Stormwater drainage: a convenient conduit for the discharge of urban effluent into the Berg River, South Africa

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ABSTRACT
Stormwater infrastructure in densely settled urban areas of South Africa is being used as a convenient conduit for the daily discharge of effluent into rivers and water bodies. This study investigates the pollution load being discharged into the Berg River at Paarl in the Western Cape. It seeks to establish whether or not there is any significant difference in loads immediately during and after wet and dry weather conditions. In theory, the quality of stormwater after a rainfall event usually contains the highest concentration of certain pollutants in urban areas that have separate stormwater and sewerage systems. There should be no discharge during dry periods coming from stormwater systems. In this study water samples were collected from twelve sites for a limited period of five months in conditions broadly representative of wet and dry weather conditions. The results show that there is no statistically significant difference in pollution levels during wet and dry conditions in the study area. The paper concludes that continuous inflow of urban effluent from informal settlements is partly responsible for the deterioration of water quality in the Berg River.

KEYWORDS
Informal settlements; Stormwater system; Urban effluent; Urban drainage.

INTRODUCTION
Urban runoff is known to contain elevated levels of physical and chemical pollutants following a rainfall event. It is also known that pollution levels are raised after the ‘first flush’ following a prolonged dry weather conditions when there has been sufficient time for pollutants to accumulate on hardened surfaces in urban areas (Jagals, 1997). In South Africa poor water quality in stormwater systems is not necessarily attributed to rainfall events alone. Studies have shown that stormwater conduits discharge a continuous flow of untreated grey- and blackwater effluent from informal settlements where limited or dysfunctional sanitation systems are the norm (Venter et al., 1997; Fatoki et al., 2001; Armitage et al., 2009). There is increasing recognition and concern that the discharge of urban effluent is causing South Africa’s urban waterways to deteriorate from a host of sources including formal and informal urban areas, and municipal and industrial activities (Venter et al., 1997; Fatoki et al., 2001; Nkwonta and Ochieng, 2009). This study aims to establish if there is a significant difference in water quality during wet and dry weather conditions by sampling point sources and in-stream water quality of the Berg River. The study was initiated on the assumption that sources of polluted water remain relatively constant during dry periods and that elevated levels of pollution in the Berg River are not necessarily due to rainfall events that are sometimes connected to the ‘first flush
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‘as suggested by urban studies elsewhere. In theory, elevated pollution levels are associated with the first flush that occurs during or soon after a rainfall event, but thereafter it is expected that the load will decrease with increasing dilution (Boyacioglu, 2006).

THE BERG RIVER
The headwaters of the Berg River arise in the Groot Drakenstein Mountains and flow for over 300 km draining an area of approximately 900 km² (Gorgens and Clercq, 2005). The river flows past two major settlements, that of Paarl and Wellington (each with over 50 000 inhabitants), and then eventually enters the Atlantic Ocean on the west coast at Port Owen, St Helena Bay (de Villiers, 2007). The Berg River catchment lies in a winter rainfall region with average annual rainfall ranging from 600 to 1000 mm at the watershed, but decreases from east to west to 200 mm or less at the west coast (River Health Programme, 2004) (Figure 1).

The Berg River Dam supplies potable water to the Cape Town Metropolitan Area and, along with the Berg River itself, provides an irrigation source for agriculture (Davies and Day, 1998). Further downstream the river receives agricultural return flows, effluent from Waste Water Treatment Works (WWTWs), and discharges from industries and urban settlements. Jackson et al. (2007) noted a general decline in water quality of the Berg River corresponding to low flow periods, while De Villiers (2007) found a general decline in water quality during drier periods when dilution was minimal. To date, studies on the effect of wet and dry conditions on water quality in the Berg River, and in South Africa in general, have received limited attention (Jagals et al., 1995; Lee et al., 2004; Jamwal et al., 2008; Chua et al., 2009). There is agreement that the Berg River is being polluted principally through salinization from irrigation return flows; nutrient enrichment from agricultural runoff; poor treatment of effluent at WWTWs, industries and wine farms; invasion by alien, aquatic and riparian organisms; and runoff from informal settlements (Davies and Day, 1998). Informal settlements are known to elevate the bacteria count as in the case of Mbekweni township and the adjoining informal areas on the periphery of Paarl and downstream of the city centre (Paulse et al., 2009). Studies have also shown that in-stream water quality reaches eutrophic status long before it passes the Mbekweni township (de Villiers, 2007).

A substantial increase in the concentrations of pollutants during wet and dry weather conditions has a negative effect on the Berg River water quality. From 1984 to 1995 an above average rainfall resulted in greater volumes of discharge and consequently an accumulation of
pollutants into the Berg River (de Villiers, 2007). It was also noted that there were elevated phosphorous concentrations along the Berg River (de Villiers, 2007). By contrast, from 1995 to 2005 reduced runoff resulted in elevated nitrogen levels with a subsequent deterioration in water quality (de Villiers, 2007).

**POLLUTED RUNOFF**

Runoff from urban surfaces after rainfall events carries pollutants such as oils, chemicals, litter and solid waste, and faecal remains of animals that have accumulated on urban land surfaces during dry periods (Osman and Houghtalen, 2003). Kloppers et al. (1993) confirm that relatively high concentrations of pollutants can be transported at ‘first flush’ when there has been sufficient time to enable pollutants to accumulate on surfaces during dry periods. Thereafter dilution tends to lower the concentrations of contaminants (Herricks, 1995). Mullis et al. (1996) also noted that the onset of precipitation results in higher aqueous loadings of all water quality indicators with peaks being associated with the largest storms, rather than the length of time of the event.

Henning (2007) classified these typical pollutants in association with runoff from different types of land use (Table 1). Pathogens are only associated with commercial and industrial land use, and from upstream waters, but is not identified as runoff as appears to be the case in some urban areas of South Africa.

**Table 1. Stormwater pollution threats to receiving waters (Henning et al., 2007).**

<table>
<thead>
<tr>
<th>Source</th>
<th>Pollutants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential land use runoff</td>
<td>Sediments, nutrients, oxygen depleting material, hydrocarbons, trace metals, pesticides and surfactants</td>
</tr>
<tr>
<td>Industrial land use runoff</td>
<td>Sediment, nutrient, oxygen depleting material, hydrocarbons, trace metals, pesticides and surfactants, pathogens</td>
</tr>
<tr>
<td>Commercial land use runoff</td>
<td>Sediment, nutrient, oxygen depleting material, hydrocarbons, trace metals, pesticides and surfactants, pathogens</td>
</tr>
<tr>
<td>Road runoff</td>
<td>Sediment and nutrient</td>
</tr>
<tr>
<td>Unstable and degraded waterways</td>
<td>Sediment, nutrient and oxygen depleting material</td>
</tr>
<tr>
<td>Open space runoff</td>
<td>Nutrient, litter and oxygen depleting material</td>
</tr>
<tr>
<td>Upstream inflows</td>
<td>Sediment, nutrient, litter and pathogens</td>
</tr>
<tr>
<td>Markets</td>
<td>Nutrients, oxygen depleting material, pathogens, sediments, litter and surfactants</td>
</tr>
</tbody>
</table>

The most common pollutants found in urban rivers include nutrients, heavy metals, organic material, suspended solids and bacteria (Henning, 2007). Yoon and Stein (2008) maintain that a high concentration of pollutants, particularly nutrients and suspended solids, does not necessarily compromise water quality directly since nutrient enrichment is a natural phenomenon that can take thousands of years to accumulate (DEAT, 1996a). However, in the
case of the Berg River, a substantial increase in phosphorus and nitrogen was identified in the vicinity of Franschhoek and Paarl as a result of the partial treatment of water discharged from WWTWs and from agricultural runoff (Mangnall et al., 2009). De Villiers (2007) also confirmed similar concentrations of phosphate in the Berg River during low flow periods when dilution was minimal.

Urban stormwater is recognized as a contributor to pollution particularly during wet weather conditions when urban runoff varies in quality, volume and in the range of pollutants found in the discharge (Lee et al., 2004). Studies are now showing that the concentration of pollutants increases considerably during dry weather conditions (Sansalone, 2003). For instance Pitt (1995) found higher concentrations of pollution during dry conditions compared to wet weather by a factor of two to five in the Coyote Creek, California, USA. Concentrations of ions and total solids were found to be significantly higher in urban runoff during dry weather conditions. The study also concluded that rain and the resultant runoff apparently diluted the concentrations of these constituents in the creek during wet weather (Pitt, 1995). Chemical oxygen demand (COD), organic nitrogen (N) and a variety of heavy metals had higher concentrations during wet weather as opposed to dry weather conditions in studies conducted in the Coyote Creek catchment (Pitt, 1995).

Urban catchments in South African typically carry bacteria in the form of E. coli and faecal coliform that is elevated during wet weather conditions. In a study of the peri-urban areas of Umtata, Eastern Cape, faecal organisms were found during wet and dry weather conditions at levels similar to that of adjoining informal settlements and also in the city centre of Umtata (Fakoti et al., 2001). Further evidence of contamination has been found at popular Western Cape beaches and at Centurion Lake, Pretoria, where the risk to human health forced local authorities to declare these waters unfit for human contact at various times. Elevated levels of faecal matter during rainfall events frequently corresponds with water related illnesses such as diarrhoea (Jagals, 1997).

Pollution from Dense Settlements
Runoff from dense informal settlements is estimated to account for a relatively high proportion of the total mass of pollutants into the receiving waters (Duke et al., 1998) with attendant negative ecological effects (Yoon and Stein, 2008). Densely populated areas with limited or dysfunctional sanitary and drainage facilities are known sources that have the potential to raise pollution levels especially after rainfall events (Jagals, 1997) and to raise the risk level to human health when stormwater runoff is contaminated with faecal matter. In South Africa pollutants found in greywater, in effluent from industrial activities, and in general stormwater runoff is being discharged with only limited or partial treatment into receiving water bodies during both wet and dry weather conditions. In a study of a densely populated informal settlement in South Africa (205 000 inhabitants) and serviced with only pit and bucket latrine sanitary facilities, it was found that faecal organism counts were exceptionally high during wet and dry conditions (Venter et al., 1997). The prolonged existence of certain faecal organisms is attributed to the ability of certain bacterial species to survive under particular physical and chemical conditions (Venter et al., 1995). Jagals et al. (1995) noted differences in the concentration of faecal organisms in the receiving water bodies during both wet and dry weather conditions. Their studies noted 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).

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1 Colony forming unit
STUDY DESIGN AND METHODS
Water samples were collected at twelve sites along the eastern banks of the Berg River within the urban boundary of Paarl. Sample sites were identified initially from GIS topographical maps of the Berg River catchment (Table 2). The selected sites were all linked to a mix of land use including residential, industrial, public roads and informal settlement housing (Figure 2). Site B1 on the upstream urban boundary was chosen as a reference point to determine water quality prior to it being affected by urban drainage. Another site was chosen to represent the downstream conditions at the furthermost point of the urban boundary (Site B12). Samples were collected at each site on six separate occasions over a period of five months (Table 3). In summary, of the twelve selected samples sites, two represented reference points at the up- and downstream urban edge of Paarl as described above; four sites were selected as point sources of discharge (PS); four were selected approximately 20 to 50m upstream of the point sources; and the remaining two sites were approximately 20m downstream of the point sources. Sampling was conducted during conditions broadly represented by wet and dry weather conditions. Dry weather was taken to mean a period in which no rain had fallen in the catchment seven days prior to sampling, while wet weather conditions meant that the sample was collected at the onset or during a rainfall event. The ideal would be capture and sample the ‘first flush effect’.

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

<table>
<thead>
<tr>
<th>Sampling points</th>
<th>Description of location</th>
<th>Geo-reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>Under the N1 highway bridge in Paarl (upstream urban edge; in-stream sample)</td>
<td>33°45.776</td>
</tr>
<tr>
<td></td>
<td></td>
<td>18°58.444</td>
</tr>
</tbody>
</table>
Water samples were analysed in a water laboratory at the University of Cape Town using a HACH 2700 spectrometer to measure Orthophosphate ($\text{PO}_4^{3-}$) and Ammonia Nitrogen ($\text{NH}_3$) loads. *Escherichia coli* (*E. coli*) were analysed using 3M® Petrifilm plates following an incubation period of 24 hours at 37°C. The study focuses on three water quality parameters chosen as convenient and conventional indicators of nutrient loading and for the presence of pathogens. Additional *in situ* measurements were used to describe the physical characteristics of water quality including Electrical Conductivity (EC), salinity, temperature and pH.
A paired sample Student’s t-test was used to determine if the two means under wet and dry conditions were significantly different to each other. The null and alternative hypothesis was constructed as follows:

\[ H_0: \mu_{\text{dry}} = \mu_{\text{wet}} \]
\[ H_1: \mu_{\text{dry}} \neq \mu_{\text{wet}} \]

Where \( \mu \) is the mean value of the observed water quality parameter collected during either dry or wet conditions. A two tailed test was chosen because the hypothesis involves a determination of difference where no ordering of the means was specified.

**Study Limitations and Challenges**

A major limitation was the inability to capture more than six samples at each site so as to represent a significant time series. Furthermore, there is uncertainty that samples collected during wet weather conditions represented the onset of a rainfall event in the catchment. In addition, on two occasions when samples were collected during wet conditions, the rainfall intensity and period of fall varied. The result was that sampling was limited to four ‘dry’ and two ‘wet’ weather conditions, and this represents a potential weakness in the study.

**Analysis and Discussion**

Observed pH and temperature at Site B5, the outlet of an industrial site, was consistently acidic and warmer by as much as 5°C compared to the adjacent in-stream flow. The pH increased immediately downstream of B5 (industrial site) and more especially at site B7 (stormwater canal) and beyond. Industrial processes are not permitted to discharge effluent with a pH outside the range of 5.5 to 9.5 because of the potential to cause significant detrimental effects to aquatic ecosystems (DWAF, 1996c). Effluent discharged into the river at Site B5 failed to meet the required standard during dry weather conditions.

Electrical conductivity (EC) was measured (\( \mu \)S) at each of the sampling sites to determine the level of suspended solids held in the water column. The results show that urban effluent entering the river at Site B5, and at point sources where receiving inflow from informal
settlements, were 13 times higher during dry conditions (ranging from 313 to 1987 µS) and 8 times higher during the wet (ranging from 80 to 1126 µS) compared to the reference site (Site B1). Urban storm runoff from formal residential areas of Paarl was comparatively lower range (dry range 87 to 120 µS; wet range 3 to 150 µS) compared to further downstream. In-stream sampling of EC showed an increase with increasing distance downstream during wet and dry conditions from numerous inflows from sources such as the Paarl WWTWs and from informal settlements downstream in the study area. In general, there was a substantial increase in peak EC levels during dry weather conditions compared to wetter conditions consistent with theory suggesting that suspended solids are more concentrated during low flow.

Orthophosphates. A pair wise correlation, combining all samples, indicated a weak relationship (p = 0.44) between wet and dry weather conditions. The weakness is attributed to variations within the samples captured during dry conditions. However a paired-wise sample t-test failed to show a statistical difference between PO$_4^{3-}$ during dry conditions (M = 1.13, s = 1.55) compared to wet conditions (M = 0.90, s = 0.95) and where t(36) = 0.94, p = 0.35, α = .05. Therefore the null hypothesis cannot be rejected. Even when only in-stream samples were taken into the account during dry conditions (M = 0.90, s = 1.47) and wet conditions (M = 0.62, s = 0.45), the value of t(24) = 0.90, p = 0.36, again suggested that the null hypothesis cannot be rejected. The difference in water quality during wet and dry conditions appears not to be statistically significant.

It was expected that maximum and mean values of PO$_4^{3-}$ would steadily increase with increasing distance downstream as a results of discharges from the Paarl WWTWs, various stormwater discharge points and also due to some agricultural activity in the study area. General conditions in river adjacent and downstream of the Mbekweni township all contribute to an increase in PO$_4^{3-}$ concentrations. Greywater runoff from informal settlements typically contains Orthophosphates (PO$_4^{3-}$) (Carden et al., 2008). It was also expected that there would be an increase in PO$_4^{3-}$ during dry weather conditions with minimal dilution.

Urban storm runoff flowing into the Berg River at Site B3 from urban residential areas does not contribute significant quantities of PO$_4^{3-}$. There was no significant difference in maximum and average PO$_4^{3-}$ levels at B3 during both wet and dry conditions. In addition at Sites B5 and B10 there was no difference between maximum PO$_4^{3-}$ values during dry and wet conditions and only 0.3 mg/l in the case of Site B7.

Orthosphate loading, as a measure of Total Phosphorous (TP) concentration, exceeded the South African guideline of 5 µg/l for P in receiving water bodies (Fatoki et al, 2001). Excess P from Sites B8 to B12 has potential to encourage rapid growth of algae.
Ammonia-Nitrogen. Mixed results were observed in the case of NH₃ during wet and dry conditions. A paired sample t-test failed to reveal a statistically reliable difference between the mean number of NH₃ during dry (M = 0.86, s = 1.45) and wet conditions (M = 0.64, s = 1.17) when all samples were considered and where the t-value was determined at t(35) = 1.53, p = 0.14, α = .05. In the upper reaches of the study area, particularly at B1, there were no significant differences in maximum and average NH₃ were observed during both wet and dry conditions. Similar observations were found downstream of the industrial outlet at Site B5 with no difference in maximum and average NH₃ concentrations during wet and dry conditions.

A strong positive correlation (p = 0.80) was found between NH₃ during wet and dry conditions. A combination of the t-test, and from descriptive statistics shows similarities in the mean and maximum values, and suggests that the null hypothesis cannot be rejected (Figure 4).

Urban stormwater runoff from formal residential areas at Sites B2 and B3 presented low NH₃ concentrations during wet and dry conditions. By contrast a sharp rise in concentrations was observed at selected point sources namely Sites B5, B7 and B10. All shows no significant difference in concentrations during dry and wet conditions. The target water quality range for the discharge of ammonia-nitrogen into freshwater systems is <0 to less than 1.0 mg NH₃/constituent.

Analysis of E. coli. A positive correlation exists under wet and dry conditions (r = 0.79) with respect to the presence of E. Coli, but showed an elevated count during wet conditions with a larger variance about the mean in contrast to dry conditions (Figure 5). A paired t-test for all samples showed no significant difference during wet and dry conditions with E. coli cfu during dry conditions and during wet conditions. The Berg River E. coli count from B1 through to B4 shows similar maximum and mean E. coli counts during wet and dry conditions. Elevated maximum and mean E. coli bacteria counts were observed downstream of the Oliver Tambo stormwater runoff at Site B11 (<100 000 cfu) during the two rainfall events in the vicinity of the formal and informal residential settlement of Mbekweni. Even when all point sources were excluded and therefore only in-stream samples were accepted the null hypothesis could not be rejected. The analysis again appears to indicate that there is no statistical significance in E. coli during wet and dry conditions.
Polluted water carrying *E. coli* that entering the study area along the Berg River confirms that maximum *E. coli* loading occurs during wet conditions. Urban storm runoff from Paarl residential areas and at Site B5 (industrial site of discharge) has a relatively low mean *E. coli* count during wet and dry conditions suggesting that human or animal faeces were not entering the river from this source. By contrast, stormwater runoff flows near the Oliver Tambo informal settlement at Site B10 is indicative of poor water management. Freshwater systems are being compromised by, among others, dark greywater and elevated *E. coli* during both wet and dry conditions.

**CONCLUSION**

In this study three primary water quality parameters were selected as conventional indicators of pollution load with the aim of determining whether or not pollution in the Berg River varied significantly during wet and dry conditions. The study findings show that samples of selected water quality parameters captured from in-stream flow and drainage canals of densely populated areas, with inadequate sanitation, contributed to elevating pollution loads during wet and dry conditions. In addition, limited dilution during dry weather conditions increased the concentration of pollutants. Water quality in the Berg River is being compromised during wet and dry weather conditions by bacteria and nutrients. The pollution load in the downstream urban area of Paarl is been generated by informal settlements where the stormwater systems are being used as a convenient conduit for discarding used and unwanted water.

Densely populated areas in Paarl, with dysfunctional sanitation services and limited drainage facilities, were found to generate elevated levels of faecal matter that is raised further during rainfall events. During low flow periods in-stream concentrations of NH$_3$ or PO$_4^{3-}$ remained consistent elevated due to limited dilution. While some researchers (Boyacioglu, 2006; Mullis *et al.*, 1996) noted that pollutants were washed out more frequently in large quantities during wet conditions compared to dry weather conditions, this study was unable to reach a similar conclusion, no doubt during to the particular conditions and historical processes the characterises the South African social and political landscape.

Concentrations of PO$_4^{3-}$ were expected to increase further downstream because of inflows from stormwater systems. At Sites B1 to B3, PO$_4^{3-}$ levels remained relatively low. No significant differences were observed in the upper reaches of the study area during wet and dry conditions. However, PO$_4^{3-}$ was found to enter the river at sites B5, B7 and B10 and showed no significant differences in the load during wet and dry conditions. Similarly, NH$_3$ concentrations at Sites B7 and B10, showed no significant differences during wet and dry conditions.
Higher counts of *E. coli* were identified during wet weather conditions compared to dry. Rainfall events increased faecal matter as a result of runoff from surfaces in dense, under-serviced settlements. Tests were unable to determine any statistically significant differences in *E. coli* in the lower reaches of the Berg River during wet and dry conditions.

The study tentatively confirms the original argument, that there is no significant difference in the concentrations of certain water quality parameters during wet and dry conditions when the water quality is being compromised by stormwater drainage that is being used as sewerage. In the situation under study, characterized by serious deficiencies in the treatment of civil and industrial wastewater, the results of the significant experimental campaign carried out confirm what is already well known, namely that, in this situation, the pollution caused by urban stormwater is essentially irrelevant with respect to the untreated foul waters for the environmental quality of the receiving watercourse. In summary, water quality in the Berg River during wet and dry weather presented a similar condition during wet and dry weather conditions. Increased runoff during wet weather conditions did result in raised bacteria counts. During the low flow periods EC, PO₄³⁻ and NH₃ in-stream concentrations remained relatively constant with limited dilution.

**RECOMMENDATIONS**

Water quality along the Berg River is influenced by a variety of sources that pollute the river including runoff from informal settlements. These pollution sources need to be managed to prevent the discharge of polluted water from entering the river. The following recommendations are offered:

- In the short term, the efficacy of cut-off trenches should be explored to determine how best to capture and divert stormwater to sewerage;
- Functional sanitation systems, including drainage and waste water disposal facilities and the management thereof, must be implemented at a priority especially in those informal settlements that are adjacent to the banks of the Berg River;
- Establish public education and awareness programmes to encourage greater responsibility and accountability in the prevention of pollution of the Berg River.

**REFERENCES**


