An Analysis of Water Quality discharging into the Berg River at Paarl, Western Cape

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Abstract

In densely settled urban and peri-urban areas of South Africa, stormwater infrastructure is frequently being used as a conduit for the daily discharge of effluents resulting in the deterioration of rivers and other receiving water bodies. This study investigates the pollution load from urban localities entering the Berg River at Paarl, and in particular, seeks to determine whether or not there is a difference in the pollution load immediately after periods of wet and dry weather conditions. Empirical studies found that the quality of stormwater soon after a rainfall event contains the highest concentration of pollutants but becomes diluted and less contaminated thereafter. Urban drainage infrastructure should not permit discharges via stormwater conduits during dry periods in countries that have separate stormwater and sewage reticulation systems, which is largely the case in South Africa. In this study a total of twelve sites were selected along a stretch of the Berg River within the confines of the urban boundaries of Paarl. Water samples were collected over a five month period on six separate occasions, each during conditions that were broadly representative of wet and dry weather conditions. Various physical and chemical water quality parameters were tested and analysed to determine the significance of any measurable differences in pollution levels between wet and dry conditions. Contrary to theory, the results show that there is no significant difference in pollution levels during wet and dry conditions in the study area. At some sampling sites the effluent load exceeding thresholds for the categorization of eutrophic water and bacteria levels exceeded the Department of Water Affairs water quality guidelines.

Declaration

I declare that this thesis is my own work, that it has not been submitted for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Sivile Mgese   Date: November 2010

Signed............................

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Chapter One: Introduction

1.1 Background and scope of study

Urban runoff is known to contain elevated levels of physical and chemical pollutants especially after rainfall events and that these levels are raised even further after prolonged dry periods in which there has been an accumulation of pollutants (Botkin & Keller, 1998; Jagals, 1997). Studies in South Africa suggest that pollution levels in urban areas remain high throughout wet and dry conditions because of continually flowing runoff from informal settlements where water quality is compromised by a combination of grey- and blackwater resulting in a toxic mix (Armitage *et al*, 2009; Fatoki *et al*, 2001; Venter *et al*, 1997). Field observations confirm that polluted runoff from urban surfaces, and not only stormwater, is found at various points along the Berg River in Paarl during both wet and dry conditions. This study is premised on these observations and research findings, and seeks to investigate claims made by Jagals (1997) and others that pollution levels are elevated during and immediately after rainfall events.

South Africa's surface water quality is threatened by increasing inflow of pollutants from various sources (Nkwonta & Ochieng, 2009; Venter *et al*, 1997). This threat is aggravated by the semi-arid climatic conditions found in large parts of South Africa and by an increasing load of general urban, municipal and industrial pollution (Fatoki *et al*, 2001; DWAF, 1996b). An increase in pollution, particularly in catchments situated in drier regions of South Africa, is at least one acknowledged reason for the rapid deterioration of surface water quality (Nkwonta & Ochieng, 2009). Researchers claim that conditions in an urban environment directly after rainfall events may contribute to even higher loads of pollutants in receiving water bodies and more particularly following a prolonged dry period (Garnaud *et al*, 1999). This study concurrently seeks to test this claim, that is, to determine whether an increase in pollution loading corresponds to rainfall events that are preceded by a prolonged period of dry weather conditions.

1.2 Hypothesis

There is no significant difference in the water quality that is being discharged into the Berg River during wet and dry weather conditions.

1.3 Research questions

The Berg River Dam provides water for the Greater Cape Town Metropolitan Area and it is also a source of irrigation for agricultural activities in the vicinity of towns such as Paarl and Wellington (Davies and Day, 1998). In addition, the Berg River serves as an environmental sink in that it receives polluted water from sources generated from agricultural return flows, effluent from Waste Water Treatment Works (WWTWs), and industries and urban settlements in the Berg River catchment. This broad context provides the scope for formulating the general aim of the study that seeks to determine whether or not a selection of pollution sources varies significantly in concentrations during wet and dry conditions as measured by the water quality at the point of discharge and the influence of this discharge on water quality in the Berg River.

The objectives are to:

- Identify point sources of discharge that enter the Berg River in the formal and informal urban area of Paarl;
- Sample and analyze water quality at each of the selected sites along the river;
- Statistically compare and contrast the findings at each site.

A recent decline in water quality of the Berg River, particularly during low flow periods, is a cause for concern (Jackson *et al*, 2007). Drier conditions result in a general decline in water quality because the concentration of contaminants is usually observed to be at elevated levels, but is also less diluted compared to wetter periods (de Villiers, 2007). In theory, therefore, higher volumes of runoff during wetter periods are assumed to have a lower impact on the receiving water bodies (Boyacioglu, 2006). The effect of wet and dry conditions on water quality has received only limited attention in the research literature (Chua *et al*, 2009; Jamwal *et al*, 2008; Lee *et al*, 2004; Jagals *et al*, 1995).

1.4 Study design

The selection of study sites was identified initially as stream channels found on government published topographic maps and confirmed later by field visits along the eastern banks of the Berg River at Paarl. In order to compare the quality of water from these point sources with that of in-stream flows, samples were taken from the river at distances of up to 50 metres upstream of these discharge points and between 5 and 20 metres downstream of these points. Samples were collected during wet and dry weather conditions. Some measurements were taken *in situ*, but this depended on the type of test, while others were analysed in the Water Analysis Laboratory in the Environmental and Geographical Science Department at UCT. Results from these tests were analysed further using the student T-test and ANOVA statistical test to determine if there were any significant differences in water quality during wet and dry weather conditions. Water quality was tested for pH, electrical conductivity (EC), *Escherichia coli (E. coli),* and orthophosphates ($PO_4^{\cdot\cdot}$). Each of these parameters was sampled at the 12 study sites along the Berg River. One of these sites (B1) was selected as a control site being upstream of the formal urban area of Paarl; and another (B12) was located approximately 2 kilometres downstream of the formal urban edge of Paarl (Figure 1.1).

1.5 The Berg River

1.5.1 Description of the Berg River

The Berg River catchment lies in the Western Cape; the river is over 300 km long and rises in the Groot Drakenstein Mountains; and drains an area of approximately 900 km^2 (Gorgens & Clercq 2005). It flows northwards through Paarl, Wellington and Gouda in the lower reaches where it is eventually joined by the Klein Berg before it enters the sea on the west coast at St Helena Bay (de Villiers, 2007; River Health Programme, 2004). The river has nine major and six minor tributaries including that of the Franschhoek and Wemmershoek rivers both of which are perennial (River Health Programme, 2004). The catchment is confined to the winter rainfall region of the Western Cape in which rainfall typically increases from west to east (River Health Programme, 2004). The geology in the catchment comprises largely of sandstone, with quartzite in the upper reaches and Cape granite in the middle reaches (de Villiers, 2007).

1.5.2 Pollution of the Berg River

The Berg River is polluted in a variety of ways, but principally through salinization from irrigation return flows; nutrient enrichment from agricultural runoff; effluent from WWTWs, industries and wine farms; invasion by alien, aquatic and riparian organisms; and runoff from informal settlements (Davies & Day, 1998). In the lower reaches of the Berg River, the Tulbagh WWTWs discharges approximately 0.2 million cubic meters per annum of treated waste water into a tributary of Klein Berg during the winter (River Health Programme, 2004). In addition, informal settlements along the river banks elevate the bacterial count organisms, particularly those near poorly serviced informal housing on the periphery of Mbekweni township (Paulse *et al*, 2009). Studies show that the river has already reached eutrophic status before it even passes the Mbekweni township in Dal Josafat (de Villiers, 2007).

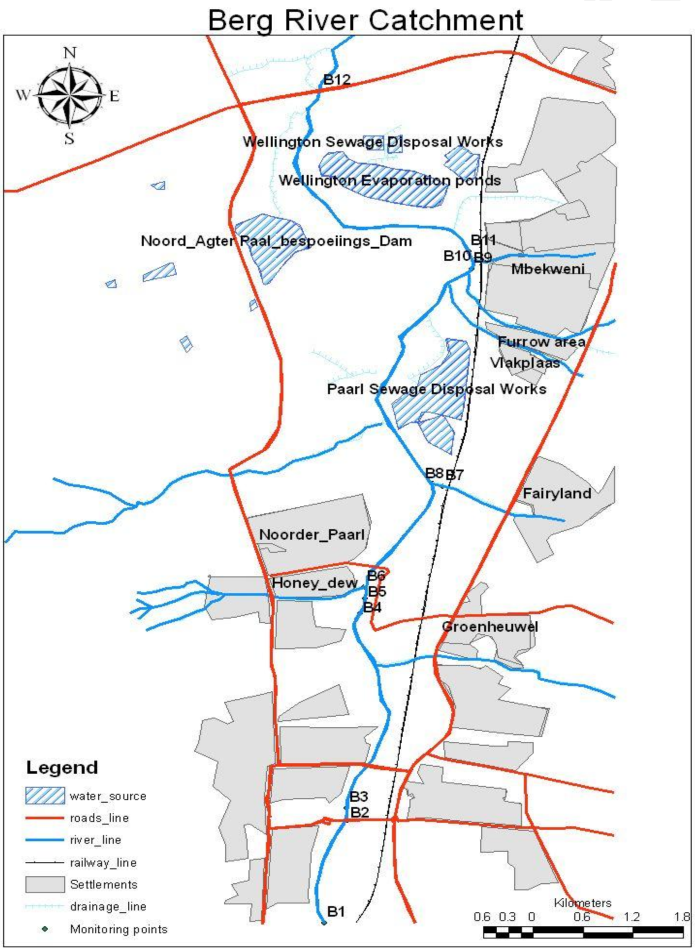

Figure 1.1 Sample sites along the Berg River

1.6 Outline of thesis structure

This first chapter has outlined the approach to the study and introduced the main argument and rationale for the research. The second chapter discusses water quality in the Berg River and factors that influence the pollution load. It also discusses pollution of urban river systems in general and identifies the leading causes of urban river pollution. Thereafter it presents a more detailed argument in which consideration is given to how the pollution load might vary during wet and dry weather conditions. The third chapter discusses study methods including a more detailed discussion of aims and objectives. The fourth chapter presents the results of water quality tests and discusses these in relation to during wet and dry weather conditions. Finally the fifth chapter concludes and offers some recommendations.

Chapter Two: Literature Review

2.1 Introduction

Wet and dry weather conditions are known to alter the level of pollution that is discharged into the receiving water bodies. For instance, during wet weather conditions, particularly after rainfall, there is evidence of increased faecal matter in South African rivers and this is elevated in areas where the discharge is being received from informal settlements (Jagals, 1997; Venter *et al*, 1997). In many cases South African water quality guidelines are exceeded after rainfall events so that water becomes unfit for consumption, recreational contact and irrigation (Paulse *et al*, 2009). Elevated levels of faecal matter during rainfall events frequently corresponds with water related illnesses such as diarrhoea (Jagals, 1997).

In South Africa, however, during dry weather conditions, pollution levels are compounded further by leaking sewage pipes and illegal connections that are responsible for the discharge of poor quality water into stormwater systems (Jagals, 1997; Coleman & Simpson, 1996). This is similar in effect to a combined sewer system where stormwater runoff and general urban effluent carries higher concentrations of pollutants into water bodies that has undergone minimal dilution (Fan, 2003).

2.2 Pollution during wet and dry weather conditions

Runoff from urban areas is often a major source of pollution that affects the quality of the receiving waters especially after a rainfall event when the 'first flush' occurs carrying with it pollutants such as oils, chemicals, litter and solid waste, and faecal remains from animals, all of which have accumulated on urban land surfaces during the dry period (Osman & Houghtalen, 2003). These pollutants are then washed off the land surface and swiftly transported along drainage systems and eventually find their way into the receiving waters. Land surfaces are unable to absorb precipitation once the infiltration capacity has been exceeded so that runoff and stormwater discharge becomes inevitable (Herricks, 1995).

Kloppers *et al* (1993) confirms that a relatively high concentration of pollution can be transported at 'first flush' if sufficient time has enabled pollutants to accumulate on surfaces during dry periods. Later in the runoff event, lower concentrations of contaminants become apparent in the runoff because the pollutants are diluted and washed out during rainfall

(Herricks, 1995). Mullis *et al* (1996) noted that the onset of precipitation results in higher aqueous loadings of all measured parameters with the highest values being associated with the largest storms. Nevertheless loadings of suspended material were found to be greatly influenced by the total volume of precipitation during storm events. Henning (2007) categorised these stormwater pollutants based on sources of origin (Table 2.1).

Table 2.1 Stormwater pollution threats to receiving waters (Henning *et al*, 2007)

Source	**Pollutants**
Residential land use runoff	Sediments, nutrients, oxygen depleting material, hydrocarbons, trace metals, pesticides and surfactants
Industrial land use runoff	Sediment, nutrient, oxygen depleting material, hydrocarbons, trace metals, pesticides and surfactants, pathogens
Commercial land use runoff	Sediment, nutrient, oxygen depleting material, hydrocarbons, trace metals, pesticides and surfactants, pathogens
Road runoff	Sediment and nutrient
Unstable and degraded waterways	Sediment, nutrient and oxygen depleting material
Open space runoff	Nutrient, litter and oxygen depleting material
Upstream inflows	Sediment, nutrient, litter and pathogens
Markets	Nutrients, oxygen depleting material, pathogens, sediments, litter and surfactants

Pollutants listed in Table 2.1 are generally found in runoff flowing from different types of urban land surfaces. The most common pollutants found in urban rivers include nutrients, heavy metals, organic material, suspended solids and microbiological quality (Henning, 2007). However, Yoon and Stein (2008) maintain that a high concentration of pollutants, particularly nutrients and suspended solids, may not compromise water quality directly because nutrient enrichment is a natural phenomenon that can take thousands of years to accumulate (DEAT, 1996).

By contrast urban catchments are significant contributors of nitrogen and phosphorus, and second only to agriculture runoff (King *et al,* 2007). Nutrients found in urban runoff constitute nitrogen (N) and phosphorous (P) (Coleman & Simpson, 1996). Both N and P can be in dissolved in a variety of ways: NO_2 and NO_3; inorganic orthophosphate or solid i.e. polyphosphate and ammonia; inorganic compound and organic P; and phosphorous is also found in a particulate form. A study conducted in dry weather conditions in the Shembe catchment showed a dissolved total phosphate ratio of 0.5 indicating a mobilization of particulate matter during stormwater runoff (Coleman & Simpson, 1996). The low flow runoff carried by stormwater conduits indicates that polluted water or debris can be deposited into drains and into water bodies without being carried by runoff (Kolsky, 1998). A study to investigate water quality undertaken in the urban drainage system of Nijmegen showed that a higher concentration of ammonia and phosphorous was present during wet weather conditions (Vermonden *et al*, 2009) and thus indicates higher mobility of these pollutants.

In Medicine Lake, Mennepin, it was found that the lake water quality suffered from high levels of nutrients that were being discharged by urban runoff (Pitt, 1995). Similarly, in South Korea in the city of Pusan, nutrient concentrations were eight times higher during wet conditions compared to drier periods (Pitt, 1995). By contrast, a substantial increase in phosphorus and nitrogen in the Berg River between Franschhoek and Paarl was found to be caused by discharges that originated from the Franschhoek WWTWs as well as agricultural runoff, and that these pollution levels were elevated during the drier, summer season (Mangnall *et al*, 2009). De Villiers (2007) found that elevated levels of phosphate in the Berg River were due to low flows of runoff during dry weather conditions when dilution was minimal.

In South Africa, the effect of wet weather conditions on runoff in urban catchments is consistent with findings from elsewhere. Along the Berg River, wet weather conditions result in increased runoff with a corresponding increase in nutrient levels (de Villiers, 2007). May and Sivakumar (2009) suggest that a commonly held assumption is that storms of longer duration typically have a lower rainfall intensity which would reduce the velocity of the runoff, and therefore limit the available pollutants flowing into freshwater systems. They concluded that a decrease in phosphorus levels was directly connected to lower rainfall intensity that in turn decreased the erosive capacity of runoff (May & Sivakumar, 2009).

2.3 Outflow from combined sewers during wet and dry weather conditions

2.3.1 Wet weather flow

Many cities and towns in Europe are serviced with combined sewer systems that have the potential to pollute water resources (Gasperi *et al*, 2010). Outflow from these combined sewer systems are known to cause a chemical, physical and bacteriological deterioration of water especially following wet weather conditions (Mullis *et al*, 1996). The impact of these combined sewers is elevated for various reasons including that of increased levels of organic matter combined with the discharge of stormwater; and the slow settling velocities of suspended matter in combined sewers because of higher volumes of stormwater that might exceed the capacity of the treatment plant to process increased inflow (Chebbo *et al*, 2001). While combined sewers were found to contaminate the receiving water at the onset of a rainfall period, these systems do have an advantage in being able to decrease the pollution load during low flow, and dry weather conditions (Lessard *et al*, 1982). In a study that was conducted to analyse the quality of combined sewers in the catchment of a Montreal suburb during a rainfall event, it was found that the concentrations of suspended solids, Biological Oxygen Demand (BOD), total carbon and nitrogen were all increased temporarily at the onset of a rainfall event because of the 'first flush' effect; that the concentration of ammonia nitrogen decreased during rainfall events; and that there was a steady increase in the concentration of pollutants towards the end of a rainfall event. The study concluded that concentrations do not vary with flow except at the onset of a rainfall event (Lessard *et al*, 1982). Wet weather runoff accounts for approximately 95% of the organic load, while the remainder includes heavy metals that are drawn along a myriad of drainage pathways after a single storm event (Fan, 2003).

Polluted water conveyed by combined sewer systems during wet weather conditions shows a direct link between suspended solids and water turbidity. In a study that examined nine rainfall events, the presence of suspended solids was found to be most significant in runoff followed by BOD concentrations (Lessard *et al*, 1982). Concentrations of suspended solids measured from Marias urban catchment confirmed these findings. The study found higher concentrations of suspended solids from combined sewer systems during wet weather flows (Chebbo, 2001). By contrast, in a study that investigated a small urban catchment north of London, it was found that combined sewer outflow produced relatively low concentrations of suspended solids but had higher levels of organic material (Mullis *et al*, 1996). This finding is contrary to many other studies presented in the literature that maintains a direct relation between rainfall intensity and levels of suspended solids. The study indicated that ‘‘factors other than the total volume of precipitation influence the loading of suspended material during storm events’’ (Mullis *et al*, 1996, p 389).

A further study showed that the highest loadings of BOD, ammonia, nitrate and phosphate were associated with the largest storm event characterised by the total discharge, rainfall volume and storm flow duration (Mullis *et al*, 1996). A total of 31 rainfall events were studied in the Marais catchment in Paris which aimed at understanding the characteristics of the flow and included an analysis of total volume, runoff volume, flow duration, and the duration of the previous dry weather period (Gromaire *et al*, 2000). The study concluded that maximum rainfall intensity and the duration of previous dry weather conditions were significant factors that resulted in increased runoff pollution and pollution of the receiving water bodies.

Some generalisations can be established from the foregoing discussion in regard to hydraulics, duration and response of flows following dry weather conditions, but it is not possible to generalise about water quality. If anything, water quality studies show inconsistent results with regards to chemical and physical composition of receiving water bodies during wet and dry weather conditions. For instance, water quality tests collected from a road highway in Japan showed a positive correlation of 0.877 between total dissolved solids and rainfall intensity due to the rapid discharge that carries material along a stream and then into a river system (Brodie, 2010). Mullis *et al* (1996) confirmed this finding and concluded that ‘‘the occurrence of a precipitation event results in a dramatic increase in the loadings of each parameter during each storm, with the largest increase associated with suspended solids and biological oxygen demand (BOD)’’ (Mullis, 1996, p 388). These studies suggest that worst case conditions do not necessarily occur during low flow periods but rather as a result of a storm event (Pitt, 1995). Pitt’s argument, among others, provides the basis for this study of the Berg River.

2.3.2 Dry weather flows

Low flow during dry weather conditions may discharge relatively low runoff volumes into the receiving waters, but concentrations of some pollutants may be exceptionally high as pollutants are poorly diluted during dry periods (Kolsky, 1998). Dry weather conditions, particularly if prolonged, encourage a gradual accumulation of pollutants, although different locations were found to accumulate pollutants at different rates in urban environments (Kolsky, 1998). The researcher found that in the dry periods, particularly between monsoons, solids accumulate on hardened surfaces such as drains, stormwater pipes and roads when there is an absence of rainfall and therefore concluded that there were no significant changes in the levels of solids before and after storms. He noted that ‘‘large amounts of solids were not flushed out during storms, or, if they were, they were replaced by others showing that major discharge of pollutants occurs during dry periods when ‘‘rubbish and construction debris find their way into the drain easily enough without being carried by runoff ’’ (Kolsky, 1998, p12).

Dry weather outflows from combined sewers can have severe consequences for receiving water bodies. This is particularly true with regard to the length or the extent of the dry weather period. Concentrations of pollutants, such as suspended solids, are relatively low for dry periods of less than 24 hours. However, dry weather periods longer than 24 hours have much higher suspended solid concentrations (Lessard *et al*, 1982). Longer dry weather periods between rainfall events or prior to the start of a rainfall event greatly influence the concentrations of different pollutants that are discharged into water bodies. The load and concentrations of these pollutants varies considerably from one storm event to the other depending on the length of the dry weather period (Fan, 2003).

In dry weather conditions, combined sewer systems receive and discharge variable volumes of pollutants. Suspended solids from dry weather flow in combined sewer systems range from 5 to 30% (Fan, 2003). The largest solids and pollutant load from combined sewers was most likely to have originated from sanitary waste water during dry weather conditions and that this created hazardous conditions in the receiving waters (Fan, 2003). Concentrations of ammonia and urea discharged into water bodies from combined sewer overflows were found to have negative effects on fish species (Field & O’Connor, 1997). As a result of these uncertainties and observations, more research is now being devoted to sediment contained in sewage as a major contributor of toxic substances in combined sewer overflows (Fan, 2003).

2.4 Water quality variables during wet and dry weather conditions

The effects of wet weather conditions on the quality of urban runoff have been investigated in urban catchments throughout the world. Urban stormwater has been identified as the main contributor to pollution of water resources particularly during wet weather conditions because urban runoff varies greatly in quality; volume of discharge; and pollutants (Lee *et al*, 2004).

Some studies show that pollutants increase considerably during dry weather conditions (Sansalone, 2003). A study conducted in Coyote Creek showed that dry weather concentrations are higher than those of wet weather concentrations by a factor of two to five. Concentrations of major ions and total solids were found to be significantly higher in urban runoff during dry weather conditions, but lower during wet weather conditions. It was found that ‘‘rain and the resultant runoff apparently diluted the concentrations of these constituents in the creek during wet weather’’ (Pitt, 1995, p147). Many constituents such as chemical oxygen demand, organic nitrogen and heavy metals were found to have much higher concentrations during the wet weather rather than during dry weather conditions in the same urban catchment (Pitt, 1995).

The quality of runoff from various urban geographical locations in India showed differences in wet and dry pollution load, reflecting largely the variability of pollution loading caused by a myriad of activities in the catchment. Runoff from commercial areas had higher microbiological pollution compared to runoff from slums in the Yamuna urban catchment. It was noted that unaccounted waste water from slums, rural villages and small scale industries were important non-point sources of pollution during wet and dry weather conditions (Jamwal *et al*, 2007). These researchers concluded that water quality during wet weather conditions in urban areas, where mixed land-use prevailed, was generally poor in comparison to dry weather conditions. They noted that areas drained by slums and institutional centres were major sources of human and animal pollution and that this was responsible for the high levels of faecal coliforms found in the receiving waters. In South African informal settlements it was found that stormwater runoff in conduits from these parts carried higher counts of faecal organisms into the receiving stream and that this was at levels similar to those found in raw sewage (Jagals *et al*, 1995).

Urban catchments in South African typically carry high levels of bacteria in which *E. coli* and faecal coliform are frequently measured and are found to have elevated levels during wet weather conditions. In a study of the peri-urban areas of Umtata, Eastern Cape, raised levels of faecal organisms were found during wet and dry weather conditions similar to those streams adjoining informal settlements and in the city centre of Umtata (Fakoti *et al*, 2001). Furthermore some popular Western Cape beaches and Centurion Lake, Pretoria, were declared unsafe for recreational use due to microbiological loading of urban runoff during both wet and dry weather periods (Coleman & Simpson, 1996). In southern California, discharge from nearby stormwater outlets in a relatively undeveloped catchment, showed raised levels of *E. coli*, *Enterococci* and total coliforms on adjacent beaches that exceeded water quality thresholds ten times more often during the wet weather conditions compared to dry. Storms with high rainfall intensity have been shown to be a major cause for exceeding water quality thresholds compared to smaller sized storms (Griffith, 2010).

A substantial increase in the concentrations of pollutants during wet and dry weather conditions has had a negative effect on the Berg River water quality. During the period from 1984 to 1995 an above average rainfall resulted in much greater discharge and consequently an accumulation of pollutants into the Berg River (de Villiers, 2007). It was noted by de Villiers (2007) that during this period elevated phosphorous levels caused eutrophic or high nutrient status conditions along the Berg River (de Villiers, 2007). On the other hand, reduced runoff in the Berg River during the period from 1995 to 2005 also had consequences for river water quality resulting elevated NO_x and consequent deterioration in water quality (de Villiers, 2007).

2.5 Pollution effects from dense settlements during wet and dry weather conditions

Stormwater runoff contains a variety of pollutants that are generated from many sources, and these have detrimental effects on water resources (Osman & Houghtalen, 2003). Runoff from dense informal settlements is estimated to account for considerable proportions of the total mass of pollutants in some receiving waters (Duke *et al*, 1998) with negative ecological effects (Yoon & Stein, 2008). The type and magnitude of pollution from various sources depends also on the density of urban development, type of urban activity, rainfall variables and proportion of receiving waters originating as urban runoff (Duke *et al,* 1998).

Densely populated areas with limited sanitary and drainage facilities are known points or areas of discharge that have the potential to raise pollution levels especially after rainfall events (Jagals, 1997) and typically when stormwater runoff washes faecal material into water bodies. In these areas, pollutants in the form of greywater and effluent from industrial and general stormwater runoff are sometimes discharged into receiving water bodies through pipes and stormwater canals during both wet and dry conditions. ‘‘When rainwater passes through these pipes, the runoff washes these pollutants out of their settled positions, pollutants are discharged into urban rivers together with surface pollutants’’ (Hongbin *et al,* 2009, p1186). These ‘‘point sources contribute a major portion of the flow in the river, especially during the dry season’’ (Venter *et al,* 1997, p124). High levels of faecal pollution drain from informal settlements where typically the flows have originated from those areas with inadequate sanitation and with serious impacts on the quality of water resources during both wet and dry weather conditions. In a study of an informal settlement in South Africa in which a densely populated settlement, consisting of 205 000 inhabitants, and serviced with only pit and bucket latrine sanitary facilities, it was found that faecal organism counts were exceptionally high during both wet and dry conditions (Venter *et al,* 1997).

Studies during wet and dry weather conditions found different types of faecal organisms in water bodies. Prolonged existence of certain faecal organisms corresponds to the ability of certain bacterial species to survive under certain physical and chemical conditions (Venter *et al,* 1995). Jagals *et al* (1995) noted differences in the concentration of faecal organisms in receiving water bodies during wet and dry weather conditions. He found that ‘‘the ratio of faecal coliforms to faecal *streptococci* in a stream downstream of a human settlement was 3.5 cfu during the dry season and 4.7 cfu after thundershowers’’ (Jagals *et al,* 1995, p240). These observations were confirmed by the presence of highly resistant *R coprophilus* bacteria which increased further downstream of the settlement during wet weather conditions. However, it was also established that the decrease in the counts of *R coprophilus* bacteria at the section of the river that joined the settlement, resulted from the dilution of effluent that consisted of low quantities of faecal organisms (Jagals *et al*, 1995).

Pollution load, including faecal organisms, that is discharged in urban areas during wet and dry weather conditions, varies considerably. A study conducted in urban residential areas of Free-State Province, South Africa, was able to differentiate the pollution distribution during wet and dry weather conditions. In the study, dysfunction sanitation and drainage facilities were found to contribute to the pollution of water resources caused by leaking sewer systems during dry weather conditions (Jagals, 1997). For example, the pollution load discharged in a stream near a central business district (CBD) had lower faecal counts compared to a site located near an informal settlement during dry conditions.

2.6 Summary

An assessment of the literature and research conducted along the Berg River reveals the severity of pollution along the river. Runoff from formal and informal settlements together with periodic outflows from WWTWs were found to be the main causes of pollution in the middle and the lower sections of the Berg River despite the fact that the discharge of effluent from the Paarl, Wellington, Pearl Valley Golf Estate and Drakenstein Prison WWTWs meets the required standards in terms of South African guidelines for bacterial thresholds for freshwater resources (Mangnall *et al,* 2009).

The assessment of literature from around the world, including from South Africa, indicates that there is a difference in urban water quality between wet and dry weather conditions. It is clearly established in the literature that excess rainfall flowing over urban land surface carries with it various loads of pollutants depending on the scale and extent of activities in the catchment. Pollution loading during wet and dry weather conditions is influenced by numerous factors which determine the quality of urban runoff. During wet weather conditions rainfall intensity plays a significant role in detachment and distribution of pollutants from urban catchments. High rainfall intensity that has high erosive potential, has the ability to distribute substantial loads of pollutants into receiving water bodies compared to that of subsequent storms. However, a study conducted north of London, United Kingdom, established that there were other factors other than the total volume of precipitation that controlled the loading of certain pollutants during storm events.

A change in river water quality is not entirely connected to rainfall intensity. Change in land use patterns may influence water quality (Ngoye & Machiwa, 2004) during both wet and dry conditions. Agricultural land surfaces are recognised as major contributors in the supply of nutrients and total suspended solids being discharged into receiving waters (de Villiers, 2007). Rainfall variables, such as rain intensity, would in most cases show a positive correlation with the loadings of some pollutants. However, not all rainfall variables correlate with loadings (Chua *et al,* 2009). They noted that only certain rainfall variables, such as rain intensity, correlated directly with high loads of some pollutants. Urban surfaces have been shown to contribute significantly to the pollution of receiving water bodies during wet and dry weather conditions. Much of this pollution would come from urban areas compared to rural area.

The first flush during wet weather significantly contributes to pollution of receiving water bodies and that this load was found to increase with an increase in the duration of antecedent dry period. High concentrations of pollutants also strongly correspond with dry weather conditions due to a lower dilution effect on receiving water bodies. Finally, storm runoff during both wet and dry weather conditions may alter the hydrological, physical and chemical quality of the receiving water bodies, but it is unclear to what degree stormwater runoff contaminates urban receiving water bodies because volume and duration of discharge were found to be highly spasmodic during wet and dry weather conditions.

Chapter Three: Methodology

3.1 Introduction

This chapter introduces the study design and methods, and describes how these are used to address the aims and objectives of this study. As described earlier, water samples were collected at various sites along a stretch of the Berg River that fell within the confines of the urban areas of Paarl, with the exception of one site that was selected to act as a reference point upstream of the urban edge and a further site situated approximately three kilometres downstream of the urban boundary of Paarl. Samples were collected during wet and dry weather conditions and subsequently analysed to determine levels of nutrients (P and N) and *E. coli*, these being typical indicators of water pollution. *In situ* measurements were also taken of Electrical Conductivity (EC), salinity, temperature and pH to determine the physical characteristics of the water.

Sample sites were identified initially through field observations and from topographical maps of the Berg River. The selected sites were all situated along the eastern banks of the river and surrounded by a mix of land uses including residential, industrial, public roads and informal settlement housing (See map Figure 1.1). A reference site (B1) was selected upstream of the urban area to provide baseline information about water quality before it passed through the formal settlement of Paarl. Samples were collected on six separate occasions to compare between sites and between wet and dry conditions.

The study method and design is outlined in Table 3.1.

Table 3.1 Methods and study design

Methods	**Study design**
Identify discharge points	To select point sources along the Berg River. To measure and compare pollution load generated from these sources.
Measure physical and chemical parameters	Monitor water quality variables discharged into the Berg River during wet and dry conditions.
Combine water quality data at each site	To examine water quality during consecutive wet and dry weather conditions.
Use statistics to compare and contrast pollution load at each site	Demonstrate the relationship between water quality variables and weather conditions (t-test, ANOVA tests, bar and line graphs).

3.2 Sample site selection

As described earlier, twelve sample sites were selected stretching from immediately outside the urban edge of Paarl, where the N1 highway bridge crosses the Berg River, to the bridge 1km north of Mbekweni beyond the formal urban edge of Paarl. Land use along this stretch includes agricultural, industrial, residential (formal and informal) and WWTWs. The table below lists the geo-referenced position of each sampling site (Table 3.2).

Table 3.2 Location of sample sites along the Berg River

Sampling points	Description of location	Geo-reference
B1	Under the N1 highway bridge in Paarl (upstream)	S33˚45.776 E018˚58.444
B2	Under Market Street bridge	S 33˚44.249 E018˚58. 274
B3	Approximately 50m upstream of the urban storm water drain	S33˚44.170 E018˚58.270
B4	Approximately 100m upstream of an industrial site	S33˚42.711 E018˚58.359
B5	An outlet from an industrial site that discharges into the Berg River	S33˚42.655 E018˚58.410
B6	Approximately 5m downstream of an industrial discharge point	S33˚42.609 E018˚58.412
B7	Approximately 20m upstream of Fairyland low income settlement storm water drain	S33˚42.545 E018˚58.824
B8	Fairyland storm water drain	S33˚41.489 E018˚58.819
B9	Approximately 2m upstream of the Oliver Tambo storm water drain	S33˚40.317 E018˚59.079
B10	Oliver Tambo storm water drain	S33˚40.249 E018˚59.109
B11	Approximately 20m downstream from the Oliver Tambo storm water drain	S33˚40.245 E018˚59.089
B12	Approximately 1km north of Mbekweni township	S33˚39.029 E018˚58.074

3.3 Water sample collection and methods of study

Water was collected at each sampling site and then analysed for physical, chemical and microbial properties. Sterilised 100ml bottles were used as sample containers. After collection, the water was stored in a cooler box and transported to the laboratory at the University of Cape Town. Bacteriological properties *(E. coli* and total coliforms) were analysed within 24 hours as these samples were required to be collected as aseptically as possible in order to reflect accurately the microbiological conditions at the time of collection (Environment Canada, 1983). After 24 hours of incubation, total coliform and *E. coli* counts were tallied under microscope.

Physical and chemical parameters of each sample were analysed in the Water Analysis Laboratory, while other parameters such as pH and temperature were measured *in situ* such as Electrical Conductivity and Total Dissolved Solids (TDS). Nitrites, Nitrates, Ortho-phosphate and Ammonia were analysed in the laboratory using HACH reagents, standard HACH methods and procedures, with the results being displayed on a digital photo spectrometer.

3.4 Statistical Analysis

Parametric statistical parameters such as mean, median and standard deviation were used to describe the variables and to compare results for wet and dry weather conditions.

The paired sample t-Test was applied to observed data of one sample and linked to the observations in the second sample (Pace, 2007). This test determines whether a statistically significant difference between the means of the first half and that of the second (Ngwenya, 2007). The t-Test was used to estimate the pollution load during wet and dry conditions. An ANOVA two factor test, without replication, was used to illustrate the degree of variance between sites, and between wet and dry conditions. The F-ratio factor derived from this test indicates if or whether a significant difference exists or not.

3.5 Water quality variables

The physical, chemical and bacteriological water quality variables selected for this study are outlined below. This study does not take into account or monitor trace metals or heavy metals. Only the selected parameters already mentioned were investigated in this study.

3.6 Study limitations and challenges

The study is confined to a relatively short period of five months during which the dry periods varied in length and rainfall intensity varied on the two separate occasions. Samples were therefore limited to four ‘dry’ and two ‘wet’ samples as shown in Table 4.1 thus weakening the potential of the statistical outcomes.

Chapter Four: Results and Discussions

4.1 Introduction

Chemical, bacteriological and physical water quality parameters were measured at a total of twelve sites that were visited on six separate occasions. Two site visits were conducted during wet conditions and four during dry. A dry period was chosen to represent conditions in which no rainfall had been recorded in the catchment seven days prior to sampling. Wet and dry climatic conditions during the data collection period are presented in Table 4.1 below. This chapter discusses the results and sets out to prove or disprove the hypothesis that water quality does not change significantly during wet and dry conditions. The assumption is that the discharge of polluted water during low flow periods remains relatively constant and that raised levels of pollution in the Berg River are not necessarily caused by wet weather conditions typical of the 'first flush' effect that elevates pollution levels as found in studies elsewhere.

Table 4.1 wet and dry climatic conditions

Date	Period	Temperature / Rainfall
14 April 2010 (Dry)	6-15 April	Max 23˚C; Mean18˚C
03 May 2010 (Dry)	26-7 May	Max 19˚C; Mean16˚C
12 May 2010 (Wet)	11-20 May	25-50mm
25 May 2010 (Dry)	18-27 May	Max 17˚C; Mean 14˚C
14 June 2010 (Wet)	11-20 June	50-100mm
30 June 2010 (Dry)	22-30 June	Max 19˚C; Mean 10˚C

4.2 Analysis of pH

4.2.1 Statistical Analysis

It is expected that the pH of the Berg River will become increasingly alkaline after receiving inflows of polluted water from various sources as it traverses through the urban area of Paarl. However, it is also expected that pH will be highly variable as it is subject to an array of complex factors including changes in temperature, volume, dilution and a tendency for hydrogen ions to interact with other components in solution. Given that the causal factors for pH are dynamic, it is unlikely that samples drawn from the Berg River will show any significant difference in pH under wet and dry conditions. Nevertheless, a t-Test using a pair wise two sample test of the means was used as an indicator of difference. The results, presented in Table 4.2, show that a tendency toward basic pH values were recorded during wet compared to dry conditions, and these are presented by a combination of samples collected during wet conditions as shown in Table 4.1. The results are unusual and contrary to expectations because rainfall and stream water flowing from mountainous regions in the Western Cape are slightly acidic because of the influence of the surrounding soil and natural vegetation (Davies & Day, 1998). It is possible that the 'first flush' effect was captured during wet conditions and that this then represents an elevated pollution load caused by the accumulation of compounds that had collected on the surface during the dry period. The output value of the t-Test (one tailed) was calculated at – 6.54 indicating above average pH levels during wet conditions (p = 2.06). The negative t-value suggests an increase in pH values during wet conditions with lower pH values during dry conditions. A Pearson correlation of 0.07 (Table 4.2) indicates an absence of any correlation between pH levels collected during both wet and dry conditions. Finally an ANOVA test was applied and this generated an F-ratio value of 0.06 (applied to data columns) indicating a difference only at certain sites along the Berg River. Sites which showed no significant difference in maximum or average pH levels are discussed in Figures 4.1 and 4.2 below.

Table 4.2 Results of the t-Test for pH: paired two sample for means for dry and wet conditions

	pH values (dry)	*pH values (wet)*
Mean	3.7125	7.339583333
Variance	14.67771277	0.463718972
Observations	48	48
Pearson Correlation	0.07035056	
Hypothesized Mean Difference	0	
Df	47	
t Stat	-6.537682931	
P(T<=t) one-tail	2.05746E-08	
t Critical one-tail	1.677926722	
P(T<=t) two-tail	4.11492E-08	
t Critical two-tail	2.01174048	

4.2.2 pH Trends

Maximum and average pH values vary in a range between 8 and 8.5 during wet and dry weather conditions along the Berg River in the upper and lower sites of the Berg River suggesting that there is no difference in pH values collected during wet and dry conditions. An increase in pH was regularly recorded at site B7 where a constant runoff was observed, generated largely from the informal settlement of Fairyland, and transported along a stormwater culvert that eventually discharged into the Berg River. An increase in pH was observed at sites where pollution sources enter the Berg River and this was a feature of both wet and dry conditions.

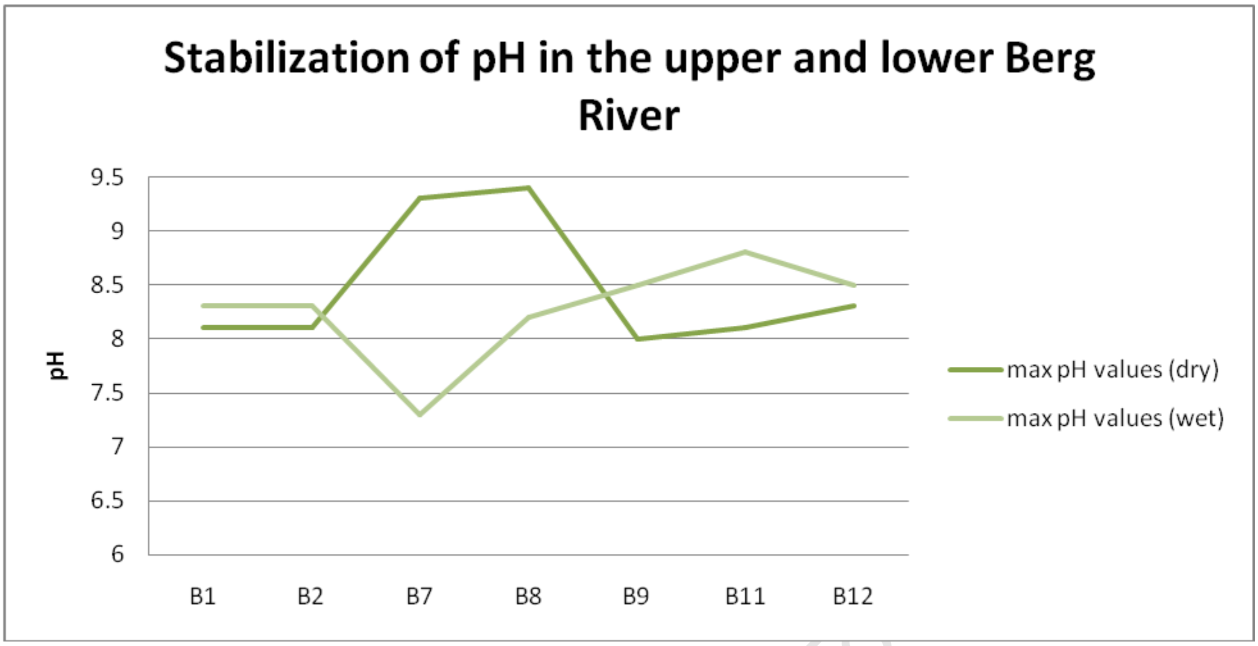

Figure 4.1 pH levels along the study area

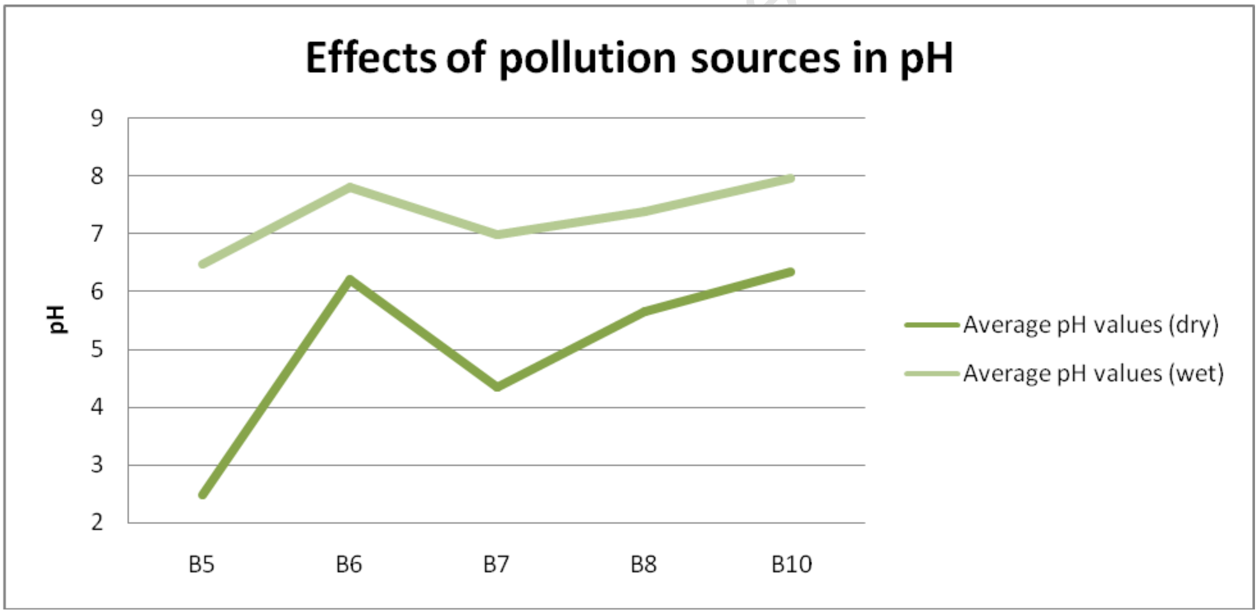

Figure 4.2 pH levels at sites with elevated pollution levels

The average pH was consistently found to be acidic during both wet and dry weather conditions at site B5 where effluent was observed being discharged from a point source and presumed to be generated from a milling industry nearby. An attempt to identify the exact source proved unsuccessful. As expected the pH level increased immediately downstream of B5 (industrial site) with a rapid increase in pH at other sites such as at site B7 (storm water canal from Fairyland); site B8 (in the Berg River immediately downstream of the Fairyland storm water runoff) and site B10 (Oliver Tambo storm water runoff in Mbekweni).

Effluent discharged into the river at site B5 resulted in a decrease in the average pH value during wet and dry conditions, but other sites showed no significant differences upstream or downstream of this site. Such industrial processes are not permitted to discharge effluents with a pH of less than or above 5.5-9.5 as they might cause significant detrimental effects on aquatic ecosystem (DWAF, 1996c). Effluent discharged into the river at B5 fails to meet the required standard. Variation in pH during wet and dry conditions is caused by discharges at various point sources where pollution is entering the Berg River.

4.3 Analysis of Electrical Conductivity

4.3.1 Statistical Analysis

Similarly electrical conductivity (EC) was measured at each of the sampling sites to determine the level of suspended solids held in the water column. A t-Test, two paired sample, shows a higher variance value for samples collected during dry conditions compared to wet (Table 4.3). A relatively strong positive correlation (p = 0.63) was found during wet and dry conditions in relation to all site data. The calculated t-Stats value of 0.38 suggests higher EC levels along the Berg River during dry periods than wet conditions, (p = 0.35, one tailed). This finding, although relatively weak, is expected since EC during low flow periods should have higher concentrations of pollutants given the continued inflow from the various point sources. However, an ANOVA test, two-factor without replication, determined an F-ratio value of 0.08 for columns indicated no significant differences in EC concentration along the Berg River during wet and dry conditions. A description of the findings is presented in Figures 4.3 and 4.4, and discussed in more detail in the next section.

Table 4.3 Results of the t-Test paired two sample for means of EC collected during wet and dry conditions

	EC µ/s (dry)	*EC µ/s (wet)*
Mean	209.0416667	190.2020833
Variance	196947.6578	59002.61
Observations	48	48
Pearson Correlation	0.630912892	
Hypothesized Mean Difference	0	
Df	47	
t Stat	0.376904956	
P(T<=t) one-tail	0.353970322	
t Critical one-tail	1.677926722	
P(T<=t) two-tail	0.707940645	
t Critical two-tail	2.01174048	

4.3.2 Trends in EC

In-stream EC samples increased in value with increasing distance downstream in both wet and dry conditions. This was expected because of numerous inflows from point sources such as from Paarl WWTWs and from informal settlements in the northern section of the study area. While there was no significant differences in EC at sites B1 to B3 during both wet and dry conditions, EC recorded at downstream sites during the dry conditions more than doubled.

At site B10, the storm water culvert conveyed a mix of effluent and greywater that entered the river from the Oliver Tambo informal settlement and resulted in an increase in EC concentrations in-stream at site B11 during both wet and dry conditions. As a consequence raised EC levels were found at site B12 during wet and dry conditions approximately 2 km downstream of site B11. In general, a substantial increase in maximum EC levels was observed during low flow periods compared to that of wet conditions especially further downstream.

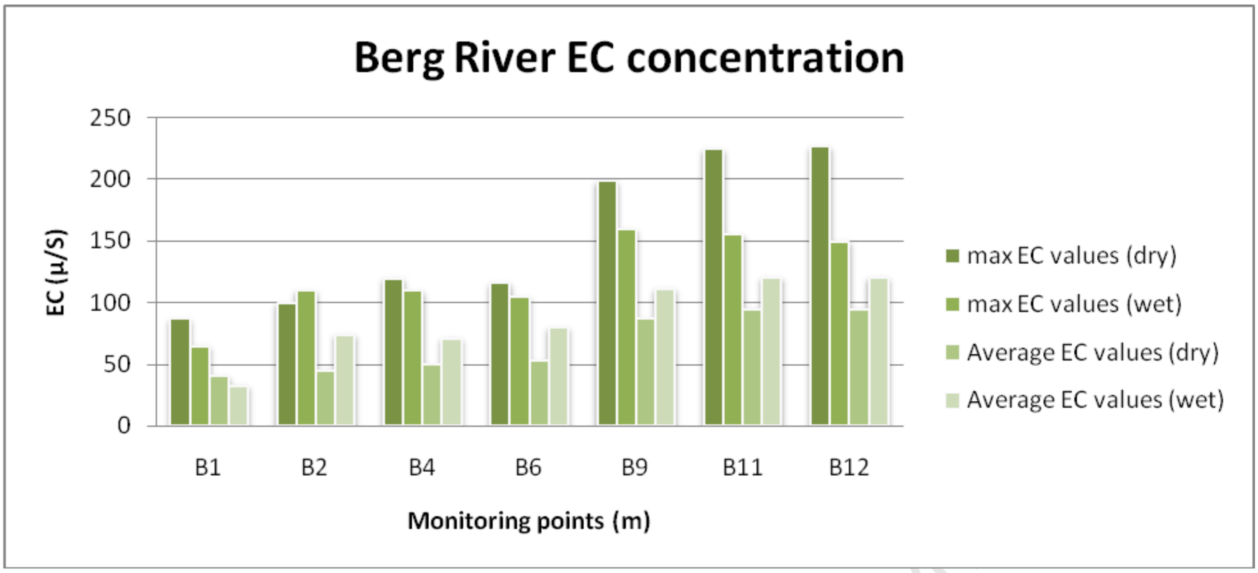

Figure 4.3 Maximum and average EC in wet and dry conditions

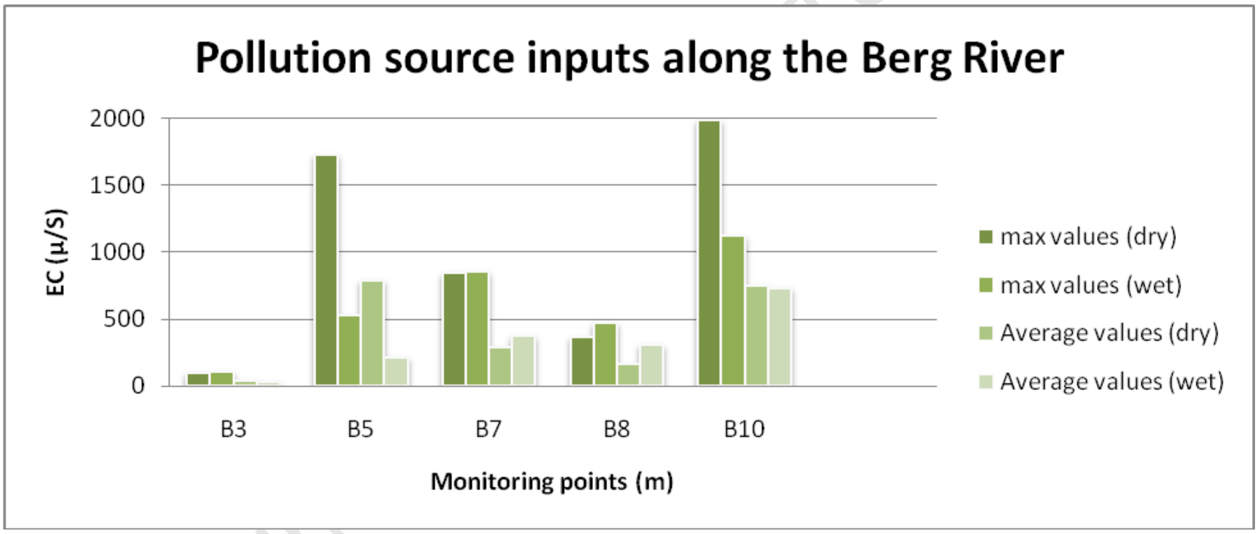

Figure 4.4 Maximum and average EC as a result of elevated pollution levels

Similar to the observed pH values, point sources discharging into the Berg River are responsible for fluctuations in EC. Urban storm runoff from various residential areas of Paarl have exceptionally low maximum and average EC values, but by contrast, effluents entering the Berg River at site B5 and also that of the polluted domestic water from Oliver Tambo informal settlement at site B10, show much higher EC values particularly during dry conditions.

4.4 Analysis of orthophosphates

4.4.1 Statistical analysis

Greywater runoff from informal settlements typically contains concentrations of Orthophosphates (PO_4^{3-}) (Carden *et al*, 2008). A pair wise correlation, taking all the samples into account, showed a weak relationship of 0.41 between PO_4^{3-}samples collected during wet and dry weather conditions. As expected, samples collected during dry conditions showed much higher variation than wet conditions. The calculated t-Stats value of 1.09 (Table 4.) below indicates a higher average PO_4^{3-}concentration during dry than wet conditions, $p = 0.14$ one tailed. An ANOVA two factor test without replication was undertaken to determine if or whether the sites were significantly different in terms of PO_4^{3-} levels. The F-ratio for columns which is a treatment for comparison indicated a value of 1.2 indicating differences in PO_4^{3-} concentrations at some monitoring points during wet and dry conditions. Sites showing no difference in maximum and average PO_4^{3-} concentrations are discussed in Figures 4.5 and 4.6 below.

Table 4.4 Results of the t Test: paired two samples for means between PO_4^{3-} collected during wet and dry conditions

	Phosphorus P04 3- mg/l (dry)	*Phosphorus P04 3- mg/l (wet)*
Mean	1.126944444	0.865
Variance	2.409616111	0.745911
Observations	36	36
Pearson Correlation	0.410782716	
Hypothesized Mean Difference	0	
Df	35	
t Stat	1.096606122	
P(T<=t) one-tail	0.140150827	
t Critical one-tail	1.68957244	
P(T<=t) two-tail	0.280301655	
t Critical two-tail	2.030107915	

4.4.2 Trends in orthophosphates

Maximum and average phosphorous results showed a steady increase in PO_4^{3-} concentrations with increasing distance downstream. This increase was prominent particularly during dry weather conditions. In the lower reaches a number of pollution sources showed high levels of

PO_4^{3-} as shown by high maximum and average PO_4^{3-} levels during dry conditions relative to low PO_4^{3-} levels upstream. Effluent from the WWTWs, storm water discharge points and agricultural activity adjacent to the river at Mbekweni all contribute to increase in maximum and average wet and dry PO_4^{3-} concentrations. In the upper reaches of study section there was no significant difference in maximum and average differences in PO_4^{3-} concentrations up to and including site B4.

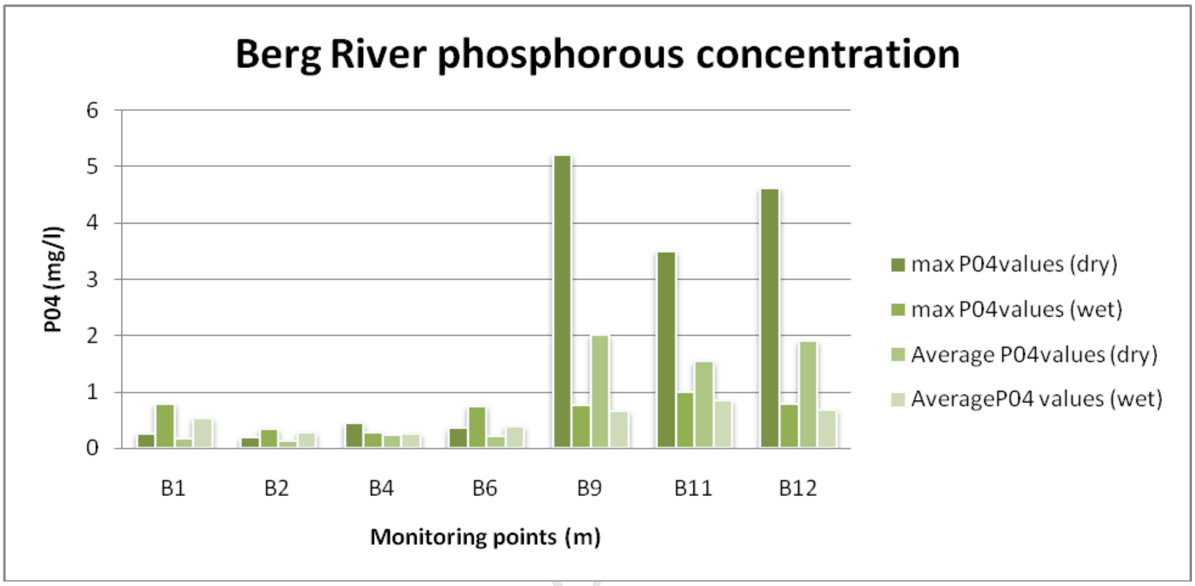

Figure 4.5 Maximum and average Orthophosphate during wet and dry conditions

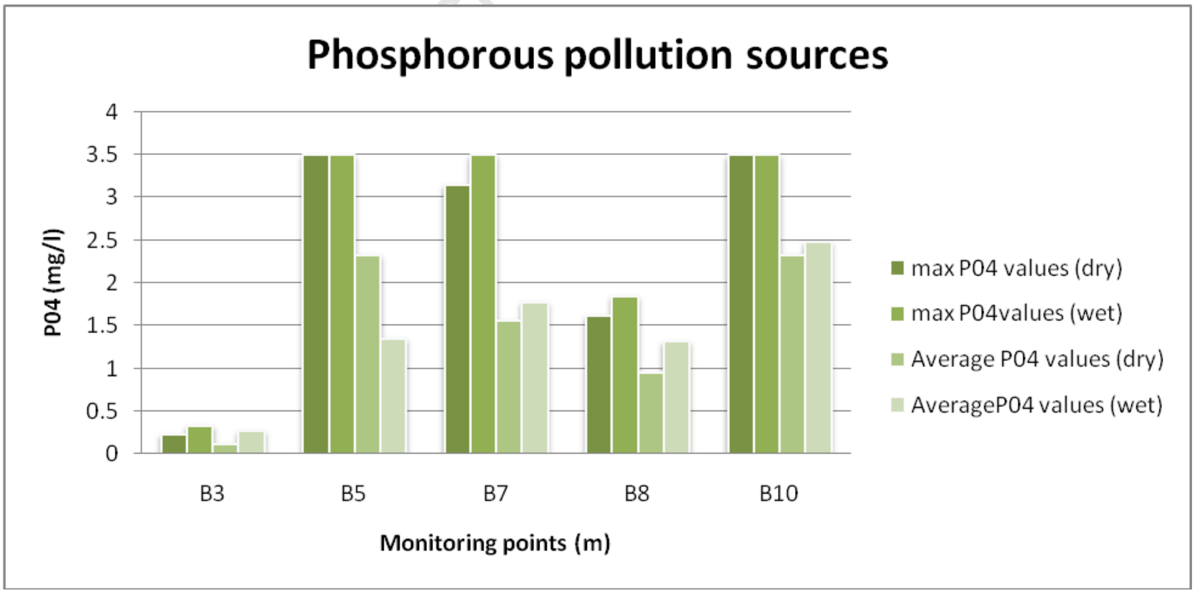

Figure 4.6 Maximum and average Orthophosphate at various discharge points

Urban storm runoff entering at site B3 from urban residential areas does not contribute significant quantities of PO_4^{3-} into the Berg River. There was no significant difference in maximum and average PO_4^{3-} levels at B3 during both wet and dry conditions. In addition point source at sites B5 (3.5; 3.5); B7 (3.2; 3.5); B8 (1.62; 1.85) and B10 (3.5; 3.5) showed no differences in maximum PO_4^{3-} during dry and wet conditions. There was also no significant differences in average PO_4^{3-} during wet and dry conditions, particularly runoff at sites B7 (1.55,1.78) and B10 (2.33; 2.48). Industrial effluents entering the river at site B5 and storm water runoff from informal settlements at sites B7 and B10 contributed to the increase in PO_4^{3-} concentrations during both wet and dry conditions. A substantial increase in P concentration at some sites along the river exceeded the South African guideline of 5 µg/l for P in receiving water bodies (Fatoki *et al*, 2001). Excess P particularly downstream of the Berg River would therefore lead to the development of algae and other plant growth. Most sites such as B5; B7; B8; and B10 receiving point discharges from various sources have reached hyper-eutrophic status. Whilst the upper reaches of the Berg River contains P levels ranging from 0.047-0.130mg/l or have reached eutrophic status during wet and dry weather conditions.

4.5 Ammonia-Nitrogen

4.5.1 Statistical analysis

Samples of ammonia-nitrogen (NH_3) were analyzed to determine any significant differences which could occur during wet and dry conditions. The t-Test results in Table 4.5 show significant differences in NH_3 concentrations during wet and dry conditions. The results of the calculated t Stats in Table 4.5 below produced a value of 1.5 indicating a high NH_3 concentration during dry conditions compared to wet conditions. The calculated variance shows no significant difference between NH_3 collected during wet and dry conditions. A strong positive correlation (p = 0.80) was found between NH_3 during wet and dry conditions. An ANOVA two-factor test without replication was undertaken to test if the sites were significantly different in terms of NH_3 concentration during wet and dry conditions. The calculated F-ratio value of 2.25 for columns, which is a treatment of comparison, indicated differences in NH_3 concentrations between the sites. Sites which were statistically similar to each other during wet and dry conditions are presented in further detail in Figures 4.7 and 4.8.

Table 4.5 Results of the t Test: paired two sample for means of NH_3 data collected during wet and dry conditions

	Nitrogen, ammonia NH3 (dry)	*Nitrogen, ammonia NH3 (wet)*
Mean	0.858611111	0.641667
Variance	2.091606587	1.36346
Observations	36	36
Pearson Correlation	0.800034453	
Hypothesized Mean Difference	0	
Df	35	
t Stat	1.500061914	
P(T<=t) one-tail	0.071282933	
t Critical one-tail	1.68957244	
P(T<=t) two-tail	0.142565865	
t Critical two-tail	2.030107915	

4.5.2 Trends in Ammonia-Nitrogen

Mix trends in ammonia-nitrogen were observed during wet and dry conditions at some monitoring sites along the Berg River. In the upper reaches of the study area, particularly at B1, no differences in maximum and average NH_3 were observed during both wet and dry conditions. Similar conclusions were observed downstream of the industrial outlet at site B5. This site showed no differences in maximum and average NH_3 concentrations during wet and dry conditions.

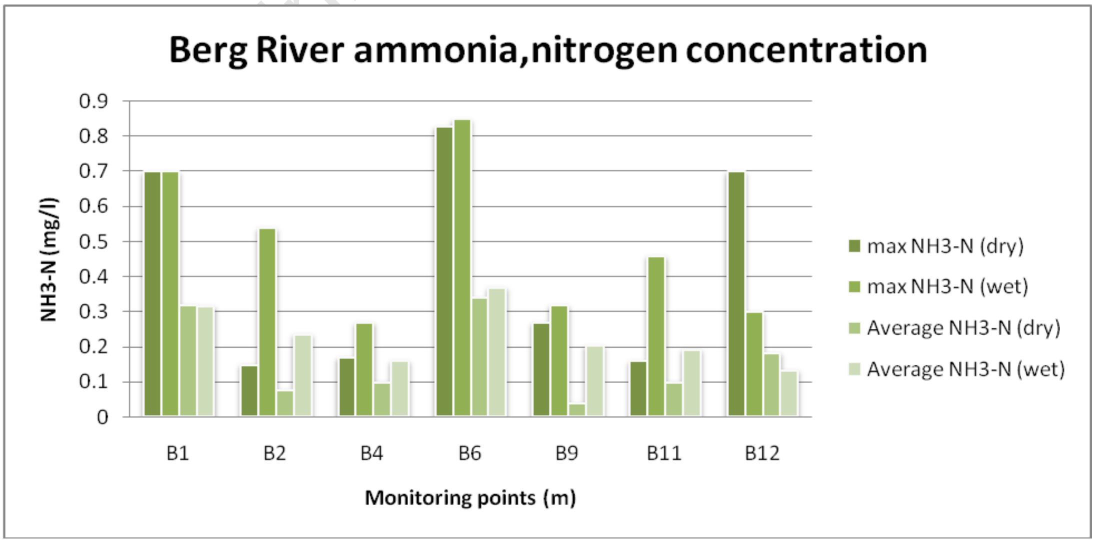

Figure 4.7 Maximum and average Ammonia Nitrogen during wet and dry conditions

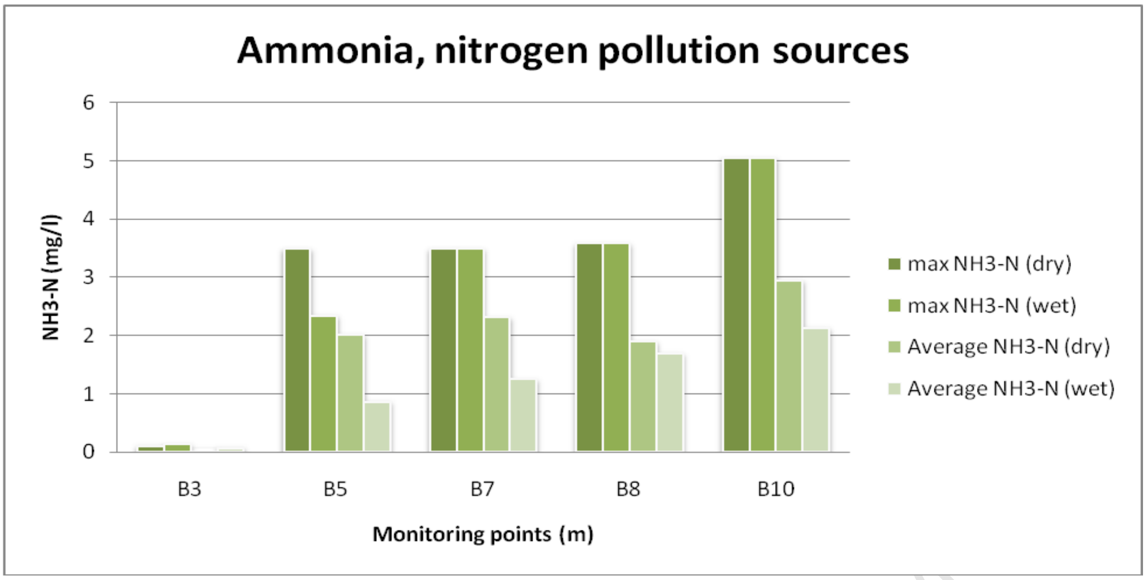

Figure 4.8 Maximum and average Ammonia Nitrogen caused by elevated pollution discharge

Urban storm runoff from formal residential areas at sites B2 and B3 indicated low NH_3 concentrations during wet and dry conditions. By contrast a sharp rise was found at points of discharge entering the Berg River at sites B5, B7, B8 and B10, and all showed no significant differences in concentrations during dry and wet conditions. A target water quality range for ammonia-nitrogen is 0-1.0 mg NH_3/constituent, water quality problems associated with consumption or domestic use may prevail when ammonia-nitrogen concentration exceeds 1.5 mg NH_3/constituent (DWAF, 1996b).

4.6 Analysis of *E. coli*

4.6.1 Statistical analysis

The results of a correlation tests for *E. coli* for wet and dry conditions exhibited a strong positive correlation (p = 0.79). The calculated t Stat of 1.88 indicates higher average *E. coli* counts during wet conditions compared to dry conditions. *E. coli* counts during wet conditions showed a greater variance compared to dry conditions. An ANOVA test showed F-ratio value of about 3.5. This value indicates that there is a difference in *E. coli* counts during wet and dry conditions. Sites that showed no significant difference in *E. coli* counts during wet and dry conditions are identified in Figure 4.9 and 4.10.

Table 4.6 Results of the t Test: two sample for means of *E. coli* counts collected during wet and dry conditions

	Dry counts	*Wet counts*
Mean	5175	9125.791667
Variance	405612553.2	570331181.1
Observations	48	48
Pearson Correlation	0.795105435	
Hypothesized Mean Difference	0	
Df	47	
t Stat	-1.883921953	
P(T<=t) one-tail	0.032884936	
t Critical one-tail	1.677926722	
P(T<=t) two-tail	0.065769872	
t Critical two-tail	2.01174048	

4.6.2 *E. coli* trends

The presence of *E. coli* organisms along the Berg River showed no significant differences during wet and dry conditions at some sites. The Berg River *E. coli* count upstream from B1 through to B4 showed no significant differences in maximum and average *E. coli* counts during wet and dry conditions. Wet weather conditions distributed a relatively larger number of *E. coli* particularly in the upper reaches of the Berg River, this phenomenon could have been caused largely by a rainfall of about 50-100mm as presented in Table 4.1. On the other hand, the lower reaches illustrated no significant difference in maximum and average wet and dry *E. coli* counts distributed along the study section of the Berg River. A sharp increase in the maximum and average *E. coli* counts downstream of the Oliver Tambo storm runoff at B11 could have been the result of human defecation on the banks of the river which could have been washed into the river during rainfall events.

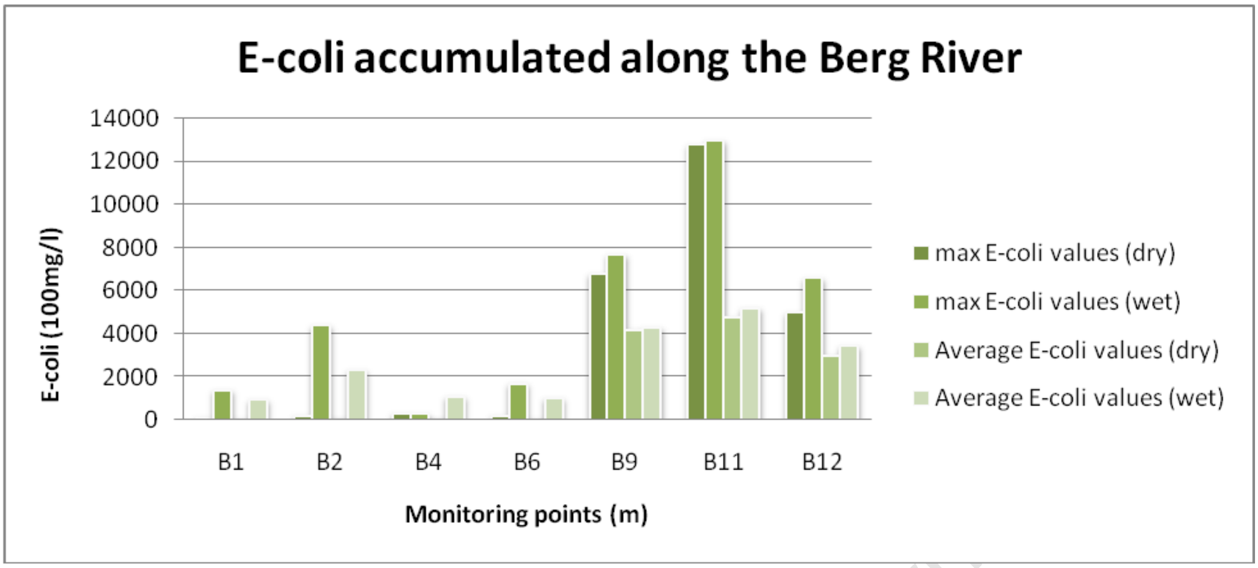

Figure 4.9 Maximum and average *E. coli* along the study section

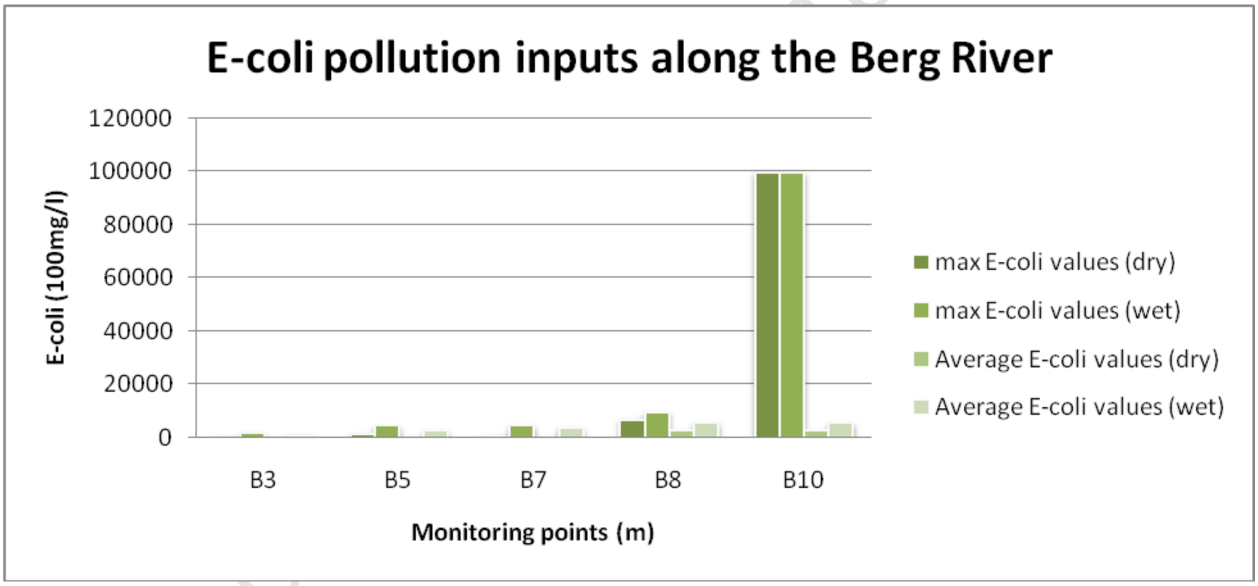

Figure 4.10 Maximum and average *E. coli* from sources of pollution discharge

Point and non-point sources of pollution entering the study site along the Berg River shown in Figure 4.10 demonstrated no significant differences in *E. coli* counts during wet and dry conditions. An urban storm runoff from Paarl residential areas at site B3; an industrial outlet from at site B5; and a storm runoff from Fairyland informal settlements at sites B7 and sites B8 contributed to the low maximum and average *E. coli* counts during wet and dry conditions, that is a lack of human faeces in the runoff waters received from these sources. No significant difference in *E. coli* was found at these points during wet and dry conditions.

A photograph of stormwater runoff observed near the Oliver Tambo informal settlement at site B10 (Figure 4.11) shows raw domestic and greywater effluent and explains the exceptionally high *E. coli* count during both wet and dry conditions. According to the South African Water Quality guidelines, if freshwater should be consumed then it should contain 0 counts /100mg/l faecal and no more than 10 counts /mg/l of total coliforms (DWAF, 1996b). The Berg River water quality particularly downstream of the informal settlement passing Mbekweni is not fit for domestic consumption.

Figure 4.11 Urban effluent runoff at Oliver Tambo informal settlement

4.7 Summary of Results

In this study, water quality variables indicative of pollution have been used to determine the pollution load that is being discharged into the river and to determine whether this pollution in the river varies significantly during wet and dry conditions. Electrical conductivity, pH, ortho-phosphorous, ammonia-nitrogen *and E. coli.,* were used to determine whether there were significant differences between wet and dry pollution load. Point sources of pollution were responsible for discharging varying quantities of pollution into the Berg River. Each water quality variable behaved differently according to type of pollution found along the river stretch in the study area. The results showed a mix of significant and insignificant differences during wet and dry conditions.

There were no significant differences in the pH during wet and dry conditions with regards to maximum and average pH data particularly in the upper and lower reaches of the study area along the Berg River. A rapid decline in the pH, particularly in the middle section was found where water was being discharged from an industrial process in which acidic effluent was recorded flowing into the Berg River. The discharge entering the Berg River at site B5 also had a relatively higher temperatures suggesting that this water was generated from an industrial process.

Electrical conductivity showed an increasing trend from the upper to the lower reaches of the study area during wet and dry conditions. On average, dry conditions had higher maximum and average EC concentrations. Wet weather conditions had comparatively high EC levels resulting in no significant differences in EC concentrations at some monitoring sites. Similar results during wet and dry conditions along the river with respect to TDS. Point sources of pollution such as industrial effluents and storm runoff coming from Oliver Tambo and Fairyland downstream raised the level of TDS and EC.

As was expected, PO_4^{3-} concentrations showed an increasing trend in the study area during wet and dry conditions. At site B1 through to B3, the PO_4^{3-} levels remained relatively low. No significant differences in maximum and average PO_4^{3-} samples were recorded in the upper reaches during wet and dry conditions. However, PO_4^{3-} was found to enter the river at sites B3; B5; B7 and B10 and showed no significant differences in the respective levels during wet and dry conditions. Similarly, NH_3 was recorded at sites B3; B7; B8 and B10, again showing no significant differences during wet and dry conditions.

E. coli counts behaved differently compared to other water quality parameters in that higher counts were identified during wet weather conditions compared to dry conditions. Rainfall events increased the count of *E. coli* in the study area in combination with feacal pollution that runs off surfaces in informal settlements. No significant differences could be found in *E. coli* counts in the lower reaches of the Berg River during wet and dry conditions.

Chapter Five: Conclusions and Recommendations

5.1 Conclusions

Urban storm runoff is a leading cause of the deterioration of water quality in freshwater systems because of high pollution loads (Qing *et al*, 2006). Densely populated areas with inadequate sanitation and drainage facilities were shown to increase the pollution load particularly after rainfall events (Jagals *et al*, 1995). Conditions directly after peak rainfall contribute to pollution of the receiving water bodies. Alternatively dry conditions increase the concentration levels of some pollutants in water bodies due to minimum dilution effect. This study has shown that water quality flowing as urban effluent during wet and dry weather conditions deposits high levels of bacteria and excess nutrients into the receiving water. In most urban catchments, high intensity rainfall detaches and carries away a large proportion of the pollution load into receiving waters than subsequent storm events. Storm rainfall following the 'first flush' may contain relatively lower pollution levels and possibly dilute receiving water bodies.

In this study densely populated areas with limited sanitary and drainage facilities, were found to generate high levels of faecal matter that are released particularly after rainfall events. Various sites along the Berg River have shown higher *E. coli* counts particularly during wet weather conditions compared to dry weather conditions. During dry weather conditions, relatively low runoff volumes are discharged into receiving water bodies. Some pollutants may constitute high concentrations during low flow period as these pollutants are less diluted during this period. The first rains during wet conditions carry those pollutants that have accumulated during dry conditions and these in turn are discharged into the receiving waters. Some pollutants are washed out more frequently in large quantities during wet conditions compared to dry weather conditions. Other pollutants showed no significant differences in concentrations during wet and dry weather conditions.

Overall, the study established that there was no significant difference between pollution levels as measured at the selected in-stream sites during wet and dry conditions. The study also established that there were no significant differences in the quality of inflow entering the Berg River during wet and dry weather conditions and this can be explained by the constant point sources of discharges entering the river during the study period. Increased runoff during wet weather conditions did result in an increase in the discharge of PO_4^{3-} and faecal material during both wet and dry conditions. However, low flow periods resulted in an increase in EC, TDS, PO_4^{3-}, NH_3 and salts along the Berg River during wet and dry conditions because of the limited volume of water able to effect dilution. These results indicated no significant differences in pollution during wet and dry conditions.

5.2 Recommendations

Water quality along the Berg River is influenced by a variety of sources that pollute the water. Pollution sources need to be managed on the land and any discharge should be treated before being allowed to enter a freshwater system. Since there is no significant differences in the quality of inflows entering the Berg River, a selection of obvious recommendations that have the potential to reduce pollution flowing into the Berg River in the proximity of the sampling study are offered:.

- Ensuring that the cut-off trenches and pump stations intended to divert storm water in the vicinity of the Oliver Tambo settlement into the municipal WWTW are operational and maintained;
- Upgrading the Paarl WWTW to increase efficiency and decrease the volume of poorly treated water being discharged into the Berg River;
- Intercept storm water from Fairyland culvert and to divert this to the WWTW for treatment;
- Provide waterborne sanitation, drainage facilities and waste water disposal facilities in the Oliver Tambo informal settlement so as to reduce the extent of human defecation and resultant foul waste that is being disposed along the banks of the Berg River;
- Upgrade and maintain the wetlands near the Berg River at Mbekweni as a partial means of treating and improving water quality; and
- Establish a viable public education and awareness strategy, with suitable incentives to encourage participation, to build capacity in the various water management issues.

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