or 95^{th} percentiles of the sample to be used over a three year period. At both sampling points, the Baynespruit water quality was “Poor”;

5.3.4 *E-coli* effect on human health in the Baynespruit

The Baynespruit stream is considered hazardous to the communities living along the stream. They use it for fishing, car washing, irrigation for vegetables and bathing. The level of risk present was evaluated, and the key results are summarized as follows:

- ✓ The minimum number of Baynespruit swimmers or bathers to be affected by gastrointestinal illness (G.I) is14 illnesses/1000 swimmers; approximately 208 people would be affected monthly;

- ✓ The maximum number is 25 illnesses/1000 swimmers; approximately 349 people would be affected monthly;
- ✓ About 2-2.5% of the population living along the Baynespruit stream between RSB001 and RSB002 sampling points are at risk of GI illnesses each month;

5.4 Recommendations

5.4.1 Mitigation action plan

It is a matter of urgency that the pathogenic water pollution levels should be reduced to required standards guidelines, or the spread of pathogens in the Baynespruit stream be stopped altogether. The action plan requires the participation of all stake-holders influencing or depending upon stream water. These include communities settled along the stream who might be disposing of fecal matter directly into the stream due to lack of proper sanitation facilities; and the WSA and WSP who are responsible for providing proper sanitation to the people. The steps required are:

1. Improvement of current monitoring methods;
2. The provision of engineering and scientific solutions;
3. Promote an awareness campaign concerning the dangers of disposal of fecal matter;

5.4.1.1 Improvement of the current monitoring

Little or no effort has been made in following up and addressing the causes of high level of pollution in the stream. In order to improve the current methodology the following activities are recommended:

- ✓ Conduct regular monitoring activities between sampling points;
- ✓ Analyze data regularly;

Establishing more sampling points between RSB001 and RSB002 would also be a vital step in monitoring pathogenic water. Three more points are required above RSB001 and, at least five more downstream of RSB002. The extra sampling points must be placed at intervals of 0.5-1 km based on high fluctuation of pollution data readings.

5.4.1.2 Engineering and scientific solutions

The treatment of polluted water is one of the options to be considered if the status of the Baynespruit is to be rehabilitated. One way in the process would be to dilute the stream with water that had been subjected to conventional water purification. But this will not deactivate pathogens. Disinfection could be carried out by applying chlorine. Although this is most efficient in killing germs during water treatment, it is suitable only in a controlled system like a water-works where the dosage is applied according to the system inflows and outflows (DWAF, 1996), and is not suitable for the Baynespruit rehabilitation. Unlike oxidation, temperature and solar radiation would be an effective means to reduce *E-coli* and other pathogens in a water body, but this at a very high cost. It should be noted that the die-off period of *E-coli* varies from less than a day to a couple of weeks, depending on external factors such as higher temperatures and solar radiation.

However, considering the current alarming status of the Baynespruit, chlorination may be one of the desperate methods that can be used. Considering that the eco-system that depends on the river and the negative effect that chlorination might have on the fauna and flora, this process may be considered as the last measure. Other disinfection methods, that may not affect sensitive species, may also be implemented such as heat treatment, oxidation and UV-light, but these methods are expensive, and in most cases are not applicable to a stream. Flushing the stream with clean water in order to dilute it may be considered as another solution, but at the higher cost.

It is recommended that methods used to treat sewerage should be implemented at each point source where pathogenic water pollution is detected. These methods are as follows:

- ✓ On-site treatment of latrines and septic tanks at each located point of sewerage to disinfect and stabilize them so that the quality of the effluent water reaches the standard guidelines as a minimum requirements before being released into the stream;
- ✓ Connection of each house to a sewer reticulation system and a waste water treatment plant. This will provide appropriate treatment before the disposal of the effluent into rivers. The Darvill WWTP would be used, but needs upgrading;
- ✓ Protection of existing sanitation infrastructures, and preventing illegal connections;
- ✓ Provision of pit latrines by the WSA as a basic sanitation service if sewerage network space is not available, or where the communities may not be able to connect to it;
- ✓ Flushing the Baynespruit stream;

5.4.1.3 Promoting campaign awareness

It is recommended to gear up campaign awareness against pathogenic water pollution in Baynespruit catchment. The WSP and WSA must inform all stakeholders about the alarming high levels of *E-coli* in the stream. All stakeholders must be informed about the negative impacts of *E-coli* on human health as revealed in section 4.6.2. They need to be informed of the sources of and dangers of pathogenic water pollution as explained in section 2.5. Finally, they need to be informed about how to mitigate pathogenic water pollution as recommended in chapter five. Neysmith (2008) and Pole (2002) had also suggested that campaign awareness be used as tool in order to reduce pathogenic water pollution in the Baynespruit.

5.5 Summary

This chapter outlined how the data was gathered and analyzed. The findings supported the research highlighted in the literature review and addressed the research question by answering the main and specific objectives of the research which were to:

- ✓ Compare the Baynespruit water quality with local and international standards water quality guidelines criteria ;
- ✓ Investigate the health impacts of pathogenic pollution on the people that use the Baynespruit stream;
- ✓ Assess trends in the stream pathogenic water pollution over the past decade 2000-2010;
- ✓ Investigate the relationship between *E-coli* concentrations at two separated sampling points along the stream, and compare concentrations at the sampling points to rainfall patterns in the catchment area;
- ✓ Propose mitigation measures to reduce or stop pathogenic water pollution in the stream.

Key results and the findings were used to draw the conclusions and recommendations of the research. This study examined in detail, the generation of pathogenic water pollution in the Baynespruit for the 2000-2010 decade and findings showed that there was no change in the level of fecal pollution during this time period. Pathogenic pollutants continued to far exceed national and international safety levels and reasons for their existence were explored as well as the impact on the health of communities situated along the Baynespruit. This research did not establish the source of *E-coli* due to a limited number of sampling points along the stream being available. It is suggested that future research should be carried out in order to locate all sources of pathogenic water pollution in the stream and, establish strategy in order to minimize pathogenic water pollution in the Baynespruit.

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APPENDICES

Appendix one: Summary tables for the Baynespruit water quality surveyed data

Table 1: Baynespruit Water Quality Survey 2000									
Data Records	Variables								
	Fixed variable	Measured variables							
	Date of survey	Rainfall @ Cedara (mm)	Rainfall @Albert fall (mm)	Rainfall Darvill (mm)	Rainfall Average (mm)	RSB001 (E-Coli) CFU/100ml	RSB002 (E-Coli) CFU/100ml	Total Coliforms CFU/100ml	Streptococci CFU/100ml
1	4-Jan-00	2.7	0.8	6.5	3.33	5900	64000	120000	
2	10-Jan-00			0	0	5600	3100	3100	
3	17-Jan-00	5.5	7.5	11.5	8.17	3200	44000	56000	10,900.00
4	24-Jan-00		0		0	14100	59000	94000	
5	31-Jan-00			0	0	49300	32000	160000	
6	7-Feb-00	1.1	2.9		2	82000	66000	90000	
7	14-Feb-00	4.3	9.4	0	4.6	38000	45000	63000	1,000.00
8	21-Feb-00	8.5	2.5	1	4	17000	19000	34000	
9	28-Feb-00	3.9	1		2.45	30000	17500	48000	
10	6-Mar-00			0	0	14000	30000	60000	
11	13-Mar-00	7.2	1.7		4.45	55000	7000	14000	
12	20-Mar-00	4.9	7.7	1.5	4.7	20400	19600	78000	13,300.00
13	27-Mar-00	1.8	2.7		2.25	19000	8600	24400	
14	3-Apr-00	6.8	2.2	0	3	4800	11600	16200	
15	10-Apr-00			0	0	32000	77000	143000	
16	17-Apr-00	1.1	0.5		0.8	27000	33000		6,400.00
17	25-Apr-00	0.7		0	0.35	25000	45000		
18	2-May-00	4	18.5	0	7.5	15700	5700	64000	
19	8-May-00			0	0	2630	1260	5600	
20	15-May-00			0	0	15000	4000	41000	4,400.00
21	22-May-00			0	0	18000	120000	290000	
22	29-May-00		0		0	12500	41000	110000	
23	5-Jun-00			0	0	4200	62000	180000	
24	12-Jun-00	1.3	1.6	0	0.97	76000	360000	590000	
25	19-Jun-00			0	0	1400	5000	14000	2,000.00
26	26-Jun-00			0	0	3600	200	500	
27	3-Jul-00			0	0	6000	1900	9100	
28	10-Jul-00			0	0	3600	3300	32000	
29	17-Jul-00		0		0	900	2400	8200	960
30	24-Jul-00			0	0	2200	3500	11200	
31	31-Jul-00			0	0	5000	5400	10000	
32	7-Aug-00			0	0	7500	490	9200	
33	14-Aug-00			0	0	370000	410000	530000	2,580.00
34	21-Aug-00		0		0	1200	2800		
35	28-Aug-00			0	0	1300	7800		
36	4-Sep-00	0.8	0.7		0.75	7800	12000	710000	
37	11-Sep-00	0.3		0	0.15	7700	30000	2800000	
38	18-Sep-00	15	15.8	2	10.93	7900	3900	11100	10,000.00
39	21-Sep-00	4.8	4.0	9	5.93				

Table 2: Baynespruit Water Quality Survey 2000 (Suite)									
Data Records	Variables								
	Fixed variable	Measured variables							
	Date of survey	Rainfall @ Cedara (mm)	Rainfall @Albert fall (mm)	Rainfall Darvill (mm)	Rainfall Average (mm)	RSB001 (E-Coli) CFU/100ml	RSB002 (E-Coli) CFU/100ml	Total Coliforms CFU/100ml	Streptococci CFU/100ml
40	2-Oct-00	0.3			0.3	4900	87000		
41	9-Oct-00		0.3		0.3	51000	200000	98000	
42	23-Oct-00	3.5	0.4		1.95	8100	22000	37000	8,200.00
43	30-Oct-00	4.1	4.7	5.5	4.77	33000	24000		
44	8-Nov-00	18.8	12.4	22	17.73				
45	13-Nov-00	0.2		0	0.1	5400	4000	42000	3,700.00
46	20-Nov-00	5.8	7.6	3	5.47	16000	88000	188000	
47	27-Nov-00	23.2	4.0	0	9.07	12000	17000	49000	
48	4-Dec-00	4.5	3.1	4.5	4.03	19000	9000	48000	
49	11-Dec-00	21.1	31.5	7	19.87	73000	93000		
50	18-Dec-00	0.3	0.3	1	0.53	28000	10000		7,600.00

Table 3: Baynespruit Water Quality Survey 2001

Data Records	Variables								
	Fixed variable	Measured variables							
	Date of survey	Rainfall @ Cedara (mm)	Rainfall @Albert fall (mm)	Rainfall Darvill (mm)	Rainfall Average (mm)	RSB001 (E-Coli) CFU/100ml	RSB002 (E-Coli) CFU/100ml	Total Coliforms CFU/100ml	Streptococci CFU/100ml
51	8-Jan-01	1	0.3	0	0.43	11000	3000		
52	15-Jan-01	0.8	0.9	1.6	1.10	60000	18600		1,980.00
53	16-Jan-01	0.1	0.7	0	0.27				
54	22-Jan-01	1	1.1	3	1.70	12400	5300	43000	
55	29-Jan-01	15.4	5.4	7.5	9.43	11600	22000	64000	
56	5-Feb-01	0.1	0.1	0	0.07	66000	16000	35000	
57	12-Feb-01			0	0	23000	18000		18,700.00
58	19-Feb-01	18.1	17.5	43.5	26.37	12700	12200	13800	
59	26-Feb-01			0	0	9000	5400	82000	
60	5-Mar-01			0	0	2100	3500	15000	
61	12-Mar-01	4.6	0.7	0	1.77	4800	4100	6000	
62	19-Mar-01	2.1	2.4	13.7	6.07	21000	17000	22000	
63	26-Mar-01	3.4	0.6	0	1.33	6200	134000	134000	
64	2-Apr-01		2.1	17	9.55	15000	39000	125000	
65	7-May-01			0	0	1290	3100	5300	
66	14-May-01			0	0	1200	610000	650000	1,300.00
67	21-May-01			0	0	14500	4600	7800	
68	28-May-01	0.3		0	0.15	4500	7800	54000	
69	4-Jun-01			0	0	500	32000	76000	
70	11-Jun-01			0	0	2390	18300	26700	
71	18-Jun-01			0	0	3200	18900	23900	2,900.00
72	25-Jun-01			0	0	4300	3600	4200	
73	2-Jul-01			0	0	3400	100	1500	
74	9-Jul-01			0	0	3800	12400	52000	
75	16-Jul-01			0	0	4400	2600	24000	1,800.00
76	23-Jul-01		0.1	0	0.05	800	4300	9800	
77	30-Jul-01		0.7	2.5	1.60	1800	8900	29000	
78	13-Aug-01			0	0	6500	3200	5500	3,500.00
79	20-Aug-01			0	0	17000	3600	17000	
80	27-Aug-01		0		0	6900	1200	54000	
81	3-Sep-01			0	0			0	

Table 4: Baynespruit Water Quality Survey 2002									
Data Records	Variables								
	Fixed variable	Measured variables							
	Date of survey	Rainfall @ Cedara (mm)	Rainfall @Albert fall (mm)	Rainfall Darvill (mm)	Rainfall Average (mm)	RSB001 (E-Coli) CFU/100ml	RSB002 (E-Coli) CFU/100ml	Total Coliforms CFU/100ml	Streptococci CFU/100ml
82	7-Jan-02	13	10.8	0	7.93	13000	4500		
83	14-Jan-02	1.2	2.1		1.65	2600	5700		6,200.00
84	21-Jan-02			0	0	5200	5700		
85	28-Jan-02	5.9	2.2	0.1	2.73	5900	31000		
86	4-Feb-02	1.1	1.1		1.1	9700	12000		
87	11-Feb-02		0		0	5700	5100		
88	18-Feb-02	0.3	0.7	2	1	5100	4500		
89	25-Feb-02	2.2	1.3	0	1.17	10100	13000		
90	4-Mar-02			0	0	43000	150000		
91	11-Mar-02	1.4	1.4	0	0.93	6100	6000		
92	18-Mar-02			0	0	2700	24000		
93	25-Mar-02			0	0	1600	2000		
94	2-Apr-02		0		0				
95	8-Apr-02			0	0	540	2070		
96	15-Apr-02	11	4.8	26	13.93	20300	19300		
97	22-Apr-02			0	0	500	6200		
98	13-May-02			0	0	2000	1500		
99	20-May-02			0	0	220	6900		
100	27-May-02			0	0	430	4100		
101	3-Jun-02			0	0	1480	15400		
102	10-Jun-02			0	0	1160	830		
103	18-Jun-02			0	0	4000	1800		
104	24-Jun-02			0	0	2640	274		
105	1-Jul-02			0	0	7300	1460		
106	8-Jul-02			0	0	27500	9800		
107	15-Jul-02		1.3	0	0.65	1700	2090		
108	22-Jul-02	4.9	1.5	1.4	2.6	14900	69000		
109	29-Jul-02			0	0	8900	1630		
110	12-Aug-02		0		0	1200	276000		
111	19-Aug-02		0.2	0	0.10	14200	24000		
112	26-Aug-02		2.8	11.5	7.15	19800	40000		
113	2-Sep-02			0	0	8200	4000		
114	9-Sep-02	4.2	1.6	0.3	2.03	22000	12100		
115	16-Sep-02			0	0	12100	5000		
116	23-Sep-02	0.7	0.9	2.5	1.37	1380	7200		
117	30-Sep-02	3.6	0.3	9.5	4.47	28800	16200		
118	7-Oct-02	3.2	2.7	2	2.63				
119	14-Oct-02			0	0	9200	6900		
120	21-Oct-02	1.7		0	0.85	11200	3000		

Table5: Baynespruit Water Quality Survey 2002 (Suite)									
Data Records	Variables								
	Fixed variable	Measured variables							
	Date of survey	Rainfall @ Cedara (mm)	Rainfall @Albert fall (mm)	Rainfall Darvill (mm)	Rainfall Average (mm)	RSB001 (E-Coli) CFU/100ml	RSB002 (E-Coli) CFU/100ml	Total Coliforms CFU/100ml	Streptococci CFU/100ml
121	28-Oct-02	10	12.3	6.4	9.57	28000	4600		
122	4-Nov-02	2.8	1.9	2.5	2.40	8600	1200		
123	11-Nov-02	0.3	0.3	0.1	0.23	112000	89000		
124	25-Nov-02		0		0	1660	4700		
125	2-Dec-02			0	0	4200	620		
126	9-Dec-02	0.9	0.5	0	0.47	24000	13000		
127	17-Dec-02	1.6	1.4	2.5	1.83	24190	32600		
128	23-Dec-02	4.1	5.7	1	3.60				
129	30-Dec-02	1.7	0.1	0	0.6	8160	2480		

Table6: Baynespruit Water Quality Survey 2003									
Data Records	Variables								
	Fixed variable	Measured variables							
	Date of survey	Rainfall @ Cedara (mm)	Rainfall @Albert fall (mm)	Rainfall Darvill (mm)	Rainfall Average (mm)	RSB001 (E-Coli) CFU/100ml	RSB002 (E-Coli) CFU/100ml	Total Coliforms CFU/100ml	Streptococci CFU/100ml
130	21-Jan-03	1.2	2.9	5.5	3.2				
131	31-Jan-03	0.5	0.2	0.3	0.33	4300	4610		
132	7-Feb-03			0	0	22800	7000		
133	19-Feb-03	0.7	2.7	0	1.13	43500	20600		
134	26-Feb-03	0.5	0.2	2	0.90	19860	5790		
135	3-Mar-03			0	0	24190	30800		
136	14-Mar-03			0	0	6870	8660		
137	20-Mar-03	10.7	9.1	19.5	13.10	21400	28500		
138	4-Apr-03	1.1	0.5	2.5	1.37	46100	10460		
139	7-Apr-03			0	0	36100	6870		
140	15-Apr-03	2.1	2.3	8	4.13	34500	17330		
141	25-Apr-03	0	0.3	0.5	0.27	3260	11200		
142	12-May-03	12.4	8.9	44	21.77	435000	241900		
143	20-May-03			0	0	12030	6290		
144	29-May-03			0	0	20100	4350		
145	6-Jun-03			0	0	15530	14140		
146	24-Jun-03	0.2	2.3	0	0.83	12500	3300		
147	4-Jul-03			0	0	11200	4110		
148	10-Jul-03			0	0	17330	3260		
149	14-Jul-03			0	0	4610	6870		
150	21-Jul-03			0	0	840	6130		
151	28-Jul-03			0	0	260	6490		
152	7-Aug-03			0	0	11200	10100		
153	15-Aug-03			0	0	9900	3100		
154	22-Aug-03			0	0	14200	14400		
155	29-Aug-03			0	0	900	5500		
156	3-Sep-03			0	0	6130	3500		
157	12-Sep-03	0.3		0	0.15	15530	12200		
158	15-Sep-03	0.9	1.2	1	1.03	18600	6100		
159	3-Oct-03	1.1	0.9	0.5	0.83	36500	15530		
160	10-Oct-03	0.2		0	0.1	4000	14700		
161	16-Oct-03	1.2	1.3	0	0.83	8160	2760		
162	21-Oct-03			0	0	31300	81600		
163	30-Oct-03		0.1	0	0.05	7400	4200		
164	7-Nov-03		0.6	0.80	0.70	16200	29100		
165	14-Nov-03	0.5	10.5	0	3.67	2600	3400		
166	18-Nov-03	0.5	0.9	0	0.47	24190	2300		
167	2-Dec-03			0	0	54800	20600		
168	10-Dec-03	0.9	1.1	6	2.67				

Table7: Baynespruit Water Quality Survey 2003 (Suite)									
Data Records	Variables								
	Fixed variable	Measured variables							
	Date of survey	Rainfall @ Cedara (mm)	Rainfall @Albert fall (mm)	Rainfall Darvill (mm)	Rainfall Average (mm)	RSB001 (E-Coli) CFU/100ml	RSB002 (E-Coli) CFU/100ml	Total Coliforms CFU/100ml	Streptococci CFU/100ml
169	18-Dec-03	1.2	0.1	1.7	1.00	19200	17330		
170	22-Dec-03	11.3	10.2	6	9.17	22800	38700		
171	29-Dec-03	0.5		0	0.25	1700	1300		

Table 8: Baynespruit Water Quality Survey 2004									
Data Records	Variables								
	Fixed variable	Measured variables							
	Date of survey	Rainfall @ Cedara (mm)	Rainfall @Albert fall (mm)	Rainfall Darvill (mm)	Rainfall Average (mm)	RSB001 (E-Coli) CFU/100ml	RSB002 (E-Coli) CFU/100ml	Total Coliforms CFU/100ml	Streptococci CFU/100ml
172	7-Jan-04	27.7	36.5	0	21.40	21800	6300		
173	15-Jan-04	1.1	15.4	32.5	16.33	29100	23600		
174	19-Jan-04			0	0	29900	4300		
175	13-Feb-04	17.1	32.2	12.5	20.60	6600	15500		
176	24-Feb-04	8.1	3.3	7.5	6.30	19400	11000		
177	1-Mar-04	2.5	0.5	6.5	3.17	17300	10100		
178	8-Mar-04		0.1	0	0.05	1800	98000		
179	18-Mar-04			0	0	1260	6130		
180	25-Mar-04	0.1	0.3	0	0.13	30800	11300		
181	1-Apr-04	0.8	0.9	0.9	0.87	440	38700		
182	5-Apr-04			0	0	9800	3260		
183	21-Apr-04	1.9	0.4	0	0.77	700	130000		
184	26-Apr-04	0.3	0.5	0.8	0.53	43500	198600		
185	6-May-04			0	0	4000	8600		
186	14-May-04			0	0	10460	7700		
187	20-May-04			0	0	7300	12100		
188	27-May-04			0	0	9100	6900		
189	11-Jun-04			0	0	86600	92100		
190	18-Jun-04			0	0	5600	34500		
191	23-Jun-04			0	0	2700	30800		
192	28-Jun-04	0.9	0.7	1.5	1.03	105000	60000		
193	8-Jul-04			0	0	9600	3600		
194	12-Jul-04			0	0	6300	4000		
195	23-Jul-04			0	0	141400	770000		
196	28-Jul-04	8.7	11.9	15	11.87	86000	44000		
197	4-Aug-04			0	0	400	2700		
198	12-Aug-04			0	0	5700	12200		
199	18-Aug-04			0	0	4000	34400		
200	26-Aug-04		4.8	12.5	8.65	241900	155300		
201	1-Sep-04			0	0	7000	3900		
202	10-Sep-04	0.8	0.7	2	1.17	10700	3000		
203	14-Sep-04		0.1	0	0.05	8000	300		
204	23-Sep-04	0.3		0	0.15	4300	2100		
205	28-Sep-04			0	0	7900	6200		
206	5-Oct-04			0	0	2000	7000		
207	11-Oct-04	1.6	1.7	2.7	2.00	19400	141400		
208	18-Oct-04	7.1	4.7	17.5	9.77	2419000	960000		
209	26-Oct-04	4.6	4.7	6.5	5.27	29000	30000		
210	4-Nov-04	1.1	1.5	0	0.87	5900	6000		

Table 9: Baynespruit Water Quality Survey 2004 (Suite)									
Data Records	Variables								
	Fixed variable	Measured variables							
	Date of survey	Rainfall @ Cedara (mm)	Rainfall @Albert fall (mm)	Rainfall Darvill (mm)	Rainfall Average (mm)	RSB001 (E-Coli) CFU/100ml	RSB002 (E-Coli) CFU/100ml	Total Coliforms CFU/100ml	Streptococci CFU/100ml
211	11-Nov-04	0.1	0.5	2.7	1.10	13300	14000		
212	15-Nov-04			0	0	1000	3800		
213	22-Nov-04	5.5	4.6	35	15.03	36500	30800		
214	30-Nov-04	13.1	12.1	2.1	9.10	14000	11000		
215	9-Dec-04	1.4	1.2	4	2.20	2000	24000		
216	17-Dec-04	24.1	13.1	0	12.40	14800	4000		
217	21-Dec-04	0.5		0	0.25	32600	17800		
218	30-Dec-04	0.4	1.5	0	0.63	17900	5500		

Table 10: Baynespruit Water Quality Survey 2005									
Data Records	Variables								
	Fixed variable	Measured variables							
	Date of survey	Rainfall @ Cedara (mm)	Rainfall @Albert fall (mm)	Rainfall Darvill (mm)	Rainfall Average (mm)	RSB001 (E-Coli) CFU/100ml	RSB002 (E-Coli) CFU/100ml	Total Coliforms CFU/100ml	Streptococci CFU/100ml
219	7-Jan-05			0	0	120300	57900		
220	12-Jan-05	3.5	6.3	0.5	3.43	6000	127000		
221	17-Jan-05	0.6	4.5		2.55	4880	92100		
222	28-Jan-05	11.3	7.3	0	6.20	155300	104600		
223	2-Feb-05			0	0	13000	99000		
224	10-Feb-05	5.8	5.9	2	4.57	1100	72700		
225	21-Feb-05	6.7	8.1	10.5	8.43	7500	155300		
226	28-Feb-05	0.5	6.1	37.6	14.73	8600	72000		
227	9-Mar-05	9.1	6.9	25.5	13.83	26100	29100		
228	16-Mar-05	3.2	3.7	0.6	2.50	15000	34500		
229	23-Mar-05			0	0	36500	7000		
230	30-Mar-05	0		0	0	8300	5000		
231	4-Apr-05			0	0	2400	2500		
232	14-Apr-05	0.2	2.5	0	0.90	1400	4000		
233	21-Apr-05	0.6	0.3	0	0.30	92100	3100		
234	26-Apr-05	7.9		0	3.95	33000	26000		
235	6-May-05			0	0	29100	9900		
236	13-May-05	3	0.1	0	1.03	26000	5600		
237	19-May-05	0.2		0	0.1	8600	2500		
238	3-Jun-05			0	0	1080	3450		
239	13-Jun-05			0	0	13300	1400		
240	22-Jun-05	2.5	1.9	6.5	3.63	1500	8700		
241	28-Jun-05	0.1		0	0.05	100	2400		
242	6-Jul-05			0	0	15530	24190		
243	15-Jul-05	0.3		0	0.15	880	17330		
244	21-Jul-05			0	0	173300	14140		
245	28-Jul-05			0	0	436000	866000		
246	3-Aug-05			0	0	12000	48800		
247	11-Aug-05	2.8	3.5	6.8	4.37	38000	65000		
248	16-Aug-05	1.8	1.3	0	1.03	1000	261000		
249	25-Aug-05			0	0	3200	1000		
250	30-Aug-05			0	0	16700	1046000		
251	8-Sep-05	2.4	1.6	0	1.33	30800	11500		
252	12-Sep-05			0	0	980000	3400		
253	20-Sep-05	0.1		0	0.05	700	86600		
254	27-Sep-05	0.4	0.5	0	0.30	1400	198600		
255	3-Oct-05			0	0	1170	173300		
256	10-Oct-05	0.7	0.3	1.5	0.83	4350	14000		
257	17-Oct-05	1.4	2.5	0	1.30	1000	92100		

Table 11: Baynespruit Water Quality Survey 2005 (Suite)									
Data Records	Variables								
	Fixed variable	Measured variables							
	Date of survey	Rainfall @ Cedara (mm)	Rainfall @Albert fall (mm)	Rainfall Darvill (mm)	Rainfall Average (mm)	RSB001 (E-Coli) CFU/100ml	RSB002 (E-Coli) CFU/100ml	Total Coliforms CFU/100ml	Streptococci CFU/100ml
258	26-Oct-05	0.7	0.6	0	0.43	6400	241900		
259	3-Nov-05	0.9	1	0	0.63	43500	48800		
260	7-Nov-05	0.9	6.1	6.5	4.50	99000	52000		
261	17-Nov-05		0.2	0	0.1	72700	20000		
262	22-Nov-05	1.2	0.1	0	0.43	6000	921000		
263	30-Nov-05	4.3	1.8	0	2.03	86600	230000		
264	5-Dec-05	0.9	2.3	0	1.07	1000	461000		
265	14-Dec-05	0.5		0	0.25	13500	130000		
266	28-Dec-05	4.9	5.7	0	3.53	241900	15000		

Table 12: Baynespruit Water Quality Survey 2006										
Data Records	Variables									
	Fixed variable	Measured variables								
	Date of survey	Rainfall @ Cedara (mm)	Rainfall @Albert fall (mm)	Rainfall Darvill (mm)	Rainfall Average (mm)	RSB001 (E-Coli) CFU/100ml	RSB002 (E-Coli) CFU/100ml	Total Coliforms CFU/100ml	Streptococci CFU/100ml
267	5-Jan-06	2.5	0.5	0	1.00	1986000	61300		
268	10-Jan-06	1.6	1.8	2	1.80	770000	308000		
269	16-Jan-06			0	0	44000	5000		
270	24-Jan-06	3.9	6.5	11.5	7.30	5000	15000		
271	1-Feb-06	14.3	4.6	0	6.30	12000	12000		
272	6-Feb-06	5.2		0.8	3.00	12030	22800		
273	15-Feb-06	0.8	0.3	0	0.37	18600	41100		
274	20-Feb-06	4.2	1.7	0	1.97	19200	158000		
275	27-Feb-06	1	0.7	0	0.57	38700	1000		
276	8-Mar-06			0	0	1000	2100		
277	15-Mar-06	0.8		0	0.4	54800	6870		
278	22-Mar-06	3.4		0	1.7	6300	61300		
279	29-Mar-06			0	0	61300	7100		
280	3-Apr-06	0.7	0.5	1.6	0.93	4800	6500		
281	11-Apr-06	21.9	29.7	22	24.53	21400	9900		
282	20-Apr-06			0	0	20600	8600		
283	25-Apr-06			0	0	38700	61300		
284	3-May-06	2.1		0	1.05	36500	20100		
285	9-May-06	1.1	2.6	0.2	1.30	9600	400		
286	18-May-06	0.2	2.5	0	0.90	46100	3650		
287	24-May-06			0	0	21000	7800		
288	30-May-06			0	0	3000	1500		
289	6-Jun-06			0	0	7700	57000		
290	12-Jun-06			0	0	11000	10000		
291	21-Jun-06			0	0	1900	241900		
292	27-Jun-06			0	0	4300	687000		
293	5-Jul-06			0	0	5600	3600		
294	12-Jul-06			0	0				
295	20-Jul-06			0	0	5000	73000		
296	27-Jul-06			0	0	4900	1000		
297	2-Aug-06	1.1	0.9	0	0.67	198600	29900		
298	8-Aug-06		0.8	0	0.40	1400	241900		
299	15-Aug-06	19.7	24.5	0	14.73	81600	2300		
300	24-Aug-06			0	0	4000	4350		
301	29-Aug-06	0.3		0	0.15	68700	2300		
302	7-Sep-06			0	0	2000	1330		
303	11-Sep-06			0	0	900	16600		
304	19-Sep-06		1.8	0	0.90	98000	99000		
305	26-Sep-06	11.1	15.3	0	8.80	8000	5600		

Table 13: Baynespruit Water Quality Survey 2006 (Suite)									
Data Records	Variables								
	Fixed variable	Measured variables							
	Date of survey	Rainfall @ Cedara (mm)	Rainfall @Albert fall (mm)	Rainfall Darvill (mm)	Rainfall Average (mm)	RSB001 (E-Coli) CFU/100ml	RSB002 (E-Coli) CFU/100ml	Total Coliforms CFU/100ml	Streptococci CFU/100ml
306	2-Oct-06	5.6	6.7	3	5.10	16200	61300		
307	9-Oct-06	9	6.0	0	5.00	9600	8800		
308	16-Oct-06	10	1.7	0	3.90	2800	2900		
309	25-Oct-06	0.7	1.3	0	0.67	6200	15700		
310	2-Nov-06	4	6	7	5.67	72700	43500		
311	6-Nov-06	0.3		0	0.15	4600	9600		
312	16-Nov-06	0.3		0.3	0.30	27600	45000		
313	20-Nov-06	0.4		0	0.20	1200	92100		
314	29-Nov-06	0.2	0.1	0	0.10	20100	8200		
315	6-Dec-06			0	0.00	1300	2200		
316	13-Dec-06			0	0.00	23100	81600		
317	19-Dec-06	3.5	3.9	0.8	2.73	5100	8600		
318	27-Dec-06	0.6	3.4	2.5	2.17	198600	24800		

Table 14: Baynespruit Water Quality Survey 2007									
Data Records	Variables								
	Fixed variable	Measured variables							
	Date of survey	Rainfall @ Cedara (mm)	Rainfall @Albert fall (mm)	Rainfall Darvill (mm)	Rainfall Average (mm)	RSB001 (E-Coli) CFU/100ml	RSB002 (E-Coli) CFU/100ml	Total Coliforms CFU/100ml	Streptococci CFU/100ml
319	4-Jan-07			0	0	7400	10100		
320	9-Jan-07	0.2	0.2	0	0.13	30800	14200		
321	15-Jan-07	0.5	2.3	0	0.93	4300	81600		
322	23-Jan-07	0.3		0	0.15	7000	241900		
323	31-Jan-07	5.4	6.9	20	10.77				
324	5-Feb-07	5.1	5.8	5.5	5.47	6100	5800		
325	14-Feb-07			0	0	23800	6800		
326	19-Feb-07	0.5		0	0.25	3600	1700		
327	26-Feb-07			0	0	5600	36500		
328	7-Mar-07	0.2	0.1	0	0.10	4100	54800		
329	14-Mar-07	0.9	1.5	0	0.80	6800	86600		
330	19-Mar-07			0	0	8800	57900		
331	28-Mar-07	1.5	1.9	0	1.13	38700	6000		
332	2-Apr-07			11	11	3200	4500		
333	10-Apr-07			0	0	3100	2300		
334	19-Apr-07	1.3		11	6.15				
335	24-Apr-07	0		0	0	3730	4110		
336	30-Apr-07			0	0	1100	7400		
337	8-May-07			0	0	7200	3600		
338	17-May-07			0	0	4800	6300		
339	23-May-07			0	0	7500	4400		
340	29-May-07			0	0	14700	3000		
341	5-Jun-07			0	0	8600	450000		
342	11-Jun-07			0	0	6200	3700		
343	20-Jun-07			0	0	1600	1400		
344	26-Jun-07	16.7		0	8.35	21900	1900		
345	4-Jul-07			0	0	72700	3100		
346	11-Jul-07			0	0	2300	2300		
347	19-Jul-07			0	0	57900	1300		
348	26-Jul-07		0.4	0	0.20	3100	2910		
349	1-Aug-07			0	0	6800	2910		
350	7-Aug-07		2.6	0	1.30	800	100		
351	14-Aug-07			0	0	2600	100		
352	23-Aug-07			58	58	2600	5480		
353	28-Aug-07			0	0	7270	4110		
354	6-Sep-07	1.7	1.4	0	1.03	4600	11100		
355	10-Sep-07			0	0	1000	3100		
356	18-Sep-07	0.1		0	0.05	2200	3200		
357	27-Sep-07	0.7	0.5	0.2	0.47	5400	1800		

Table 15 : Baynespruit Water Quality Survey 2007 (Suite)									
Data Records	Variables								
	Fixed variable	Measured variables							
	Date of survey	Rainfall @ Cedara (mm)	Rainfall @Albert fall (mm)	Rainfall Darvill (mm)	Rainfall Average (mm)	RSB001 (E-Coli) CFU/100ml	RSB002 (E-Coli) CFU/100ml	Total Coliforms CFU/100ml	Streptococci CFU/100ml
358	1-Oct-07	12.1	15.3	15	14.13	27600	141400		
359	8-Oct-07	23.8	23.5	2.5	16.60	100	600		
360	15-Oct-07	3.2	3.6	7	4.60	135000	54800		
361	24-Oct-07	4.6	1.9	16.5	7.67	29100	20100		
362	31-Oct-07	4.5	3.4	4.5	4.13	7500	7300		
363	8-Nov-07	8		0	4	2100	16100		
364	15-Nov-07	9.9	13.4	0	7.77	6300	5600		
365	20-Nov-07	5.5	2.5	1	3.00	10500	37800		
366	29-Nov-07	19.9	29.3	0	16.40	15200	3400		
367	6-Dec-07	7.6		3	5.3	16100	241900		
368	12-Dec-07	0.9		0	0.45	10500	649000		
369	19-Dec-07	1.1		0	0.55	19200	75000		
370	27-Dec-07	0.7		4.5	2.6	22800	17000		

Table 16: Baynespruit Water Quality Survey 2008									
Data Records	Variables								
	Fixed variable	Measured variables							
	Date of survey	Rainfall @ Cedara (mm)	Rainfall @Albert fall (mm)	Rainfall Darvill (mm)	Rainfall Average (mm)	RSB001 (E-Coli) CFU/100ml	RSB002 (E-Coli) CFU/100ml	Total Coliforms CFU/100ml	Streptococci CFU/100ml
371	3-Jan-08	8.9	8.1	0	5.67	5600	9600		
372	8-Jan-08	6	6.4	4	5.47	15800	15400		
373	14-Jan-08	0.3	9.6	0	3.30	36500	326000		
374	22-Jan-08			0	0	18000	10000		
375	30-Jan-08	0.1	0.1	0	0.07	26100	4300		
376	4-Feb-08			0	0	64900	13500		
377	12-Feb-08	26.7	12.5	26	21.73	15600	15200		
378	19-Feb-08	4.7	5.9	0	3.53	4000	2300		
379	26-Feb-08	4.7	2.7	0	2.47	7200	5170		
380	5-Mar-08			0	0	18500	4700		
381	12-Mar-08	5.6	16.1	8.5	10.07	64900	1120000		
382	19-Mar-08	4.5	3.8	8	5.43	7300	70000		
383	26-Mar-08		0.3	0	0.15	11800	10400		
384	2-Apr-08	0.9	0.1	2	1.00	2400	131000		
385	9-Apr-08	0.3		0	0.15	4500	64900		
386	16-Apr-08			0	0	51700	57900		
387	23-Apr-08			0	0	60000	30800		
388	30-Apr-08	0.1	0.1	0	0.07	23000	64900		
389	7-May-08			0	0	86600	1000		
390	15-May-08			0	0	22000	25000		
391	22-May-08			0	0	4600	198600		
392	29-May-08			0	0	38700	1000		
393	5-Jun-08		4.3	9.5	6.90	43000	25000		
394	12-Jun-08			0	0	3000	1600		
395	18-Jun-08	2.7	2.3	4	3.00	7500	15400		
396	26-Jun-08			0	0	6500	2900		
397	2-Jul-08			0	0	8160	5480		
398	9-Jul-08			0	0	9600	1000		
399	16-Jul-08			0	0	3000	8800		
400	23-Jul-08			0	0	8100	1400		
401	30-Jul-08			0	0	3500	1440		
402	6-Aug-08			0	0	13300	4350		
403	13-Aug-08			0	0	17800	4600		
404	20-Aug-08	1.1	0.9	3	1.67	4500	11200		
405	27-Aug-08	0.2	0.1	0.3	0.20	1700	4000		
406	3-Sep-08			0	0	11200	26000		
407	10-Sep-08		0.9	0	0.45	30800	8600		
408	17-Sep-08		0.4	0	0.20	28000	54800		
409	23-Sep-08			0	0	10400	10000		

Table 17: Baynespruit Water Quality Survey 2008 (Suite)									
Data Records	Variables								
	Fixed variable	Measured variables							
	Date of survey	Rainfall @ Cedara (mm)	Rainfall @Albert fall (mm)	Rainfall Darvill (mm)	Rainfall Average (mm)	RSB001 (E-Coli) CFU/100ml	RSB002 (E-Coli) CFU/100ml	Total Coliforms CFU/100ml	Streptococci CFU/100ml
410	29-Sep-08			0	0	9100	2700		
411	6-Oct-08	2.4	2.8	1.8	2.33	6500	17330		
412	13-Oct-08		0.4	0	0.20	9210	5800		
413	20-Oct-08			0	0	3100	3260		
414	27-Oct-08	2.9	0.6	1.5	1.67	7270	8600		
415	3-Nov-08	0.9	1.3	0	0.73	5500	6490		
416	10-Nov-08	3.5	2	3.2	2.90	6600	5480		
417	17-Nov-08	3.9	2.9	4.5	3.77	16200	21900		
418	24-Nov-08	0.2	0.8	3	1.33	2200	1610		
419	1-Dec-08		0.7	2	1.35	29100	14140		
420	9-Dec-08		0.3	0	0.15	24900	3200		
421	17-Dec-08	0.1		0	0.05	46100	19000		
422	23-Dec-08		8.5	0	4.25	7000	8000		
423	30-Dec-08		0.1	0	0.05	21900	6600		

Table 18: Baynespruit Water Quality Survey 2009									
Data Records	Variables								
	Fixed variable	Measured variables							
	Date of survey	Rainfall @ Cedara (mm)	Rainfall @Albert fall (mm)	Rainfall Darvill (mm)	Rainfall Average (mm)	RSB001 (E-Coli) CFU/100ml	RSB002 (E-Coli) CFU/100ml	Total Coliforms CFU/100ml	Streptococci CFU/100ml
424	5-Jan-09	6.2	2.5	0.5	3.07	15500	27200		
425	12-Jan-09	1.2	0.4	0.3	0.63	27600	19200		
426	19-Jan-09	3.1	7.5	2.5	4.37	16100	29100		
427	26-Jan-09	3.7	2.7	0.6	2.33	34500	11800		
428	2-Feb-09			6	6	219000	61000		
429	9-Feb-09	0.5	1.1	0	0.53	22000	12000		
430	16-Feb-09	6	2.9	8	5.63	12200	10000		
431	2-Mar-09	3.2	1.4	4	2.87	78000	98000		
432	9-Mar-09	0.2		0	0.1	326000	400000		
433	16-Mar-09			0	0	4000	5800		
434	23-Mar-09			0	0	13400	10100		
435	30-Mar-09	0.2		0	0.1	38700	5300		
436	6-Apr-09	6.7	0.9	0	2.53				
437	16-Apr-09			0	0	150000	8160		
438	20-Apr-09		2.1	0	1.05	60000	6000		
439	28-Apr-09			0	0	155300	141400		
440	5-May-09	6.7	7.1	6	6.60	866000	326000		
441	12-May-09			0	0	17000	16000		
442	20-May-09			0	0	4600	4600		
443	26-May-09			0	0	7400	5600		
444	3-Jun-09			0	0	22800	6600		
445	9-Jun-09			0	0	22800	2400		
446	17-Jun-09	0.7	0.2	0	0.30	11500	12030		
447	23-Jun-09	0.1		0	0.05	20000	8160		
448	30-Jun-09			0	0	241900	68700		
449	7-Jul-09			0	0	626	700		
450	14-Jul-09			0	0	6490	6400		
451	21-Jul-09			0	0	190	2600		
452	28-Jul-09			0	0	6500	1200		
453	5-Aug-09			0	0	1940	30800		
454	12-Aug-09			0	0	10460	6200		
455	18-Aug-09			0	0	3000	6800		
456	25-Aug-09			0	0	5900	4500		
457	2-Sep-09			0	0	3500	7900		
458	9-Sep-09	2.7	2.7	3.5	2.97	14800	38700		
459	16-Sep-09			0.4	0.4	18700	21000		
460	23-Sep-09	2.2	2.1	3	2.43	1100	11400		
461	1-Oct-09	14.3	11	0	8.43	3450	34500		
462	7-Oct-09			0	0	92100	12500		

Table 19: Baynespruit Water Quality Survey 2009 (Suite)									
Data Records	Variables								
	Fixed variable	Measured variables							
	Date of survey	Rainfall @ Cedara (mm)	Rainfall @Albert fall (mm)	Rainfall Darvill (mm)	Rainfall Average (mm)	RSB001 (E-Coli) CFU/100ml	RSB002 (E-Coli) CFU/100ml	Total Coliforms CFU/100ml	Streptococci CFU/100ml
463	14-Oct-09		1.1	0	0.55	18600	7200		
464	21-Oct-09	2.3	0.7	0	1.00	12200	20100		
465	28-Oct-09	16.8	14.1	0	10.30	77000	30800		
466	4-Nov-09	0.3		0.2	0.25	1000	2000		
467	11-Nov-09			3	3	3300	26000		
468	18-Nov-09	8	11.4	0.8	6.73	141400	51700		
469	25-Nov-09		0	0	0	3800	24800		
470	2-Dec-09	4.5	21.8	3.5	9.93	10500	57900		
471	9-Dec-09	18.3	8.2	11	12.50	22800	48000		
472	15-Dec-09	0.3	0	0.7	0.33	54800	61300		
473	23-Dec-09		5.3	0	2.65	15000	10000		
474	29-Dec-09		0	0	0	241900	5700		

Table 20: Baynespruit Water Quality Survey 2010									
Data Records	*Variables*								
	Fixed variable	*Measured variables*							
	Date of survey	*Rainfall @ Cedara (mm)*	*Rainfall @Albert fall (mm)*	*Rainfall Darvill (mm)*	*Rainfall Average (mm)*	*RSB001 (E-Coli) CFU/100ml*	*RSB002 (E-Coli) CFU/100ml*	*Total Coliforms CFU/100ml*	*Streptococci CFU/100ml*
475	4-Jan-10	4.8	2	0.3	2.37	11800	18500		
476	11-Jan-10	1.7	0	0.5	0.73	3000	63000		
477	18-Jan-10		0	0.5	0.25	43500	46000		
478	27-Jan-10		0	74	37	4000	6000		
479	1-Feb-10	1.5	5.7	5	4.07	51700	141400		
480	8-Feb-10		0	0	0	11100	13300		
481	15-Feb-10		0	0	0	930000	30800		
482	22-Feb-10		0	0	0	53000	31000		
483	1-Mar-10		0	0.1	0.05	79000	4000		
484	8-Mar-10		0	0	0	70000	4000		
485	15-Mar-10		0	1.1	0.55	61300	54800		
486	24-Mar-10		3.3	0	1.65	9300	13700		
487	29-Mar-10		0	0	0	6600	12400		
488	8-Apr-10		0	1.5	0.75	98000	3600		
489	12-Apr-10		0	0	0	8000	7300		
490	22-Apr-10		0	0	0	198600	6100		
491	26-Apr-10		0	0	0	19000	9300		
492	4-May-10			0	0	104600	3100		
493	11-May-10			0	0	98000	9600		
494	18-May-10			0	0	248000	9600		
495	25-May-10			0	0	68700	3900		
496	1-Jun-10			0	0	155000	7900		
497	8-Jun-10			0	0	22000	4900		
498	15-Jun-10			0	0	3000	19200		
499	22-Jun-10			0	0	2100	6800		
500	29-Jun-10			2	2	1600	5500		
501	6-Jul-10			0	0	6490	613000		
502	13-Jul-10			0	0	51700	12000		
503	20-Jul-10			0	0	36000	3000		
504	27-Jul-10			0	0	7500	700		
505	3-Aug-10			0	0	3300	11600		
506	10-Aug-10			0	0	310000	1500		
507	17-Aug-10			0	0	3000	3450		
508	24-Aug-10			0	0	36500	8400		

Appendix two: Calculation of the Single sample limits (SSL)

Equation 3.1

$$SSL = GM * 10^{[CL*Log\sigma]}$$

Sources: USEPA (1986)

Whereby SSL means Singe sample limit;

GM is the Geometric mean of the indicated bacterial densities;

CL is the Confidence level factor;

Log σ is the Log standard deviation constant equal to 0.4;

No sample should exceed a one-sided confidence limit (C.L) calculated using the following confidence level factors:

- ✓ Designated bathing beach (75^{th} percentile) equal to 0.675;
- ✓ Moderate use for bathing (82^{nd} percentile) equal to 0.935;
- ✓ Light use for bathing (90^{th} percentile) equal to 1.280;
- ✓ Infrequent use for bathing (95^{th} percentile) equal to 1.650;

It should be noted that the geometric mean of the indicated bacterial densities will be based on a statistically sufficient number of samples and, must not exceed one or the other of the following as criterion one of the USEPA as reviewed in section 2.8.3:

- ✓ *E-coli* 126 cfu/100 ml; or
- ✓ *Enterococcus* 33 cfu/100 ml;

For *Enterococcus*

$$GM = 33cfu/100ml$$
$$Log\sigma = 0.4$$

A. Designated bathing (75^{th} percentile)

CL is 0.675

$$SSL = 33 * 10^{(0.675*0.4)}$$

$$SSL = 61.4 or 61$$

B. Moderate full body contact bathing (82^{nd} percentile)

CL is 0.935

$$SSL = 33 * 10^{(0.935*0.4)}$$

$$SSL = 78.075 or 78$$

C. <u>Lightly used full body contact recreation (90th percentile)</u>

CL is 1.28

$$SSL = 33 * 10^{(1.28*0.4)}$$

$$SSL = 107.278 or 107$$

D. <u>Infrequently used full body contact recreation (95th percentile)</u>

CL is 1.65

$$SSL = 33 * 10^{(1.65*0.4))}$$

$$SSL = 150.839 or 151$$

For *E-coli*

$$GM = 126 cfu / 100 ml$$
$$Log\sigma = 0.4$$

E. <u>Designated bathing (75th percentile)</u>

CL is 0.675

$$SSL = 126 * 10^{(0.675*0.4)}$$

$$SSL = 234.622 or 235$$

F. <u>Moderate full body contact bathing (82nd percentile)</u>

CL is 0.935

$$SSL = 126 * 10^{(0.935*0.4)}$$

$$SSL = 298.105 or 298$$

G. <u>Lightly used full body contact recreation (90th percentile)</u>

CL is 1.28

$$SSL = 126 * 10^{(1.28*0.4)}$$

$SSL = 409.609 or 409$

H. <u>Infrequently used full body contact recreation (95th percentile)</u>

CL is 1.65

$SSL = 126 * 10^{(1.65*0.4))}$

$SSL = 575.931 or 575$

Appendix three: Summary table of processed data

Table1:Monthly,seasonal and annual summaries from 2000 to 2002

Months	***Seasons***	***Years***	***Monthly Average Rainfall***	***Seasonal Average Rainfall***	***Annual Average Rainfall***	***Monthly 95th Percentile E-coli at RBS001***	***Monthly 95th Percentile E-coli at RBS002***	***Seasonal 95th Percentile E-coli at RBS001***	***Seasonal 95th Percentile E-coli at RBS002***	***Annual 95th Percentile E-coli at RBS001***	***Annual 95th Percentile E-coli at RBS002***
Jan-00	Summer 2000	2000	104.0	330.0	896.0	42260	63000	73743	62993	183501	330767
Feb-00			226.0			75400	62850				
Mar-00	Autumn 2000		78.0	199.0		49810	28440	47954	101000		
Apr-00			64.0			31250	72200				
May-00			57.0			17540	104200				
Jun-00	Winter 2000		4.0	4.0		65230	315300	290586	346233		
Jul-00			0.0			5800	5020				
Aug-00			0.1			315625	349670				
Sep-00	Spring 2000		70.0	230.0		7890	28200	45030	172835		
Oct-00			53.0			48300	183050				
Nov-00			107.0			15600	80900				
Dec-00	Summer 2001		134.0	345.0		68500	84700	67605	78379		
Jan-01		2001	103.0		874.0	52860	21490			55871	297899
Feb-01			108.0			59550	17700				
Mar-01	Autumn 2001		40.0	163.0		18780	116450	18402	479348		
Apr-01			113.0			15000	39000				
May-01			10.0			13000	519670				
Jun-01	Winter 2001		1.0	10.0		4135	30035	14971	28202		
Jul-01			2.0			5800	11700				
Aug-01			7.0			15990	3560				
Sep-01	Spring 2001		111.0	346.0		1	1	1	1		
Oct-01			100.0			1	1				
Nov-01			135.0			1	1				
Dec-01	Summer 2002		144.0	372.0		1	1	11746	25770		
Jan-02		2002	179.0		897.0	11935	27205			66353	185685
Feb-02			49.0			10040	12850				
Mar-02	Autumn 2002		57.0	133.0		37465	131100	35551	119789		
Apr-02			51.0			18324	17990				
May-02			26.0			1843	6620				
Jun-02	Winter 2002		21.0	218.0		3796	13360	24406	232876		
Jul-02			94.0			24980	57160				
Aug-02			103.0			19240	252400				
Sep-02	Spring 2002		55.0	167.0		27440	15380	94238	74051		
Oct-02			55.0			26320	6670				
Nov-02			57.0			101660	80570				
Dec-02	Summer 2003		150.0	308.0		24162	29660	39703	28618		
Jan-03			70.0			4300	4610				
Feb-03			88.0			41430	19240				

Table2:Monthly,seasonal and annual summaries from 2003 to 2005											
Months	***Seasons***	***Years***	***Monthly Average Rainfall***	***Seasonal Average Rainfall***	***Annual Average Rainfall***	***Monthly 95th Percentile E-coli at RBS001***	***Monthly 95th Percentile E-coli at RBS002***	***Seasonal 95th Percentile E-coli at RBS001***	***Seasonal 95th Percentile E-coli at RBS002***	***Annual 95th Percentile E-coli at RBS001***	***Annual 95th Percentile E-coli at RBS002***
Mar-03	Autumn 2003	2003	96.0	189.0	627.0	23911	30570	358619	30570	204580	50565
Apr-03			55.0			44600	16411				
May-03			37.0			393510	30570				
Jun-03	Winter 2003		13.0	37.0		15379	13137	16031	13693		
Jul-03			0.0			16104	6794				
Aug-03			25.0			13750	13755				
Sep-03	Spring 2003		47.0	169.0		18293	11590	34253	64200		
Oct-03			23.0			35460	68386				
Nov-03			100.0			23391	26530				
Dec-03	Summer 2004		74.0	361.0		50000	35985	47982	34585		
Jan-04		2004	148.0		830.0	29820	21980			1040784	740350
Feb-04			138.0			18760	15275				
Mar-04	Autumn 2004		79.0	89.0		28775	84995	37478	177979		
Apr-04			10.0			38445	188310				
May-04			0.4			10256	11575				
Jun-04	Winter 2004		14.0	64.0		102240	87285	199132	608707		
Jul-04			35.0			133090	661100				
Aug-04			15.0			206470	137165				
Sep-04	Spring 2004		70.0	258.0		10160	5740	1857650	756233		
Oct-04			69.0			2060500	837210				
Nov-04			120.0			32000	27440				
Dec-04	Summer 2005		132.0	468.0		30395	23070	138085	144534		
Jan-05		2005	228.0		757.0	150050	123640			595056	830590
Feb-05			108.0			12340	146855				
Mar-05	Autumn 2005		124.0	142.0		34940	33690	78406	32591		
Apr-05			15.0			83235	22700				
May-05			4.0			28790	9470				
Jun-05	Winter 2005		9.0	35.0		11530	7913	360310	874073		
Jul-05			0.1			396595	739729				
Aug-05			26.0			33740	889000				
Sep-05	Spring 2005		15.0	166.0		837620	181800	763510	727681		
Oct-05			75.0			6093	231610				
Nov-05			77.0			96520	782800				
Dec-05	Summer 2006		79.0	362.0		219060	427900	1645146	412210		
Jan-06			198.0			1803600	270995				
Feb-06			86.0			34800	134620				

Table3:Monthly,seasonal and annual summaries from 2006 to 2008											
Months	***Seasons***	***Years***	***Monthly Average Rainfall***	***Seasonal Average Rainfall***	***Annual Average Rainfall***	***Monthly 95th Percentile E-coli at RBS001***	***Monthly 95th Percentile E-coli at RBS002***	***Seasonal 95th Percentile E-coli at RBS001***	***Seasonal 95th Percentile E-coli at RBS002***	***Annual 95th Percentile E-coli at RBS001***	***Annual 95th Percentile E-coli at RBS002***
Mar-06	Autumn 2006	2006	92.0	221.0	903.0	60325	53170	58711	53548	89983	428153
Apr-06			94.0			36105	53590				
May-06			35.0			44180	17640				
Jun-06	Winter 2006		3.7	44.0		10505	620235	158731	578162		
Jul-06			0.3			5540	66060				
Aug-06			40.0			175200	199500				
Sep-06	Spring 2006		43.0	224.0		84500	86640	82418	86244		
Oct-06			77.0			15210	54460				
Nov-06			104.0			63680	82680				
Dec-06	Summer 2007		131.0	245.0		172275	73080	157777	203378		
Jan-07		2007	82.0		820.0	27290	217855			89983.0	475251.0
Feb-07			32.0			21145	32045				
Mar-07	Autumn 2007		149.0	185.0		34215	82295	32156	74762		
Apr-07			34.0			3651	6965				
May-07			3.0			13620	6015				
Jun-07	Winter 2007		48.0	77.0		19905	383055	65423	345270		
Jul-07			2.0			70480	3072				
Aug-07			27.0			7176	5206				
Sep-07	Spring 2007		25.0	361.0		5280	9915	10560	115127		
Oct-07			163.0			113820	124080				
Nov-07			173.0			14495	34545				
Dec-07	Summer 2008		85.0	265.0		22260	587935	55183	555530		
Jan-08		2008	114.0		607.0	34420	263880			67824	213654
Feb-08			67.0			57490	14945				
Mar-08	Autumn 2008		74.0	142.0		57940	57940	77308	167082		
Apr-08			67.0			58340	117780				
May-08			1.0			79415	172560				
Jun-08	Winter 2008		23.0	28.0		37675	23560	35620	22225		
Jul-08			0.0			9312	8136				
Aug-08			4.0			17125	10210				
Sep-08	Spring 2008		32.0	153.0		30240	36045	28692	34399		
Oct-08			36.0			8919	16021				
Nov-08			85.0			14760	19589				
Dec-08	Summer 2009		104.0	421.0		42700	18028	183640	53372		
Jan-09		2009	170.0		796.0	33465	28815			484412	306545
Feb-09			147.0			199300	56100				
Mar-09	Autumn 2009		37.0	97.0		276400	339600	692425	333590		
Apr-09			22.0			154770	128076				
May-09			39.0			738650	279500				

Table4:Monthly,seasonal and annual summaries from 2009 to 2010

Months	***Seasons***	***Years***	***Monthly Average Rainfall***	***Seasonal Average Rainfall***	***Annual Average Rainfall***	***Monthly 95th Percentile E-coli at RBS001***	***Monthly 95th Percentile E-coli at RBS002***	***Seasonal 95th Percentile E-coli at RBS001***	***Seasonal 95th Percentile E-coli at RBS002***	***Annual 95th Percentile E-coli at RBS001***	***Annual 95th Percentile E-coli at RBS002***
Jun-09	Winter 2009	2009	2.0	43.0	796.0	198080	57366	179250	54349	484412	306545
Jul-09			1.0			6499	5830				
Aug-09			41.0			9776	27200				
Sep-09	Spring 2009		26.0	218.0		18115	36045	117592	46665		
Oct-09			140.0			89080	33760				
Nov-09			52.0			120760	47845				
Dec-09	Summer 2010		120.0	299.0		204480	60620	739053	118418		
Jan-10		2010	137.0		228.0	38745	60450			613134	383547
Feb-10			43.0			798450	124840				
Mar-10	Autumn 2010		23.0	42.0		77200	46580	222192	42882		
Apr-10			8.0			183510	9000				
May-10			11.0			226490	9600				
Jun-10	Winter 2010		6.0	6.0		128400	16940	254918	472259		
Jul-10			0.0			49345	522850				
Aug-10			0.0			268975	11120				

Appendix four: Statistical tables for probability function distributions

Source: C.Dougherty 2001-2002

TABLE A.3 (continued)

F Distribution: Critical Values of F (5% significance level)

v_1 / v_2	25	30	35	40	50	60	75	100	150	200
1	249.26	250.10	250.69	251.14	251.77	252.20	252.62	253.04	253.46	253.68
2	19.46	19.46	19.47	19.47	19.48	19.48	19.48	19.49	19.49	19.49
3	8.63	8.62	8.60	8.59	8.58	8.57	8.56	8.55	8.54	8.54
4	5.77	5.75	5.73	5.72	5.70	5.69	5.68	5.66	5.65	5.65
5	4.52	4.50	4.48	4.46	4.44	4.43	4.42	4.41	4.39	4.39
6	3.83	3.81	3.79	3.77	3.75	3.74	3.73	3.71	3.70	3.69
7	3.40	3.38	3.36	3.34	3.32	3.30	3.29	3.27	3.26	3.25
8	3.11	3.08	3.06	3.04	3.02	3.01	2.99	2.97	2.96	2.95
9	2.89	2.86	2.84	2.83	2.80	2.79	2.77	2.76	2.74	2.73
10	2.73	2.70	2.68	2.66	2.64	2.62	2.60	2.59	2.57	2.56
11	2.60	2.57	2.55	2.53	2.51	2.49	2.47	2.46	2.44	2.43
12	2.50	2.47	2.44	2.43	2.40	2.38	2.37	2.35	2.33	2.32
13	2.41	2.38	2.36	2.34	2.31	2.30	2.28	2.26	2.24	2.23
14	2.34	2.31	2.28	2.27	2.24	2.22	2.21	2.19	2.17	2.16
15	2.28	2.25	2.22	2.20	2.18	2.16	2.14	2.12	2.10	2.10
16	2.23	2.19	2.17	2.15	2.12	2.11	2.09	2.07	2.05	2.04
17	2.18	2.15	2.12	2.10	2.08	2.06	2.04	2.02	2.00	1.99
18	2.14	2.11	2.08	2.06	2.04	2.02	2.00	1.98	1.96	1.95
19	2.11	2.07	2.05	2.03	2.00	1.98	1.96	1.94	1.92	1.91
20	2.07	2.04	2.01	1.99	1.97	1.95	1.93	1.91	1.89	1.88
21	2.05	2.01	1.98	1.96	1.94	1.92	1.90	1.88	1.86	1.84
22	2.02	1.98	1.96	1.94	1.91	1.89	1.87	1.85	1.83	1.82
23	2.00	1.96	1.93	1.91	1.88	1.86	1.84	1.82	1.80	1.79
24	1.97	1.94	1.91	1.89	1.86	1.84	1.82	1.80	1.78	1.77
25	1.96	1.92	1.89	1.87	1.84	1.82	1.80	1.78	1.76	1.75
26	1.94	1.90	1.87	1.85	1.82	1.80	1.78	1.76	1.74	1.73
27	1.92	1.88	1.86	1.84	1.81	1.79	1.76	1.74	1.72	1.71
28	1.91	1.87	1.84	1.82	1.79	1.77	1.75	1.73	1.70	1.69
29	1.89	1.85	1.83	1.81	1.77	1.75	1.73	1.71	1.69	1.67
30	1.88	1.84	1.81	1.79	1.76	1.74	1.72	1.70	1.67	1.66
35	1.82	1.79	1.76	1.74	1.70	1.68	1.66	1.63	1.61	1.60
40	1.78	1.74	1.72	1.69	1.66	1.64	1.61	1.59	1.56	1.55
50	1.73	1.69	1.66	1.63	1.60	1.58	1.55	1.52	1.50	1.48
60	1.69	1.65	1.62	1.59	1.56	1.53	1.51	1.48	1.45	1.44
70	1.66	1.62	1.59	1.57	1.53	1.50	1.48	1.45	1.42	1.40
80	1.64	1.60	1.57	1.54	1.51	1.48	1.45	1.43	1.39	1.38
90	1.63	1.59	1.55	1.53	1.49	1.46	1.44	1.41	1.38	1.36
100	1.62	1.57	1.54	1.52	1.48	1.45	1.42	1.39	1.36	1.34
120	1.60	1.55	1.52	1.50	1.46	1.43	1.40	1.37	1.33	1.32
150	1.58	1.54	1.50	1.48	1.44	1.41	1.38	1.34	1.31	1.29
200	1.56	1.52	1.48	1.46	1.41	1.39	1.35	1.32	1.28	1.26
250	1.55	1.50	1.47	1.44	1.40	1.37	1.34	1.31	1.27	1.25
300	1.54	1.50	1.46	1.43	1.39	1.36	1.33	1.30	1.26	1.23
400	1.53	1.49	1.45	1.42	1.38	1.35	1.32	1.28	1.24	1.22
500	1.53	1.48	1.45	1.42	1.38	1.35	1.31	1.28	1.23	1.21
600	1.52	1.48	1.44	1.41	1.37	1.34	1.31	1.27	1.23	1.20
750	1.52	1.47	1.44	1.41	1.37	1.34	1.30	1.26	1.22	1.20
1000	1.52	1.47	1.43	1.41	1.36	1.33	1.30	1.26	1.22	1.19

TABLE A.3 (continued)

F Distribution: Critical Values of F (1% significance level)

ν_2 \ ν_1	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20
1	4052.18	4999.50	5403.35	5624.58	5763.65	5858.99	5928.36	5981.07	6022.47	6055.85	6106.32	6142.67	6170.10	6191.53	6208.73
2	98.50	99.00	99.17	99.25	99.30	99.33	99.36	99.37	99.39	99.40	99.42	99.43	99.44	99.44	99.45
3	34.12	30.82	29.46	28.71	28.24	27.91	27.67	27.49	27.35	27.23	27.05	26.92	26.83	26.75	26.69
4	21.20	18.00	16.69	15.98	15.52	15.21	14.98	14.80	14.66	14.55	14.37	14.25	14.15	14.08	14.02
5	16.26	13.27	12.06	11.39	10.97	10.67	10.46	10.29	10.16	10.05	9.89	9.77	9.68	9.61	9.55
6	13.75	10.92	9.78	9.15	8.75	8.47	8.26	8.10	7.98	7.87	7.72	7.60	7.52	7.45	7.40
7	12.25	9.55	8.45	7.85	7.46	7.19	6.99	6.84	6.72	6.62	6.47	6.36	6.28	6.21	6.16
8	11.26	8.65	7.59	7.01	6.63	6.37	6.18	6.03	5.91	5.81	5.67	5.56	5.48	5.41	5.36
9	10.56	8.02	6.99	6.42	6.06	5.80	5.61	5.47	5.35	5.26	5.11	5.01	4.92	4.86	4.81
10	10.04	7.56	6.55	5.99	5.64	5.39	5.20	5.06	4.94	4.85	4.71	4.60	4.52	4.46	4.41
11	9.65	7.21	6.22	5.67	5.32	5.07	4.89	4.74	4.63	4.54	4.40	4.29	4.21	4.15	4.10
12	9.33	6.93	5.95	5.41	5.06	4.82	4.64	4.50	4.39	4.30	4.16	4.05	3.97	3.91	3.86
13	9.07	6.70	5.74	5.21	4.86	4.62	4.44	4.30	4.19	4.10	3.96	3.86	3.78	3.72	3.66
14	8.86	6.51	5.56	5.04	4.69	4.46	4.28	4.14	4.03	3.94	3.80	3.70	3.62	3.56	3.51
15	8.68	6.36	5.42	4.89	4.56	4.32	4.14	4.00	3.89	3.80	3.67	3.56	3.49	3.42	3.37
16	8.53	6.23	5.29	4.77	4.44	4.20	4.03	3.89	3.78	3.69	3.55	3.45	3.37	3.31	3.26
17	8.40	6.11	5.18	4.67	4.34	4.10	3.93	3.79	3.68	3.59	3.46	3.35	3.27	3.21	3.16
18	8.29	6.01	5.09	4.58	4.25	4.01	3.84	3.71	3.60	3.51	3.37	3.27	3.19	3.13	3.08
19	8.18	5.93	5.01	4.50	4.17	3.94	3.77	3.63	3.52	3.43	3.30	3.19	3.12	3.05	3.00
20	8.10	5.85	4.94	4.43	4.10	3.87	3.70	3.56	3.46	3.37	3.23	3.13	3.05	2.99	2.94
21	8.02	5.78	4.87	4.37	4.04	3.81	3.64	3.51	3.40	3.31	3.17	3.07	2.99	2.93	2.88
22	7.95	5.72	4.82	4.31	3.99	3.76	3.59	3.45	3.35	3.26	3.12	3.02	2.94	2.88	2.83
23	7.88	5.66	4.76	4.26	3.94	3.71	3.54	3.41	3.30	3.21	3.07	2.97	2.89	2.83	2.78
24	7.82	5.61	4.72	4.22	3.90	3.67	3.50	3.36	3.26	3.17	3.03	2.93	2.85	2.79	2.74
25	7.77	5.57	4.68	4.18	3.85	3.63	3.46	3.32	3.22	3.13	2.99	2.89	2.81	2.75	2.70
26	7.72	5.53	4.64	4.14	3.82	3.59	3.42	3.29	3.18	3.09	2.96	2.86	2.78	2.72	2.66
27	7.68	5.49	4.60	4.11	3.78	3.56	3.39	3.26	3.15	3.06	2.93	2.82	2.75	2.68	2.63
28	7.64	5.45	4.57	4.07	3.75	3.53	3.36	3.23	3.12	3.03	2.90	2.79	2.72	2.65	2.60
29	7.60	5.42	4.54	4.04	3.73	3.50	3.33	3.20	3.09	3.00	2.87	2.77	2.69	2.63	2.57
30	7.56	5.39	4.51	4.02	3.70	3.47	3.30	3.17	3.07	2.98	2.84	2.74	2.66	2.60	2.55
35	7.42	5.27	4.40	3.91	3.59	3.37	3.20	3.07	2.96	2.88	2.74	2.64	2.56	2.50	2.44
40	7.31	5.18	4.31	3.83	3.51	3.29	3.12	2.99	2.89	2.80	2.66	2.56	2.48	2.42	2.37
50	7.17	5.06	4.20	3.72	3.41	3.19	3.02	2.89	2.78	2.70	2.56	2.46	2.38	2.32	2.27
60	7.08	4.98	4.13	3.65	3.34	3.12	2.95	2.82	2.72	2.63	2.50	2.39	2.31	2.25	2.20
70	7.01	4.92	4.07	3.60	3.29	3.07	2.91	2.78	2.67	2.59	2.45	2.35	2.27	2.20	2.15
80	6.96	4.88	4.04	3.56	3.26	3.04	2.87	2.74	2.64	2.55	2.42	2.31	2.23	2.17	2.12
90	6.93	4.85	4.01	3.53	3.23	3.01	2.84	2.72	2.61	2.52	2.39	2.29	2.21	2.14	2.09
100	6.90	4.82	3.98	3.51	3.21	2.99	2.82	2.69	2.59	2.50	2.37	2.27	2.19	2.12	2.07
120	6.85	4.79	3.95	3.48	3.17	2.96	2.79	2.66	2.56	2.47	2.34	2.23	2.15	2.09	2.03
150	6.81	4.75	3.91	3.45	3.14	2.92	2.76	2.63	2.53	2.44	2.31	2.20	2.12	2.06	2.00
200	6.76	4.71	3.88	3.41	3.11	2.89	2.73	2.60	2.50	2.41	2.27	2.17	2.09	2.03	1.97
250	6.74	4.69	3.86	3.40	3.09	2.87	2.71	2.58	2.48	2.39	2.26	2.15	2.07	2.01	1.95
300	6.72	4.68	3.85	3.38	3.08	2.86	2.70	2.57	2.47	2.38	2.24	2.14	2.06	1.99	1.94
400	6.70	4.66	3.83	3.37	3.06	2.85	2.68	2.56	2.45	2.37	2.23	2.13	2.05	1.98	1.92
500	6.69	4.65	3.82	3.36	3.05	2.84	2.68	2.55	2.44	2.36	2.22	2.12	2.04	1.97	1.92
600	6.68	4.64	3.81	3.35	3.05	2.83	2.67	2.54	2.44	2.35	2.21	2.11	2.03	1.96	1.91
750	6.67	4.63	3.81	3.34	3.04	2.83	2.66	2.53	2.43	2.34	2.21	2.11	2.02	1.96	1.90
1000	6.66	4.63	3.80	3.34	3.04	2.82	2.66	2.53	2.43	2.34	2.20	2.10	2.02	1.95	1.90

$P_{0.01} = \sout{3.91}$ 4.75 > 0.377

$P_{0.05} = \sout{1.70}$ 1.54 > 0.377

Appendix five: Detailed calculated example of *E-coli* effect on human health in the Baynespruit

According to figure 4.8, the minimum risk of being affected by gastrointestinal illness (GI) was 14 illnesses/1000 swimmers, or approximately 208 people affected monthly. The maximum risk of being affected by GI illness was 25 illnesses/1000 swimmers, or approximately 328 people may be affected every month. Both these figures exceeded the target water quality range set by the SAGWQ for expected illness that would occur, with an *E-coli* level of 130 cfu/100 ml, which is 8 illnesses/1000 swimmers or, approximately 103 people affected. Figure 4.8 estimated that 2 to 2.4 % of the population that live along the Baynespruit between RSB001 and RSB002 sampling points would be at risk of being infected by gastrointestinal illness each month if they swam in the stream.

1. Reference: Appendix 3

The highest 95th percentile of *E-coli* count is estimated in October 2004 at RSB001 and is 2060500 cfu/100ml.At RSB002 in the same month *E-coli* count is estimated at 837210 cfu/100ml. The average of the 95th percentile of *E-coli* count at both sampling point in the same month is 1448855 cfu/100 ml per month. This is above 400 cfu/100 ml limit provided by local and international standards guidelines in section 3.4.4.

2. Applying Equation 3-4

$Y = -150.5 + 423.5(\log x)$ ………………………………………………….. (3-4);

Where by Y means illness rate/100 000 persons and;
X means number of *E-coli*/100 ml;

$$Y = -150.5 + 423.5*(1448855)$$

$$Y = 2500il\ln essrate/100000 persons$$

$$Y = 25il\ln essrate/1000 persons$$

Or 25 illnesses per 1000 swimmers per month;

3. Estimate of the minimum number of population at risk along the Baynespruit (figure 4-10)

The Baynespruit population was estimated at 12532 people in 2001(Stassa, 2001) in section 3.3. Applying the growth rate of 2.2% in a period of 10 years, this population (Z) is now estimated at 13842 people.
If the 25 illnesses/1000 swimmers per month is the risk of GI illness contamination along the stream, then the number (N) of people at risk is estimated as follows:

$N = Y * Z$

$$N = \frac{25 * 13843}{1000}$$

$N = 349\, people / moth$ (Refer section 4.10 and figure 4-8).The population that was at risk of contaminating G.I illness along the stream in 2004.

4. <u>Calculation of person equivalents to gastrointestinal illness rate figure 4-9</u>

The ratio (R) of person equivalents to gastrointestinal illness rate is calculated as follows:

$$R = \frac{N * 100}{Z}$$

If N=349 and Z=13843 then;

$$R = \frac{349 * 100}{13843}$$

$$R = 2.48\%$$

Figure 4-9 estimated that 2 to 2.4 % of the population that live along the Baynespruit between RSB001 and RSB002 sampling points would be at risk of being infected by gastrointestinal illness each month if they swam in the stream.