DEMONSTRATION OF HOW HEALTHY ECOLOGICAL INFRASTRUCTURE CAN BE UTILIZED TO SECURE WATER FOR THE BENEFIT OF SOCIETY AND THE GREEN ECONOMY THROUGH A PROGRAMMATIC RESEARCH APPROACH BASED ON SELECTED LANDSCAPES

Deliverable 10: Report on water quality in identified case study sub-catchments of the lower uMngeni catchment and the relationship between catchment and water quality

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by

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Executive Summary

In urban environments, watercourses can be contaminated from a variety of sources including human use, sewerage network failure, disposal of industrial effluents and runoff from impermeable surfaces. Polluted watercourses contribute to environmental degradation, negative impacts on human health and negative effects on tourism and sport.

This report comprises of three studies in two sub-catchments of the uMngeni River, namely the Baynespruit and the Palmiet River catchments. The first study looks at the effects of catchment urbanization on the water quality of the Palmiet River. The second study shows the links between pathogenic water quality of the Palmiet River and its potential health risks for communities who interact with the water regularly in the Quarry Road Informal Settlement alongside the river. The third study is on the Baynespruit River and the effects of water quality on the presence of heavy metals in the crops grown by the Sobantu community on the floodplains of the river.

Palmiet River

E.coli concentrations in the Palmiet River are high, with 50 % of results between 2007 and 2015 exceeding 2 000 cfu/100ml. Failures within the sewerage network are a key source of E.coli in watercourses. Organic loading rate is also high with over 50 % of samples over 5 mg/l and spikes that exceed 36 mg/l. Fats, oils and grease from industrial sites and fast food outlets are likely to contribute to this. The minimum turbidity in the river is 4 NTU, whilst samples downstream of the industrial area average 100 NTU. The macroinvertebrate population of the river, measured using miniSASS further indicates that the water quality is poor.

River walks were undertaken to identify the impacts of catchment urbanization on the river. These impacts were classified as indigenous vegetation removal, exotic vegetation, bank erosion, channel modification, water abstraction, inundation, flow modification, bed modification, water quality and rubbish dumping. It was seen that water quality was adversely affected by the presence of industrial areas and informal settlements in the upstream catchment.

Water samples taken downstream of the Quarry Road Informal Settlement between February 2015 and February 2016 showed E.coli and Enterococci levels of 4.7 log10 MPN/100ml and 4.6 log10 MPN/100ml respectively. Sediment samples at the same location, average E.coli and Enterococci concentrations were 5.9 log10 MPN/100ml and 5.2 log10 MPN/100ml respectively. Higher numbers of indicator organisms in sediments indicate that the river receives high loads of faecal pollution.

A quantitative microbial risk assessment was carried out using E. coli spp, Salmonella spp, Campylobacter spp and Shigella spp as the main hazard organisms. The concentration of E. coli spp and Salmonella spp were based on results stated above, while that of Campylobacter spp and Shigella spp were taken from literature. The assessed exposure pathways were accidental ingestion during swimming or bathing, surface water for household use such as laundry and consumption of vegetables irrigated with surface water. This analysis showed that children were most likely to be infected. Women’s probability of infection increased due to the additional exposure pathway of household water use. The surface water from the Palmiet River exceeds the World Health Organisation recommended target value for risk of infection.

Baynespruit River

The presence of E.coli and heavy metals (As, Cd, Cu, Pb, Hg, Zn) in the surface water and sediment from the Baynespruit were assessed. Additionally the presence of heavy metals in the soil of fields on the river’s floodplain and the crops grown on those fields were measured. Surface water was
sampled upstream, at and downstream of the irrigation point (points 1, 2 and 3 respectively) and in the wetland pool (point 4) which is used for irrigation of one of the farm sites.

Heavy metals concentrations above the maximum permissible limits were sporadic but were detected at all sampling points at least once. The low frequency of these detections suggest that heavy metal pollution is not problematic for the irrigation of crops. E.coli greatly exceeded the permissible limits.

The sediments tested at the sampling points 1, 2 and 3 were compared to USA Freshwater Sediment Guidelines as such guidelines do not exist for South Africa. As, Cr, Ni, Pb, Fe and Mn levels all exceeded their respective maximum permissible limits in both summer and winter months. Cu and Ag exceeded their respective maximum permissible limits in winter only.

Soil samples were taken from fields irrigated from a communal tap, the wetland pond and the Baynespruit River (farm sites 1, 2 and 3 respectively). All three samples had concentrations of Cd, Cu and Zn above the maximum permissible limits, whilst concentrations of Pb exceeded the maximum permissible limit only at farm sites 1 and 2. The concentration of Cr was below the maximum permissible limit at all three sites.

Crops were sampled for heavy metals and the concentration compared to the maximum permissible limits set out by the Food and Agriculture Organisation and the World Health Organisation. Cd was present in spinach, carrots and cabbage at concentrations greater than the maximum permissible limit whereas its presence in maize and pumpkins fell below maximum permissible limits. The Cr and Pb concentrations in all crops across all farming sites exceeded the maximum permissible limit and the concentration of Zn in spinach was above the maximum permissible limit across all farming sites.

These results demonstrate that heavy metals tend to be present at higher levels in the river sediment that in the water itself. This makes its way onto the fields that are located on the primary floodplain of the river as a result of flooding and contaminates the soil. This in turn leads to contamination of crops, particularly broad leafy crops and edible roots.

Summary
Both the Palmiet and the Baynespruit Rivers suffer from poor water quality. This is a result of the urbanisation of their respective catchments but is also likely to have a negative effect on human health in the catchment, particularly in communities that rely on the river for bathing, household use and farming.

A key recommendation from studies in both catchments was the need to include sampling and testing of sediment in any analysis of the river’s water quality. Higher concentrations of heavy metals and micro-organisms are found in sediments than in surface water and this can provide a better indication of the river’s health than looking at the water quality alone.
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<tr>
<td>cfu</td>
<td>Colony forming unit</td>
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<tr>
<td>COD</td>
<td>Chemical oxygen demand</td>
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<tr>
<td>DO</td>
<td>Dissolved oxygen</td>
</tr>
<tr>
<td>DUCT</td>
<td>Duzi-uMgeni Conservation Trust</td>
</tr>
<tr>
<td>EC</td>
<td>Electrical conductivity</td>
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<tr>
<td>EWS</td>
<td>eThekwini Water and Sanitation</td>
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<td>GIS</td>
<td>Geographic information system</td>
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<tr>
<td>GPS</td>
<td>Global positioning system</td>
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<td>IHI</td>
<td>Index of Habitat Integrity</td>
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<td>MAP</td>
<td>Precipitation</td>
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<td>MPL</td>
<td>Maximum permissible limit</td>
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<td>MPN</td>
<td>Most probable number</td>
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<td>MUG</td>
<td>4-methyl-umbelliferyl-β-D-glucuronide</td>
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<tr>
<td>NTU</td>
<td>Nephelometric turbidity unit</td>
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<tr>
<td>ONPG</td>
<td>Ortho-nitrophenyl-β-D-galactopyranoside</td>
</tr>
<tr>
<td>PBS</td>
<td>Phosphate-buffered saline</td>
</tr>
<tr>
<td>PCR</td>
<td>Polymerase chain reaction</td>
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<tr>
<td>PRW</td>
<td>Palmiet River Watch</td>
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<td>PV4</td>
<td>Permanganate value after 4 hours</td>
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<td>QMRA</td>
<td>Quantitative microbial risk assessment</td>
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<td>qPCR</td>
<td>Quantitative real-time polymerase chain reaction</td>
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<td>Quarry Road informal settlement</td>
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<td>UKZN</td>
<td>University of KwaZulu-Natal</td>
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<td>VS</td>
<td>Volatile solids</td>
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<td>WRC</td>
<td>Water Research Commission</td>
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1 Introduction

Despite the vital importance of water as a natural resource, it remains one of the most poorly managed resources worldwide (Fakayode, 2005).

In urban environments, contamination of watercourses, estuaries and oceans can come from a variety of sources. In informal settlements, people may use river water for bathing, drinking, cooking and washing. The placement of toilets along the banks of rivers can result in human faeces contaminating the water (Umgeni Water, 2016). In urban areas, factories use rivers, in many cases illegally, as a means to dispose of industrial effluents and other waste streams. Household owners who live near to or alongside rivers may use river as a means to dispose of their rubbish and garden refuse. Many urban areas have water borne sewerage systems. Failures at pump stations and blockages in the sewer pipes result in the discharge of sewage into the surrounding environment. Along with urban runoff, which contains pollutants from roads and gardens, this eventually ends up in nearby watercourses (D’Eathe, 2016). Polluted watercourses contribute to the degradation of the environment, reduced water quality, negative impacts on human health and negative effects on tourism and sport (Browne and Mugwedi, 2017).

An earlier report (KS/2354 Deliverable 3) considered the water quality of the upper-uMngeni catchment with a focus on nutrient inputs to the impoundments located therein. This report consists of three studies undertaken on two sub-catchments of the uMngeni River, namely the Palmiet and the Baynespruit Rivers with a shift of focus from catchments dominated by agriculture and forestry to urban areas and from nutrients to pathogens and heavy metals. The first study links the built infrastructure of the Palmiet Catchment to the water quality in the Palmiet River. The second study considers the effects that the water quality, particularly in terms of pathogen content, has on the catchment and the people who make use of the water. The third study similarly links water quality to its effects on the catchment, this time in the Baynespruit River. This study focuses on the transfer of heavy metals from the water to crops grown in the lower catchment. All three of these studies have been carried out as part of Masters projects as follows:

- The first study was carried out by Semeshan Naidoo for his MScEng thesis entitled “The relationship between the infrastructure, within the Palmiet catchment, and the condition of the Palmiet River water quality and riparian zone” (Naidoo, 2016)
- The second study was carried out by Ayanda Sithebe for her MSc thesis entitled “A comparative microbiological assessment of river basin sites to elucidate fecal impact and the corresponding risks” (Sithebe, 2017)
- The third study was carried out Jédine Govender for her MSc thesis entitled “An assessment of the water quality of the Baynespruit River and its linkages to the health of the Sobantu community” (Govender, 2016)

Although the three studies are linked through this project, they were undertaken independently by researchers in different locations and institutions with different laboratory facilities and supervision teams. Inevitably, there are some differences in analysis and approach. This means results are not directly comparable, but that common lessons can be drawn from them. In this Deliverable, we have made a start at drawing out those common lessons in preparation for the full analysis that will form part of project Deliverable 13.

After this introduction, the report starts with a description of the Palmiet catchment in Section two. Section three focuses on the effects of the catchment on the water quality of the Palmiet River. Section four focuses on the effects of water quality of the Palmiet River on the wider catchment.
Section five gives a description of the Baynespruit catchment and section six focuses on the effects of water quality of the Baynespruit River on the wider catchment.
2 Description of the Palmiet catchment

The Palmiet River is situated in the eThekwini Municipality extending from 29°47’6.0”S, 30°51’9.7”E to 29°48’16.5”S, 30°58’16.4”E. The Palmiet River is about 23 km in length. About 6 km of the river passes through the Palmiet Nature Reserve. Outside of the nature reserve, industrial and residential areas and ten informal settlements border the river.

![Palmiet River and its tributaries](Source: ArcMap 10.2)

The Palmiet River meanders through the Palmiet catchment flowing over undulating terrain with the exception of the Pinetown/New Germany area, which is relatively flat. Residential areas within the catchment encompass both the high and middle-income categories. Low-income areas in the form of informal settlements also border the river. The Pinetown/New Germany industrial area is the only industrial area within the Palmiet Catchment. The geology of the Palmiet catchment consists of sedimentary rocks. This includes Natal sandstone in the western and central areas of the catchment and Dwyka, Eccca and Alluvian formation in the eastern areas of the catchment (du Preez and de Villiers, 1987).

Within the Palmiet catchment, there are numerous smaller streams, which join the Palmiet River. Pollution in any of these streams will contribute to the pollution present within the Palmiet River. In assessing the condition of the Palmiet River, it is therefore vital to investigate its major tributaries. Figure 2.1 illustrates the extent of the Palmiet River as well as its numerous tributaries. The red line represents the Palmiet River whereas the yellow lines represent the tributaries of the Palmiet River. The majority of the tributaries have no name and are non-perennial streams.

The Palmiet River is used by a variety of people. Its uses range from recreational activities to satisfying the basic needs of people living in informal settlements. Rivers are usually impacted by their surroundings and the Palmiet River is no exception. Figure 2.2 and Figure 2.3 show the key areas of interest along the river. Figure 2.2 illustrates the course of the Palmiet River from its source down to the Westville North residential area. Figure 2.3 illustrates the section of the Palmiet River, which flows down from the Westville North residential area, flows through the Palmiet Nature Reserve, passes the University of KwaZulu-Natal Westville Campus and the informal settlements and to where it ultimately joins the uMngeni River.
Figure 2.2 - Palmiet River from source to Westville North residential area (Source: ArcMap 10.2)

Figure 2.3 - Palmiet River from Westville North residential area to its confluence with the uMgeni River (Source: ArcMap 10.2)
3 The effects of the state of the catchment on water quality in the Palmiet

3.1 Water quality in the Palmiet River

![Image: Location of sampling points used by EWS Pollution and Environment branch]

The eThekwini Water and Sanitation (EWS) Pollution and Environment branch samples the Palmiet River on a monthly basis. Figure 2.3 indicates the points along the Palmiet River where sampling takes place.

The sampling points are based on points of interest and ease of accessibility. Thus, the Pollution and Environment branch samples the river at five different locations along its course. Each sample is tested for a variety of substances including conductivity, E.coli, pH, total coliforms, turbidity and organic loading (measured as permanganate value after 4 hours (PV4)). EWS is primarily concerned with the efficiency of eThekwini’s sanitation systems. Therefore, the Unicity River Quality Indices, published on the EWS website (eThekwini Water and Sanitation, 2011; 2012; 2013; 2014; 2015; 2016), incorporates only two of the variables tested: organic loading and E.coli.

Existing chemical and microbiological testing results were obtained with help from the EWS Pollution and Environment Department, who had conducted the testing. In addition, Unicity River Quality Indices, summarising the overall water condition of the rivers in eThekwini Municipality, as well as rainfall data, for the Palmiet River catchment, was obtained directly from the eThekwini Municipality website.

3.1.1 E.coli and organic loading

Organic loading and E.coli were the key variables assessed as they provide an indication of the state of the sewer infrastructure within the Palmiet Catchment. The data obtained was summarized in the form of box and whisker plots to analyse the range and trends in the data over the years. In addition, turbidity results were analysed. Turbidity can be caused in a number of ways. Particulate matter in the water can originate from erosion, algal growth, organic matter from sewage discharges, and pollutants from urban runoff. Table 3.1 presents the thresholds for E.coli and organic loading used by EWS on the Unicity River Quality Indices.
Table 3.1 - EWS thresholds for E.coli and organic loading (Source: EWS, 2016)

<table>
<thead>
<tr>
<th>Category</th>
<th>E.coli [cfu/100ml]</th>
<th>Organic loading (PV4) [mg/l]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ideal (blue)</td>
<td>0 – 400</td>
<td>0 – 2</td>
</tr>
<tr>
<td>Acceptable (green)</td>
<td>400 – 2 000</td>
<td>2 – 5</td>
</tr>
<tr>
<td>Poor (yellow)</td>
<td>2000 – 10 000</td>
<td>5 – 8</td>
</tr>
<tr>
<td>Critical (red)</td>
<td>&gt;10 000</td>
<td>&gt;8</td>
</tr>
</tbody>
</table>

The composition of the Palmiet River continually changes and chemical and microbiological samples offer a snapshot of water quality in both space and time. There are a relatively small number of sampling points along the river and more points would enable improved identification of problem areas. Similarly, pollution incidents that happen in between EWS monthly sample collection may not be reflected in the results of subsequent samples.

Table 3.2 presents the mean recorded values at the various sampling locations, for the period 2007-2015.

Table 3.2 - Mean E.coli and organic loading results for 2007-2015. N.B.: Colours reflect the Unicity River Water Quality Index thresholds

<table>
<thead>
<tr>
<th>Location</th>
<th>E.coli [cfu/100 ml]</th>
<th>Organic Loading (PV4) [mg/l]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Varsity Drive Bridge (SP1)</td>
<td>3408</td>
<td>3.9</td>
</tr>
<tr>
<td>Birdhurst Road (SP2)</td>
<td>9188</td>
<td>4.7</td>
</tr>
<tr>
<td>Blair &amp; Otto Volek Roads (SP3)</td>
<td>8670</td>
<td>5.3</td>
</tr>
<tr>
<td>Crompton Street (SP4)</td>
<td>8160</td>
<td>5.5</td>
</tr>
<tr>
<td>Glenugie Road (SP5)</td>
<td>6838</td>
<td>6.3</td>
</tr>
</tbody>
</table>

Both the Varsity Drive Bridge (SP1) and Birdhurst Road (SP2) sampling points are located in a residential area. The Blair and Otto Volek Roads (SP3) sampling point is located on the outskirts of the Pinetown industrial area. On Blair Road, there is also a sewage pump station, which is upstream of the Birdhurst Road sampling point. Both Crompton Street (SP4) and Glenugie Road (SP5) sampling points are in an area that combines residential and retail areas, featuring a number of shopping centres and fast food outlets.

Whilst Table 3.2 illustrates which sample points have a continuously high E.coli or organic loading levels, it does not indicate the large variation in the sampling results over time. Figure 3.2 to Figure 3.10 illustrate the spread in yearly E.coli and organic loading results at the five sampling points selected by the EWS.
Figure 3.2 - 2007 E.coli results. N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.

Figure 3.3 - 2008 E.coli results N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.
Figure 3.4 - 2009 E. coli results N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.

Figure 3.5 - 2010 E. coli results N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.
Figure 3.6 - 2011 E.coli results N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.

Figure 3.7 - 2012 E.coli results N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.
Figure 3.8 - 2013 E. coli results N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.

Figure 3.9 - 2014 E. coli results N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.
Figure 3.10 - 2015 E.coli results N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.
Between 2007 and 2012 the majority of sampling points have a large range of E.coli results. High E.coli values can be attributed to major pollution events arising from failures at sewage pump stations or blockages and overflows in the sewer network. The range of E.coli results between 2013 and 2015 is significantly lower than for 2007 to 2012. However, this is a result of an increase in the lowest E.coli results. Between 2007 and 2015, across the majority of sampling points, 50 % of the E.coli results are above 2 000 cfu/100 ml. According to the EWS thresholds, E.coli values above 2 000 cfu/100 ml are classified as poor or critical.

The majority of the sample points lie in the poor category. SP3 is downstream of the Blair Road sewage pump station. When the pump station fails, there is a storage tank with capacity to contain two hours flow of sewage whilst the problem at the pump station is rectified. If the volume of sewage exceeds this capacity, this sewage then overflows into the Palmiet River. This procedure is the same at all the pump stations within the Palmiet catchment. As a result the water quality deteriorates and the effects of this sewage discharge are felt and seen downstream.

Areas with sanitary facilities that cater for a number of people, such as shopping centres and factories, which are common around SP3, SP4 and SP5, can contribute to high E.coli counts. Residential households, where dairy products are washed down the kitchen sink or rotten food is thrown down the sewer also contribute to high E.coli counts. SP1 is downstream of numerous sewer manholes, which are prone to overflowing incidents due to blockages in the sewer network. As the sewer network runs alongside the Palmiet River for the majority of its length, overflowing incidents at these manholes result in raw, untreated sewage contaminating the Palmiet River.

Organic loading includes proteins, amino acids, fats and pesticides as well as the variety of chemicals used in industrial areas. Raw sampling data obtained from EWS has been summarized and illustrated in Figure 3.11 to Figure 3.19. According to EWS, peaks in organic loading greater than 1.56 on the log scale, i.e. 36 mg/l are most likely attributed to industrial effluent. However, problems with sewer pipes and connecting infrastructure that lead to wastewater discharging into the Palmiet River also lead to elevated levels of organic loading in the river. In addition, there have been numerous industries who have been prosecuted for illegally dumping their industrial effluent into the Palmiet River.
Figure 3.11 - 2007 organic loading results N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.

Figure 3.12 - 2008 organic loading results N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.
Figure 3.13 - 2009 organic loading results. N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.

Figure 3.14 - 2010 organic loading results. N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.
Figure 3.15 - 2011 organic loading results N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.

Figure 3.16 - 2012 organic loading results N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.
Figure 3.17 - 2013 organic loading results. N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.

Figure 3.18 - 2014 organic loading results. N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.
Figure 3.19 - 2015 organic loading results. N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.
The worst year in terms of organic loading was 2010 with more than 25% of the organic loading levels across SP2, SP3, SP4 and SP5 above the 1.56 mark on the log scale, i.e. 36 mg/l. With the exception of 2010, 50% of the organic loading levels across all sample points, average at a maximum value of 0.7 on the log scale, i.e. 5 mg/l. According to the EWS thresholds, this is the border between acceptable and poor.

SP5 portrays constantly poor organic loading results in comparison to SP1, between 2007 and 2015. The primary reason for the poorer results is the difference in the surrounding land use at the two sampling points. SP5 is situated in the middle of shopping centres and fast food outlets and is downstream of residential areas and the Wyebank Municipal Dumpsite. SP1 on the other hand is located downstream of residential buildings only.

Shopping centres and fast food outlets are a major contributor to the increase in organic loading levels (Heger, 2015). They use detergents and chemicals to keep the area clean and during the cooking of food a variety of oils and fats are used. All of this is then disposed of into the sewer system (Arthur and Blanc, 2013). The cumulative effect of these wastes from the different areas coupled with the fact that some industries illegally dispose of their waste into the sewer systems results in high organic loading levels in sewer pipelines. Sewer pipe blockages and pump station failures, which happen on an all too frequent basis, cause this sewage to spill into the Palmiet River, thereby, elevating the level of pollutants within the river. Should sewage enter the Palmiet River, SP5 is a prime example of the poor organic loading levels that follow.

SP4 contains the second highest organic loading levels. SP4 is located in the New Germany/Pinetown industrial areas, surrounded mainly by car repair and manufacturing industries. The large area of impermeable surfaces particularly in the industrial area, allows for petrol, diesel and oil leaks from stationary vehicles in these areas to run off the impermeable surfaces and find their way to the Palmiet River, especially during rainfall events. Generally, residential areas will have far less stationary/parked vehicles on impermeable surfaces where petrol, diesel and oil leaks can occur and enter the river. In addition, certain industries in the area have been known to hose down their pavement surfaces. As a result, all the pollutants present on the surface will be transported straight into the stormwater drains and into the Palmiet River.

The organic loading indicator is related to the Chemical Oxygen Demand (COD) of the river. In addition to the common fats, amino acids and proteins that elevate the organic loading levels, decaying plant matter and algae can also contribute to the high PV4 level present in the Palmiet River.

From the results obtained it is evident that both residential and industrial areas contribute to the organic loading levels of the Palmiet River. Therefore, it cannot be assumed that only industrial areas are responsible for the peaks in organic loading. Domestic sewage can be high in proteins, fats and chemicals which increase the organic loading levels. Sewage from residential households can include cooking oils, butter, mayonnaise, soap, toothpaste, washing detergents and paint washed from paint brushes (Botha, 2016), all of which can play a part in the higher levels of organic loading in residential effluent. Therefore, problems with the sewer network can result in this effluent contaminating the Palmiet River and leading to peaks in the organic loading results.

3.1.2 Turbidity

Turbidity is a water characteristic, which can easily be seen by the naked eye and provides an indication of whether or not the river is polluted. Turbidity results have been presented as an
increase in turbidity can be attributed to a decrease in water quality as well as an increase in the flow rate of the Palmiet River.

Soil particles found in the Palmiet River, due to soil erosion and scour, contribute to the suspended matter present in the water. In addition, discharge of sewage and other wastes decrease the water quality and increase turbidity levels in the Palmiet River. An increase in hardened surfaces allows a larger volume of runoff to enter the river system over a shorter time span, which can result in higher flow rates within the Palmiet River. The resultant scouring can lead to an increase in suspended matter and turbidity levels in the river. Figure 3.20 to Figure 3.28 present the distribution of turbidity results, across all five sampling points, for 2007 to 2015.
Figure 3.20 - 2007 turbidity results. N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.

Figure 3.21 - 2008 turbidity results. N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.
Figure 3.22 - 2009 turbidity results N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.

Figure 3.23 - 2010 turbidity results N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.
Figure 3.24 - 2011 turbidity results N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.

Figure 3.25 - 2012 turbidity results N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.
Figure 3.26 - 2013 turbidity results N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.

Figure 3.27 - 2014 turbidity results N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.
Figure 3.28 - 2015 turbidity results. N.B. Distance is measured from the river mouth so that the plot shows source to mouth from left to right.
Minimum turbidity values lie at an average log value of 0.6, i.e. 4 NTU. SP3 presents relatively constant turbidity levels with maximum values averaging log 2, i.e. 100 NTU. The upstream industrial area has introduced numerous pollutants into the river from sewer network failures and from runoff carrying pollutants. These have all played a role in affecting the turbidity results. In addition, there are areas upstream of SP3 where the riverbanks have been severely eroded; this will be discussed in subsequent sections.

There has been a significant increase in the upper limits of turbidity between 2013 and 2015 at SP2, SP4 and SP5. There has been a steady increase in overall organic loading within the Palmiet River. SP5 was also the sampling point with the highest mean organic loading result. Therefore, sewer network failures could result in pollutants from residential areas, shopping centres and fast food outlets entering the Palmiet River and thereby increasing the turbidity of the river.

It can be concluded that whilst both E.coli and organic loading levels do affect the turbidity levels, it is evident that there are other factors that affect turbidity. Suspended matter can arise from a variety of other sources besides sewage, including river bank scouring which displaces soil sediments into the river. There are a number of potable water leaks within the Palmiet Catchment, which release small to large volumes of water into the river system. This can also increase the turbidity levels of the river as the excess water erodes the soil which runs off into the river.

The poor E.coli and organic loading results indicate failures in the sanitation system. The increase in turbidity indicates both a failure in the sanitation system as well as increased runoff levels and an increased flow rate leading to scouring of the Palmiet River. Chemical and microbiological composition of the river vary greatly. Whilst the sampling conducted by EWS provides only an indication of the short-term water quality of the Palmiet River, the quality is consistently poor and longer-term effects are likely. miniSASS provides an indication of the long-term water quality of the Palmiet River and is discussed in the next section.

3.2 Invertebrate biodiversity in the Palmiet River

In South Africa, the miniSASS system has been devised to incorporate macroinvertebrates as indicators to analyse the health and water quality of rivers (miniSASS, 2016). miniSASS results are not an indication of drinking water quality and do not replace chemical and microbiological analyses. Instead, they offer an indication of the effects of water quality on river biodiversity, based on the fact that many macroinvertebrates are sensitive to the chemical composition of their environment. Using this system, the river is classified into one of five categories depending on its overall score, which is an average of the identified macroinvertebrate’s sensitivity to pollution scores. Table 3.3 illustrates the five classes that river can be categorised into, for both a rocky and a sandy river.

<table>
<thead>
<tr>
<th>Score (Rocky River)</th>
<th>Score (Sandy River)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 7.2</td>
<td>&gt; 6.9</td>
<td>Natural (blue)</td>
</tr>
<tr>
<td>6.2 – 7.2</td>
<td>5.9 – 6.8</td>
<td>Good (green)</td>
</tr>
<tr>
<td>5.7 – 6.1</td>
<td>5.4 – 5.8</td>
<td>Fair (yellow)</td>
</tr>
<tr>
<td>5.3 – 5.6</td>
<td>4.8 – 5.3</td>
<td>Poor (red)</td>
</tr>
<tr>
<td>&lt; 5.3</td>
<td>&lt; 4.8</td>
<td>Very Poor (purple)</td>
</tr>
</tbody>
</table>

Table 3.3 - miniSASS score limits for rocky and sandy rivers (Source: miniSASS, 2016)

Figure 3.29 illustrates the location of the observation points along the Palmiet River. miniSASS sampling has been carried out along the river at points where there is a change in the land use.
Members of the Palmiet River Watch (PRW) also sampled areas that had been found to have recurring pollution incidents. Points were chosen based on the surrounding significance as well as accessibility. There are significantly more observation points along the river in comparison to the EWS sampling points. miniSASS observational data were obtained from the miniSASS website (http://www.minisass.org/en/). miniSASS results from 2014 to 2016 were plotted using Microsoft Excel. The mean values were computed and categorized according to the miniSASS score limits.

![Figure 3.29 – Location of miniSASS sampling points (Source: miniSASS, 2016)](image)

There are limitations to the miniSASS results. The majority of samples in any given year were carried out in the same month. The sampling months were not consistent from 2013 to 2016 and therefore seasonal variations may affect the scores when comparing between different years. The presence of alien species may also have an effect on the native macroinvertebrates present. It is not clear from the miniSASS results available whether alien species were present in any of the samples included in this study. A member of EWS mentioned that miniSASS is a good sampling method to use in rural areas, which are not heavily populated and dominated by sanitation issues, but it is unadvisable to use miniSASS in highly urbanised areas such as the Palmiet Catchment.

Figure 3.30 to Figure 3.33 illustrate the ecological condition, measured by the macroinvertebrates present, at the observation points along the Palmiet River. Sampling points are identified by their distance from the mouth of the river, with the source shown on the left and the mouth on the right of each plot.

Figure 3.30 provides a summary of the 2013 miniSASS observations. The overall mean score of 5.6 lies in the poor category. Point 14 contains the worst result. Point 14 is downstream of a large sewer network that runs along the Palmiet River. There are numerous sewer manholes, which due to blockages in the sewer pipes, are prone to overflowing. Due to the close proximity of these manholes to the Palmiet River, untreated sewage overflowing from these pipes contaminates the Palmiet River. Immediately evident is the good result at Point 17. This result is particularly unexpected as it was hypothesised that the Wyebank Municipal Dumpsite, upstream of Point 17, would have a negative impact on the water quality in the Palmiet River.

Figure 3.31 illustrates the ecological condition of the Palmiet River in 2014, measured at a number of sample points. It clearly indicates that the overall river health lies in the very poor category. The mean score is 3.95. The condition of the Palmiet River at Point 17 has significantly decreased from 2013 to 2014. Consultation with EWS officials revealed that observation Point 17 was conducted at a
point along the Palmiet River, which is inside a residential property in Kloof. As a result, the
observation point contained animal faeces as well as rotten fruit and they do not consider this point
as an acceptable observation point. However, a large part of the Palmiet River and the majority of its
tributaries flow through residential properties where there are pets and fruit-bearing trees.

Figure 3.32 summarizes the results obtained from 2015 and illustrates that the overall water quality
remains in the very poor category. It can be noted that the mean score of 4.44 is an improvement
from 2014; however, this mean is still far below acceptable results.

Figure 3.33 provides a summary of the 2016 miniSASS observations. The mean score of 4.89, whilst
an improvement from 2015, still remains in the very poor region. Areas that are in very poor
ecological conditions include the industrial area as well as the area around the Papwa Sewgolum golf
course. The Palmiet River around the Papwa Sewgolum golf course has a significant decrease in its
ecological condition from 2014 to 2016. The golf course is downstream of the Quarry Road informal
settlement; hence, inadequate sanitation facilities as well as a lack of service delivery, i.e. the
collection of waste, has significantly affected the state of the river.
Figure 3.30 - 2013 miniSASS results N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.

Figure 3.31 - 2014 miniSASS results N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.
Figure 3.32 - 2015 miniSASS results N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.

Figure 3.33 - 2016 miniSASS results N.B.: Distance is measured from the river mouth so that the plot shows source to mouth from left to right.
3.3 Links to the wider Palmiet catchment

A core component of the data collection was walking the Palmiet River. Between June and September 2016, different sections of the Palmiet River and its tributaries, were walked. During these walks, impacts imposed on the river and its riparian zone were recorded. These walks provided information on the current state of the Palmiet Catchment in greater detail than is possible using water quality parameters or LandSat imagery alone.

Data record sheets were used to accurately record impacts on the Palmiet River and riparian zone as observed on the river walks. The data record sheets were devised after analysing the Index of Habitat Integrity (IHI) and the Riparian Health Audit (RHA) produced by the WRC (WRC, 2016). However, both documents are primarily focused on rural, undeveloped areas where there are greater impacts from agricultural activities. Therefore, further research into the impacts from urbanisation was conducted and an impact list was devised which took into account variables that cause impact in an urban environment. These impacts were:

- Indigenous vegetation removal – This impact category is primarily focused on the removal of indigenous vegetation in the riparian zone for the implementation of built infrastructure.
- Exotic vegetation – This includes household gardens (a major source of alien vegetation) as well as the growing of commercial crops. However, primary focus is placed on alien vegetation.
- Bank erosion – This includes all factors that may result in the erosion of the riverbank. The force of the river itself is also considered as a major contributor.
- Channel modification – This includes any changes along or in the channel of the river that would not have occurred without the interference of humans.
- Water abstraction – This refers to areas where water has been taken from the river for use in domestic, industrial or agricultural applications.
- Inundation – This refers to areas where the riparian zone has been flooded by the construction of impoundments or dams.
- Flow modification – This includes all factors which play a role in increasing or decreasing the flow rate of the river.
- Bed modification – This includes all modifications made to the riverbed by hard infrastructure as well as alterations caused by the scouring force of the river.
- Water quality – This refers to any factors which affected water quality in the river.
- Rubbish dumping – This includes the dumping of solid waste, garden refuse and building rubble.

After each river walk, any new factors influencing the natural condition of the Palmiet River and riparian zone were included in the data record sheet. The final data record sheets are the product of the literature reviewed as well as on-site observations. Each data record sheet is similar with the only differences being the waypoint names, co-ordinates, comments and impact and causes applicable for that particular section. Please note that only text appearing in black applies to the section being observed; text that has been greyed out is not applicable. The comments column contains any information that was considered noteworthy or aided in the description of that particular section of river.

In addition to recording the impacts, a system has been used to rate each impact. The rating system used has been adjusted from the RHA, which uses a simplified version of the rating system presented in the IHI. As the IHI is designed for professional users with hands-on experience in their particular field, the rating system used in the RHA was considered more suitable for this particular
study. It provides an ecological condition of the accessible areas of the Palmiet River, its tributaries and riparian zone, with areas requiring immediate attention being easily identified based on their scores. Impacts, as presented in the data record sheets, have been rated on a scale from 0 (best case) to 5 (worst case) based on their severity and extent. The ecological categories are:

- 0: Natural, shown in blue
- 0.5-1: Good, shown in green
- 1.5-2: Fair, shown in light orange
- 2.5-3: Poor, shown in yellow
- 3.5-4: Very Poor, shown in dark orange
- 4.5-5: Critical, shown in red

Similar categories are used in miniSASS samplings. Whilst the actual scores may be debatable, with different assessors recording small differences in the scores, the scoring system is used as a means of identifying critical areas requiring immediate attention the underlying identification of problem areas along the Palmiet River, its tributaries and the riparian zone.

The area directly adjacent to river and stream banks are termed riparian areas. The riparian areas give way to terrestrial vegetation as shown in Figure 3.34.

![Figure 3.34 - The riparian zone](image)

The data collection on river walks have been devised to incorporate impacts to the river and to the riparian zone as the riparian zone plays an important part in maintaining the functionality of rivers and streams. The process for walking the river was adapted from the procedure followed by the Dusi-uMngeni Conservation Trust (DUCT). The following steps were taken:

1. The Palmiet River was divided into 7 units based on land use. The different units were:
   - Unit 1 – Wyebank and Kloof Residential Area
   - Unit 2 – Pinetown/New Germany Industrial Area
   - Unit 3 – Cowies Hill/Westville North Residential Area
   - Unit 4 – The Kingfisher Catchment (a sub-catchment of the Palmiet Catchment located in the Westville North Area)
   - Unit 5 – Westville Residential Area
   - Unit 6 – Palmiet Nature Reserve down to the UKZN’s Westville Campus
   - Unit 7 – Quarry Road Informal Settlement

2. Maps were prepared for each unit. Waypoints were added at 200 m intervals along the river or in some cases wherever access to the river could be gained.
3. The co-ordinates of each waypoint were loaded onto a handheld Global Positioning System (GPS) so that the location of each waypoint could be found whilst walking the river. Garmin Basecamp software was used to load the co-ordinates onto the GPS.

4. Maps illustrating the infrastructure in each unit were compiled in order to identify if said infrastructure was affecting the river and riparian zone in any way.

5. Individuals living or working alongside the river were alerted to the fact that there would be someone walking the river through the PRW messaging group (on WhatsApp).

6. Safety procedures were followed, including wearing appropriate protective equipment and alerting someone to the start and end times of each walk.

7. Pictures were taken with location tags on the camera switched on so that the pictures had co-ordinates associated with them.

8. After each day’s walk, the data collected was backed up to prevent the loss of information.

9. The data collected was then analysed and represented using GIS software.

The legality of walking the Palmiet River, and rivers in general, is based on land ownership. The Palmiet River flows through both public/municipal areas as well as through private properties. The general by-laws regarding public/municipal land were replaced in 2015 by the “Nuisance and Behaviour in Public Places By-Law”.

The GIS software, ArcMap 10.2, was used to produce the maps used in this study. Certain shape-files such as rivers, drainage catchments, roads, storm water and sewer networks were required to provide context to which the river impact shape-files could be added. The maps of the units are shown in Appendix 1 and are summarised in Section 3.4 and represent the observed ecological condition of each section of the Palmiet River, based on each of the 10 impacts. A summary of the impacts with colour coding according to the rating is shown in Appendix 2. This allows areas requiring immediate attention to be easily identified. Factors influencing each impact are also included on this summary. For example, a sewer pump station may have a major effect on water quality and so the location of the sewer pump stations are indicated.

No previous studies investigating the ecological condition of the Palmiet River and riparian zone have been conducted, therefore the results obtained here serve as a baseline for the current condition of the Palmiet Catchment. This allows for future comparisons between this baseline and the ecological condition of the Palmiet Catchment in future years. Additionally, the effectiveness of any future interventions can be assessed based on the positive or negative effect it produces on the ecological condition of the relevant area of the catchment.

Areas requiring immediate attention have been stated based on visual observations, the ecological scores, reported and recorded problem areas and after gaining a better understanding of the area.

3.3.1 Limitations

Not every part of the Palmiet River and its tributaries could be observed due to accessibility issues. The causes of these issues include:

- Personal safety was of concern in the Pinetown/ New Germany Industrial area. Crime is an issue in the area and suspected criminal gangs have been seen loitering under bridges and on the banks of the Palmiet River. In addition, the informal settlement areas also posed a major security risk. There are nine settlements all located in the lower end of the Palmiet Catchment, downstream of the University Road Bridge.

- The majority of the tributaries of the Palmiet River flow through residential properties. The owners have often fenced up their properties providing no access to the streams.
• Certain areas of the Palmiet Catchment were covered in dense vegetation preventing access. In addition, areas where the river has been piped were deemed inaccessible.

3.4 Results of the river walks

3.4.1 Unit 1 – Wyebank and Kloof Residential Area

Unit 1 is the highest point in the Palmiet catchment where the water quality is affected. The streams which form the source of the Palmiet Catchment have been significantly affected by the pollutants seeping out of the Wyebank Dumpsite.

Riparian corridors have been severely impacted in this area due to the fragmentation of the natural land. Table 3.4 presents details regarding some of the infrastructure which has aided in the fragmentation of the land. The number of points where the road crosses the river includes tributaries of the Palmiet River.

Table 3.4 - Details regarding some of the infrastructure within Unit 1

<table>
<thead>
<tr>
<th>Land use</th>
<th>Residential area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area [km²]</td>
<td>4.8</td>
</tr>
<tr>
<td>Hardened surfaces [%]</td>
<td>60.5</td>
</tr>
<tr>
<td>Length of roads [km]</td>
<td>96.9</td>
</tr>
<tr>
<td>Length of storm water network [km]</td>
<td>11.1</td>
</tr>
<tr>
<td>Length of sewer network [km]</td>
<td>25.4</td>
</tr>
</tbody>
</table>

Table 3.5 presents the overall ecological condition of the observable areas of Unit 1. Unit 1 is an area which averages fair ecological condition. Being a residential area, the majority of the Palmiet River and its tributaries flow through residential properties and has been fenced up. Ideally more points along the river should be investigated to provide a better indication of the overall ecological condition. However, it is clear that at the majority of the observation points, the impacts on the Palmiet River and its riparian zone are similar. Therefore, whilst more observation points would be ideal, the areas which have been observed do provide a good estimate of the ecological condition.

Table 3.5 - Overall ecological condition at each waypoint in Unit 1

<table>
<thead>
<tr>
<th>Observation Point</th>
<th>*Overall Rating [ /40]</th>
<th>*Percentage Change [%]</th>
<th>*Overall Ecological Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>OB10</td>
<td>13</td>
<td>32.5</td>
<td>Fair</td>
</tr>
<tr>
<td>OB9</td>
<td>9.5</td>
<td>23.75</td>
<td>Good</td>
</tr>
<tr>
<td>OB8</td>
<td>12.5</td>
<td>31.25</td>
<td>Fair</td>
</tr>
<tr>
<td>OB7</td>
<td>14</td>
<td>35</td>
<td>Fair</td>
</tr>
<tr>
<td>OB6</td>
<td>11</td>
<td>27.5</td>
<td>Good</td>
</tr>
<tr>
<td>OB5</td>
<td>12</td>
<td>30</td>
<td>Fair</td>
</tr>
<tr>
<td>OB4</td>
<td>13</td>
<td>32.5</td>
<td>Fair</td>
</tr>
<tr>
<td>OB3</td>
<td>18.5</td>
<td>46.25</td>
<td>Fair</td>
</tr>
<tr>
<td>OB2-OB1</td>
<td>22</td>
<td>55</td>
<td>Poor</td>
</tr>
<tr>
<td>OB1-CA18</td>
<td>24.5</td>
<td>61.25</td>
<td>Poor</td>
</tr>
</tbody>
</table>

*Inundation and Water Abstraction have been omitted from the "Overall Rating", "Percentage Change" and in calculating the "Overall Ecological Condition" as they are not applicable in this area. The inclusion of them decreases the score, therefore, it doesn't accurately portray the conditions of the area.
Presenting overall ecological conditions at each observation point, whilst providing a good indication of how much of the natural land has been transformed or altered by the activities of urbanisation, provides little information with regards to the critical problems within Unit 1. Therefore, Figure 3.35 identifies impacts which are a common problem throughout Unit 1.

![Graph showing ecological impact scores]

*Figure 3.35 – Average ecological impact scores for Unit 1*

Exotic vegetation, in particular alien plants, are a problem present at each observation point producing the high average score. As previously stated, Unit 1 is a residential area and homeowners have planted numerous alien plants in their gardens. The alien vegetation has spread over the fences and into areas containing indigenous vegetation. The alien vegetation has out-competed the indigenous vegetation for resources and the growth rate has been augmented by the surrounding conditions, such as the increased nutrient content of the Palmiet River and its tributaries. Leachate seeping out the Wyebank Dumpsite as well as leakages and blockages in the sewer network, as observed downstream of waypoint WK2, are major contributors to the increased nutrient content of the river.

Whilst exotic vegetation is a problem at every observation point in Unit 1, there are a number of isolated impacts within Unit 1 which require immediate attention. These are:

- Observation Points OB2 to OB1 (Bank Erosion) - There are two areas, in-between observation points OB2 and OB1, which require immediate intervention to stabilise the riverbank. Further erosion of the riverbank will put the sewer line at risk creating a major problem. If the integrity of the sewer line is compromised, the river will be polluted with untreated sewage.

- Observation Point OB2 to OB1 (Water Quality) - The river appears to be contaminated by sewage, however, this was not confirmed at the time of print. The river was slightly grey...
with a faint odour, however, no foam or sanitary wipes were spotted. Grey water, odour, foam and sanitary wipes are usually a clear indication of sewage pollution.

- Observation points OB8 and OB10 (Alien Invasive Plants) - Lollipop climbers were spotted in this area. Identified as a problem four years ago, efforts were made to have them removed. However, they are growing again in the area around the dumpsite and the railway track.

- The Wyebank Municipal Dumpsite - In addition to the air pollution, leachate and other substances seep out of the area and affect the water quality of the Palmiet River, flowing below the dumpsite.

3.4.2 Unit 2 – Industrial Area

There are numerous businesses and factories in the area as well as a sewer pump station, located on Blair Road. This pump station has had numerous problems resulting in untreated sewage being discharged directly into the Palmiet River. The last major discharge occurred on 31st May 2016 due to a blockage in the pipe network during maintenance of the pumps. In addition to the impacts caused by the pump station, a small number of industries have illegally discharged trade effluent into the Palmiet River. This unit covers the Palmiet River from Glenugie Road, a predominantly residential area with many housing complexes, down through the Pinetown/New Germany residential area and up to Ambleside Lane, a residential area.

Table 3.6 presents details regarding some of the infrastructure which has aided in the fragmentation of the land. The number of points where the road crosses the river includes tributaries of the Palmiet River as well.

Table 3.6 - Details regarding some of the infrastructure within Unit 2

<table>
<thead>
<tr>
<th>Land use</th>
<th>Industrial area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area [km²]</td>
<td>5.5</td>
</tr>
<tr>
<td>Hardened surfaces [%]</td>
<td>85.1</td>
</tr>
<tr>
<td>Length of roads [km]</td>
<td>137.8</td>
</tr>
<tr>
<td>Length of stormwater network [km]</td>
<td>30.4</td>
</tr>
<tr>
<td>Length of sewer network [km]</td>
<td>49.6</td>
</tr>
</tbody>
</table>

Immediately noticeable is the increase in infrastructure present within Unit 2 as compared to Unit 1. Access to certain parts of the Palmiet River was not possible due to safety concerns.

Table 3.7 presents the overall ecological condition of the Palmiet River analysed in Unit 2. Based on the ecological condition of the Palmiet River as well as visual observations, areas requiring immediate attention were highlighted.
Table 3.7 - Overall ecological condition at each waypoint in Unit 2

<table>
<thead>
<tr>
<th>Waypoints</th>
<th>*Overall Rating [ /40]</th>
<th>*Percentage Change [%]</th>
<th>*Overall Ecological Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA18</td>
<td>24.5</td>
<td>61.25</td>
<td>Poor</td>
</tr>
<tr>
<td>CA18-CA17</td>
<td>24.5</td>
<td>61.25</td>
<td>Poor</td>
</tr>
<tr>
<td>CA17-CA16</td>
<td>29.5</td>
<td>73.75</td>
<td>Very Poor</td>
</tr>
<tr>
<td>CA16-CA15</td>
<td>23</td>
<td>57.5</td>
<td>Poor</td>
</tr>
<tr>
<td>CA15-CA14</td>
<td>25.5</td>
<td>63.75</td>
<td>Poor</td>
</tr>
<tr>
<td>CA14-CA13</td>
<td>22.5</td>
<td>56.25</td>
<td>Poor</td>
</tr>
<tr>
<td>CA13-CA12</td>
<td>27.5</td>
<td>68.75</td>
<td>Poor</td>
</tr>
<tr>
<td>CA12-CA11</td>
<td>30.5</td>
<td>76.25</td>
<td>Very Poor</td>
</tr>
<tr>
<td>CA11-CA10</td>
<td>29.5</td>
<td>73.75</td>
<td>Very Poor</td>
</tr>
<tr>
<td>CA10-CA9</td>
<td>33</td>
<td>82.5</td>
<td>Very Poor</td>
</tr>
<tr>
<td>CA4-CA3</td>
<td>22</td>
<td>55</td>
<td>Poor</td>
</tr>
<tr>
<td>CA3-CA2</td>
<td>27.5</td>
<td>68.75</td>
<td>Poor</td>
</tr>
<tr>
<td>CA2-CA1</td>
<td>23.5</td>
<td>58.75</td>
<td>Poor</td>
</tr>
<tr>
<td>CA1-CA0</td>
<td>22.5</td>
<td>56.25</td>
<td>Poor</td>
</tr>
<tr>
<td>CH1-CH0</td>
<td>22.5</td>
<td>56.25</td>
<td>Poor</td>
</tr>
</tbody>
</table>

*Inundation and Water Abstraction have been omitted from the "Overall Rating", "Percentage Change" and in calculating the "Overall Ecological Condition" as they are not applicable in this area. The inclusion of them decreases the score, therefore, it doesn’t accurately portray the conditions of the area.

Unit 1 presented conditions ranging between good and fair. Unit 2 presents conditions ranging from poor to very poor. Unit 2 is a vastly more urbanised area containing larger storm water and sewer networks, more impervious surfaces and more areas where pollutants enter the river and decrease the water quality. In order to identify common problems throughout Unit 2, the impact scores were summarised, as illustrated by Figure 3.36.

Figure 3.36 - Average Ecological Impact Scores for Unit 2
Comparison of Figure 3.35 and Figure 3.36 further indicated that Unit 2 has significantly poorer results than Unit 1. The removal of indigenous vegetation, the growth of alien vegetation, the erosion of the riverbank, the modification of the river channel, the increased flow rate of the river and the modification to the riverbed are all common problems throughout Unit 2. In addition, Unit 2 has substantially more areas which require immediate attention in comparison to Unit 1. The areas which require prioritization are all related to infrastructure issues as follows:

- **Waypoints CA18 to CA17 (Bank Erosion)** - The riverbank behind the Glenugie Gardens complex had suffered a significant loss in its structural integrity resulting in the implementation of gabion baskets. However, there are certain areas of the riverbank absent of any gabion baskets or reinforcing measures and these areas continue to be eroded away. After a few more heavy rainfall events, the fences may fall down due to the significant bank erosion.

- **Waypoints CA12 to CA10 (Bank Erosion)** - Gabion baskets have been implemented at intervals, but in some cases they have only been implemented along one side of the riverbank. As a result, the force of the river has significantly eroded the opposing banks in these areas. In addition, gabion baskets which have been incorrectly placed serve little function against the force of the river.

- **Waypoints CA11 to CA9 (Bed Modification)** - The Palmiet River between these waypoints has been scoured down to bedrock, a direct result of the increased flows within the river.

- **Waypoints CA3 to CA2 (Bed Modification)** - There is little natural material remaining between waypoints CA3 and CA2 as much of the natural material has either been removed or replaced with cement.

- **Waypoints CA15 to CA14, CA13 to CA9, CA3 to CA2 (Channel Modification)** - The Palmiet River channel has been significantly modified along its length, but these waypoints are of particular concern. The riparian zone between these waypoints has been replaced with gabion baskets, cemented banks and bridge culverts. This hard infrastructure, in addition to decreasing the functionality of the riparian zone, plays a large role in increasing the flow rate of the Palmiet River.

- **Waypoints CA13 to CA9 (Flow Modification)** - The cementation of the river banks and the implementation of gabion baskets along the river bank has reduced the natural infiltration ability of the river water. As a result, higher volumes of water are channelled into flowing downstream. In addition, the bridges between waypoints CA13 and CA9 have reduced the
channel width, and as a result the water flowing out of the downstream side of these bridges are at a significantly higher velocity than the water entering the bridge culverts.

- **Waypoints CA17 to CA14 (Rubbish Dumping)** - There has been excessive dumping of both solid waste and garden refuse between waypoints CA17 and CA14. The problematic area is directly adjacent to Broadway Street, where individuals have easy access to dump their waste and drive off. Further upstream, some of the housing complexes have discarded their garden refuse over the fences, directly into the Palmiet River’s riparian zone.

- **Waypoints CA11 to CA9 (Water Quality)** - The Palmiet River between waypoints CA11 and CA9 is polluted on a weekly basis. The Ivy Road culvert appears to be the largest contributor with regular reports of foam or colour changes to the water flowing out the culvert being reported. This is a direct result of blocked or defective sewer lines or the illegal activities of industries.

- **Waypoints CA3 to CA2 (Water Quality)** - A major problem between waypoints CA3 and CA2 is the Blair Road sewer pump station. There are often failures within the pump station or in the sewer lines leading to the pump station, and as a result untreated sewage is often discharged directly into the Palmiet River.

### 3.4.3 Unit 3 – Cowies Hill/ Westville North Residential Area

The majority of the infrastructure constructed consists of houses, sewer networks (transporting predominantly household effluent), stormwater systems and roads. Table 3.8 presents the lengths of the roads, sewer pipes as well as stormwater pipes within the Palmiet Catchment, in Unit 3. Unit 3 extends from the Cowies Hill residential area down to the Methven Road sewer pump station, located in the Westville North residential area.

The loss of indigenous vegetation has been a major problem throughout the Palmiet Catchment, however, one of the residents along Unit 3 of the Palmiet River has tried to re-introduce the Palmiet plant into the riparian zone. As is synonymous with the other sections observed, there have also been significant impacts on this section of the Palmiet River. Bed modification, i.e. the exposure of bedrock, is of particular concern along Unit 3, of the Palmiet River, and it has been caused due to the numerous modifications made to the river system.

*Table 3.8 - Details regarding some of the infrastructure within Unit 3*

<table>
<thead>
<tr>
<th>Land use</th>
<th>Residential area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area [km²]</td>
<td>4.1</td>
</tr>
<tr>
<td>Hardened surfaces [%]</td>
<td>46.7</td>
</tr>
<tr>
<td>Length of roads [km]</td>
<td>51.1</td>
</tr>
<tr>
<td>Length of stormwater network [km]</td>
<td>13.8</td>
</tr>
<tr>
<td>Length of sewer network [km]</td>
<td>15.1</td>
</tr>
</tbody>
</table>
The statistics presented in Table 3.8 indicate that Unit 3 is the least developed when compared to Units 1 and 2. However, even though there is less infrastructure, when compared to Unit 1 and 2, there are still many significant impacts imposed on the Palmiet River and its riparian zone. These will be explored in the subsequent sections beginning at the removal of the indigenous vegetation.

3.4.3.1 Overall State of Unit 3

Error! Reference source not found. presents the overall rating and ecological condition for each waypoint observed in Unit 3. The overall ecological condition is an average of all the impacts observed in Unit 3.

Table 3.9 - Overall ecological condition at each waypoint in Unit 3

<table>
<thead>
<tr>
<th>Waypoints</th>
<th>*Overall Rating [ /40]</th>
<th>*Percentage Change [%]</th>
<th>*Overall Ecological Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA0-B13</td>
<td>22.5</td>
<td>56.25</td>
<td>Poor</td>
</tr>
<tr>
<td>B13-B12</td>
<td>16</td>
<td>40</td>
<td>Fair</td>
</tr>
<tr>
<td>B12-B11</td>
<td>22.5</td>
<td>56.25</td>
<td>Poor</td>
</tr>
<tr>
<td>B11-B10</td>
<td>23</td>
<td>57.5</td>
<td>Poor</td>
</tr>
<tr>
<td>B10-B9</td>
<td>21.5</td>
<td>53.75</td>
<td>Poor</td>
</tr>
<tr>
<td>B9-B8</td>
<td>20</td>
<td>50</td>
<td>Poor</td>
</tr>
<tr>
<td>B8-B7</td>
<td>16</td>
<td>40</td>
<td>Fair</td>
</tr>
<tr>
<td>B7-B6</td>
<td>23.5</td>
<td>58.75</td>
<td>Poor</td>
</tr>
<tr>
<td>B6-B5</td>
<td>19.5</td>
<td>48.75</td>
<td>Fair</td>
</tr>
<tr>
<td>B5-B4</td>
<td>18.5</td>
<td>46.25</td>
<td>Fair</td>
</tr>
<tr>
<td>B4-B3</td>
<td>15</td>
<td>37.5</td>
<td>Fair</td>
</tr>
<tr>
<td>B3-B2</td>
<td>15.5</td>
<td>38.75</td>
<td>Fair</td>
</tr>
<tr>
<td>B2-B1</td>
<td>23</td>
<td>57.5</td>
<td>Poor</td>
</tr>
<tr>
<td>B1-B0</td>
<td>18</td>
<td>45</td>
<td>Fair</td>
</tr>
</tbody>
</table>

*Inundation and Water Abstraction have been omitted from the "Overall Rating", "Percentage Change" and in calculating the "Overall Ecological Condition" as they are not applicable in this area. The inclusion of them decreases the score, therefore, it doesn't accurately portray the conditions of the area.

Table 3.9 indicates that the average ecological condition of the Palmiet River, observed in Unit 3, fluctuates between fair and poor.

The areas which require immediate attention are as follows:

- Waypoints CA0 to B13 (Bank Erosion) - The bank along this section of the river is being severely eroded. Recently there has been a case where a larger tree had fallen into the river channel after the riverbank had lost its structural integrity. This tree then acted as an obstruction to the flow of the river.

- Waypoints B11 to B9 (Flow Modification) - This section of the river channel has been severely modified. There are more hard infrastructure in this area than natural vegetation. These have been implemented to protect the riverbanks bordering residential properties and the Birdhurst Bridge, however, due to the hard infrastructure interventions, the river has been channelled downstream resulting in the severe downstream scouring.
- **Waypoints CA0 to B13 (Water Quality)** - The water has been overflowing from the sewer pipe for quite some time. Residents downstream have also reported numerous instances where they see foam on the river. It is highly likely that blockages in the sewer networks are common resulting in the discharge of sewage into the Palmiet River.

- **Waypoints B10 to B9 (Water Quality)** - The Birdhurst Road pump station is located in this area. There have been no recent reports of discharge from the pump station, however, residents often report pollution incidents downstream which have been traced back to problems at the pump station.

The above areas require immediate attention, however, there are also impacts which are common throughout Unit 3. Figure 3.37 illustrates the average scores of each impact, higher average impact scores indicate problems common throughout Unit 3.

![Figure 3.37 - Average Ecological Impact Scores for Unit 3](image)

Clearly evident from Figure 3.37 is the problem of bed modification. The riverbed, particularly downstream of the Birdhurst Road weir, has been scoured down to bedrock. As previously explained, this is a direct result of the increased flow rate of the Palmiet River which has resulted in an increase in its scouring ability.

Unit 3 present similar scores to Unit 1 in terms of the removal of the indigenous vegetation. In addition, when considering the overall ecological conditions of Units 1 to 3, Units 1 and 3 exhibit similar ecological conditions, i.e. averaging in the fair to poor regions. Unit 1 and 3 are both residential areas and it is, therefore, expected that the impacts to the surrounding environment will be of a similar scale.
3.4.4 Unit 4 - The Kingfisher Catchment

The Kingfisher Stream has its source in the New Germany Nature Reserve. The formation of the stream can be attributed to the fact that it is at a low point in a grassveld area which allows for the accumulation of both groundwater and surface water. The stream then flows in a South Easterly direction, passing through a dam along its course. The Kingfisher Stream is joined by a number of smaller streams along its course, mostly non perennial, and ultimately joins the Palmiet River about 5m downstream of the Methven Road sewage pump station.

Along Ashwin Avenue, the Kingfisher stream is bordered on both banks by residential properties. Atholl Heights School is located about 1200m downstream, on the right bank, from the streams source, the left hand bank is still bordered by residential properties. A former wetland area, now converted into Sunnybrae Park, is located around 800m upstream from where the Kingfisher Stream joins the Palmiet River. There is only one remaining wetland in the Kingfisher Catchment located along Duncan Drive.

The Kingfisher Catchment, as a whole, is a highly urbanised area characterised by hard, impermeable surfaces. The only remnants of natural vegetation are the areas which the stream flows through, the area allocated to the New Germany reserve and the small wetland located near Duncan Road. Table 3.10 presents some details regarding the infrastructure within Unit 4.

Table 3.10 - Details regarding some of the infrastructure within Unit 4

<table>
<thead>
<tr>
<th>Area category</th>
<th>Residential area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area [km$^2$]</td>
<td>2.3</td>
</tr>
<tr>
<td>Hardened surfaces [%]</td>
<td>60.9</td>
</tr>
<tr>
<td>Length of roads [km]</td>
<td>56.9</td>
</tr>
<tr>
<td>Length of stormwater network [km]</td>
<td>9.4</td>
</tr>
<tr>
<td>Length of sewer network [km]</td>
<td>19.9</td>
</tr>
</tbody>
</table>

Table 3.10 indicates that Unit 4 has similar levels of infrastructure in comparison to Unit 3. Whilst, the level of development in the area may be similar, in terms of the figures presented in Table 3.10, the Kingfisher Catchment encompasses an area of 2.2km$^2$. The impacts of the development of the area within the Kingfisher Catchment has had significant impacts which will be discussed in the subsequent sections. Not every section of the stream was accessible as the stream flowed through residential properties and areas where the vegetation was too dense to see the stream.

3.4.4.1 Overall State of Unit 4

Error! Reference source not found. presents the overall ecological condition at each waypoint.
Table 3.11 - Overall ecological condition at each waypoin in Unit 4

<table>
<thead>
<tr>
<th>Waypoints</th>
<th>Overall Rating [ /50]</th>
<th>Percentage Change [%]</th>
<th>Overall Ecological Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>KA15</td>
<td>3.5</td>
<td>7</td>
<td>Natural</td>
</tr>
<tr>
<td>KA15-KA14</td>
<td>8.5</td>
<td>17</td>
<td>Good</td>
</tr>
<tr>
<td>KA14-KA13</td>
<td>11</td>
<td>22</td>
<td>Good</td>
</tr>
<tr>
<td>KA13-KA8</td>
<td>21.5</td>
<td>43</td>
<td>Fair</td>
</tr>
<tr>
<td>KA8-KA7</td>
<td>19</td>
<td>38</td>
<td>Fair</td>
</tr>
<tr>
<td>KA7-KA6</td>
<td>22.5</td>
<td>45</td>
<td>Fair</td>
</tr>
<tr>
<td>KA6-KA5</td>
<td>23.5</td>
<td>47</td>
<td>Fair</td>
</tr>
<tr>
<td>KA5-KA4</td>
<td>25.5</td>
<td>51</td>
<td>Poor</td>
</tr>
<tr>
<td>KA4-KA3</td>
<td>27.5</td>
<td>55</td>
<td>Poor</td>
</tr>
<tr>
<td>KA3-KA1</td>
<td>24</td>
<td>48</td>
<td>Fair</td>
</tr>
<tr>
<td>KA1-KA0</td>
<td>22</td>
<td>44</td>
<td>Fair</td>
</tr>
<tr>
<td>KF1-KF0</td>
<td>10.5</td>
<td>21</td>
<td>Good</td>
</tr>
<tr>
<td>KH3</td>
<td>19</td>
<td>38</td>
<td>Fair</td>
</tr>
<tr>
<td>KJ2</td>
<td>9</td>
<td>18</td>
<td>Good</td>
</tr>
<tr>
<td>KJ3</td>
<td>14.5</td>
<td>29</td>
<td>Good</td>
</tr>
<tr>
<td>KJ3-KJ2</td>
<td>18.5</td>
<td>37</td>
<td>Fair</td>
</tr>
<tr>
<td>KJ2-KJ1</td>
<td>11.5</td>
<td>23</td>
<td>Good</td>
</tr>
<tr>
<td>KJ1-KJ0</td>
<td>7</td>
<td>14</td>
<td>Good</td>
</tr>
</tbody>
</table>

Table 3.11 indicates that the average ecological condition of the Kingfisher Stream is in the fair region. However, please note that both Inundation and Water Abstraction have been included in calculating the overall ecological condition. There is an area in the New Germany Nature Reserve where the riparian zone has been flooded and water has been taken to fill a dam. Unit 4 is the only unit observed where Inundation and Water Abstraction have played a role in affecting the stream and the riparian zone and has, therefore, been included.

Areas which need immediate attention, summarized from the previous sub-sections, include:

- Waypoints KA5 to KA3 (Bank Erosion) - The edge of the bank at the edge of Sunnybrae Park is almost vertical with an estimated 5m drop to the Kingfisher Stream. After every rainfall event, more and more of the bank is being eroded away.

- Waypoints KA6 to KA5 (Channel Modification) - The Kingfisher Stream has been piped to allow for the Jupiter Road crossing. However, this has significantly reduced the channel width which has significantly increased the flow on the downstream side of the crossing. However, should future heavy rainfall events occur, this road crossing may cause a barrier and result in the “back flooding” of the Kingfisher Stream.
• Waypoints KJ3 to KJ2 (Flow Modification) - The flow in this section has significantly increased due to the stormwater outlets which discharge water when the Mount Moriah Reservoirs overflow. Deep gullies and holes have been formed in the soil.

• Waypoint KH3 (Flow Modification) - The stormwater outlets convey water from the M19, the water being discharged has been directed via a channel into a single area. As such, the increased flow rate has eaten away at the bank and undermined the gabion baskets.

• Waypoints KA5 to KA1 (Bed Modification) - There has been severe scouring of the stream bed with bed rock exposed in certain sections.

• Waypoints KA1 to KA0 (Rubbish Dumping) - There are people living behind the Chiltern Road Sports Club who take peoples rubbish and sort through it behind the Sports Club and then leave the rubbish lying there providing a breeding ground for pests.

• Waypoints KA6 and KA5 (Water Quality) - Residents have connected their stormwater to the sewer networks. During heavy rainfall events, the sewer networks are unable to cope with the increased volumes resulting in the overflowing of the sewer networks. Thus, sewage is discharged into the Kingfisher Stream, affecting the water quality.

The most critical of the above mentioned areas are the areas where the stream flow has been substantially augmented, i.e. in-between waypoints KJ3 to KJ2 and waypoint KH3. Figure 3.38 illustrates the average scores of each impact observed in Unit 4.
Being a residential area, it is expected that the scores will be similar to those of Unit 1 and 3. For the majority of the scores this assumption proved valid, however, both flow modification and bank erosion portray scores which are on par with Unit 2, the industrial area. As previously explored, this is due to the occasional overflowing of the reservoirs and the channelization of the stormwater outlets, conveying water from the M19, directly into the source of the stream at waypoint KH3. The increased volume of water flows through a river channel which has been significantly modified by hard infrastructure which reduces the waters infiltration ability. This increased flow results in the scouring of the riverbanks, particularly evident at the Sunnybrae Park. These factors, whilst not a norm in residential areas, results in the elevated flow modification and bank erosion scores.

3.4.5 Unit 5 – Methven Road Pump Station to Palmiet Nature Reserve

Access was available to the main Palmiet River, however, the tributaries of the Palmiet River were inaccessible as they flowed through residential properties. As a result, fences and gates prevented access to the tributaries. The length of the Palmiet River covered by Unit 5 extends from about 70m upstream of the Methven Road Sewer Pump Station down to the Frank Ferrer Hall at the Palmiet Nature Reserve, a distance of approximately 4.7km. This unit of the Palmiet River has a significantly wider riparian zone, averaging around 6m, in comparison to the previous sections analysed.

Households directly adjacent to the Palmiet River have converted their gardens into small parks with seating areas as well as areas to braai and relax. These areas lead directly onto the banks of the Palmiet River. Table 3.12 presents average statistics of some of the infrastructure present within Unit 5.

<table>
<thead>
<tr>
<th>Area category</th>
<th>Residential area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area [km²]</td>
<td>4.8</td>
</tr>
<tr>
<td>Hardened surfaces [%]</td>
<td>53.3</td>
</tr>
</tbody>
</table>
The decreased length of the sewer pipelines, in Unit 5, is easily noticeable. It is significantly less than Units 1 to 4. This indicates that the bulk of the households are on septic tanks. The effect of the reduced sewer network in the area will be explored in the subsequent sections. Table 3.13 illustrates the extent of the Palmiet River analysed as per Unit 5.

### 3.4.5.1 Overall State of Unit 5

Table 3.13 - Overall ecological condition at each waypoint in Unit 5

<table>
<thead>
<tr>
<th>Waypoints</th>
<th>*Overall Rating [ /40]</th>
<th>*Percentage Change [%]</th>
<th>*Overall Ecological Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1-WC23</td>
<td>18</td>
<td>45</td>
<td>Fair</td>
</tr>
<tr>
<td>WC23-WC22</td>
<td>23.5</td>
<td>58.75</td>
<td>Poor</td>
</tr>
<tr>
<td>WC22-WC21</td>
<td>22</td>
<td>55</td>
<td>Poor</td>
</tr>
<tr>
<td>WC21-WC20</td>
<td>18.5</td>
<td>46.25</td>
<td>Fair</td>
</tr>
<tr>
<td>WC20-WC19</td>
<td>24</td>
<td>60</td>
<td>Poor</td>
</tr>
<tr>
<td>WC19-WC18</td>
<td>23.5</td>
<td>58.75</td>
<td>Poor</td>
</tr>
<tr>
<td>WC18-WC17</td>
<td>20.5</td>
<td>51.25</td>
<td>Poor</td>
</tr>
<tr>
<td>WC17-WC16</td>
<td>18.5</td>
<td>46.25</td>
<td>Fair</td>
</tr>
<tr>
<td>WC16-WC15</td>
<td>20</td>
<td>50</td>
<td>Poor</td>
</tr>
<tr>
<td>WC15-WC14</td>
<td>25</td>
<td>62.5</td>
<td>Poor</td>
</tr>
<tr>
<td>WC14-WC13</td>
<td>22</td>
<td>55</td>
<td>Poor</td>
</tr>
<tr>
<td>WC13-WC12</td>
<td>18</td>
<td>45</td>
<td>Fair</td>
</tr>
<tr>
<td>WC12-WC11</td>
<td>18</td>
<td>45</td>
<td>Fair</td>
</tr>
<tr>
<td>WC11-WC10</td>
<td>19.5</td>
<td>48.75</td>
<td>Fair</td>
</tr>
<tr>
<td>WC10-WC9</td>
<td>19.5</td>
<td>48.75</td>
<td>Fair</td>
</tr>
<tr>
<td>WC9-WC8</td>
<td>17.5</td>
<td>43.75</td>
<td>Fair</td>
</tr>
<tr>
<td>WC8-WC7</td>
<td>16.5</td>
<td>41.25</td>
<td>Fair</td>
</tr>
<tr>
<td>WC7-WC6</td>
<td>17.5</td>
<td>43.75</td>
<td>Fair</td>
</tr>
<tr>
<td>WC6-WC5</td>
<td>17</td>
<td>42.5</td>
<td>Fair</td>
</tr>
<tr>
<td>WC5-WC4</td>
<td>15</td>
<td>37.5</td>
<td>Fair</td>
</tr>
<tr>
<td>WC4-WC3</td>
<td>15</td>
<td>37.5</td>
<td>Fair</td>
</tr>
<tr>
<td>WC3-WC2</td>
<td>12.5</td>
<td>31.25</td>
<td>Fair</td>
</tr>
<tr>
<td>WC2-WC1</td>
<td>17</td>
<td>42.5</td>
<td>Fair</td>
</tr>
<tr>
<td>WC1-WC0</td>
<td>17</td>
<td>42.5</td>
<td>Fair</td>
</tr>
</tbody>
</table>

*Foundation and Water Abstraction have been omitted from the "Overall Rating", "Percentage Change" and in calculating the "Overall Ecological Condition" as they are not applicable in this area. The inclusion of them decreases the score, therefore, it doesn’t accurately portray the conditions of the area.

Table 3.13 presents the overall ecological condition, in between each waypoint of the Palmiet River observed in Unit 5.

As indicated by Table 3.13, the condition of the Palmiet River observed in Unit 5 ranges between the fair and poor conditions. Impacts which are problematic throughout Unit 5 are summarized in Figure 3.39.
Unit 5, a typical residential area, has impacts on par with Unit 3. Unit 5, however, has slightly poorer riverbed conditions. A major tributary, the Kingfisher Stream, joins the Palmiet River downstream of waypoint WC23. The factors which have increased the flow rate of the Kingfisher Stream, discussed in Unit 4, also have a significant impact on the Palmiet River. The increased volume of water flowing into the Palmiet River, encompassed by Unit 5, as well as the increased volumes of water from upstream have scoured the riverbed more than in Unit 3. The degree to which the indigenous vegetation has been removed as well the extent of alien vegetation is on par with the other residential areas. Using the ecological impacts, for each individual impact, and visual observations, priority areas encompassed within Unit 5 were defined and are linked to the surrounding infrastructure. The following areas require immediate attention:

- **Waypoints WC23 to WC22 (Bank Erosion)** - The bank has been severely eroded in this section. The Kingfisher Stream joins the Palmiet River in this section. The increased flow rate from two different directions has eroded the bank.

- **Waypoints WC23 to WC22, WC19 to WC18, WC15 to WC14 (Flow Modification)** - There have been bridges constructed over the river channel in-between the above mentioned waypoints. As such the riverbanks have been cemented and gabion baskets implemented both upstream and downstream of these bridges. As a result, the narrowing of the river channel coupled with the reduced infiltration ability of the river water has had a significant impact on increasing the flow rate.
- Waypoints WC23 to WC22 (Water Quality) - There have been numerous reports of instances where the Methven Road pump station has had some sort of failure resulting in raw untreated sewage being discharged directly into the Palmiet River.

- Waypoints WC22 to WC20 (Rubbish Dumping) - There has been excessive amounts of garden refuse being thrown over the fence directly on the river's riparian zone, particularly at waypoint WC21. The dead vegetation smothers the natural vegetation and attracts pests to the area.

3.4.6 Unit 6 – Palmiet Nature Reserve to University Road Bridge

The part of the Palmiet River, analysed as per Unit 6, extends from around the Frank Ferrer Hall down to the University of Kwa-Zulu Natal, Westville Campus. Boulder hopping and wading through the river was necessary in order to reach all waypoints, selected for this section, as the majority of the riparian zone has become overgrown with alien vegetation. In addition, caution was necessary as a Black Mamba had made its home in the area upstream of the University Road Bridge.

A large area of the land observed in Unit 6 forms part of the PNR boundary. The committee of the PNR have tried to preserve the natural area as much as possible. As a result, in comparison to the previous units, Units 1-5, Unit 6 appears to be the least affected by infrastructure implementation.

There is only one bridge constructed across the river, i.e. the University Road Bridge. In addition, the majority of the Palmiet River does not flow alongside sewer pipelines. There are houses constructed along the Palmiet River, however, when comparing the number of houses bordering the river, it is significantly less than the residential areas observed upstream.

Many residents have also not needed to implement hard infrastructure solutions to stabilise the riverbank. Reeds, small shrubs and low-lying vegetation along the riverbank have aided reducing and preventing bank erosion. However, much of this is considered alien vegetation. Alien vegetation is one of the largest problems present in Unit 6 of the Palmiet River. Table 3.14 presents average statistics of some of the infrastructure present within Unit 5.

Table 3.14: Details regarding some of the infrastructure within Unit 6.

<table>
<thead>
<tr>
<th>Area category</th>
<th>Residential area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area [km²]</td>
<td>3.7</td>
</tr>
<tr>
<td>Hardened surfaces [%]</td>
<td>47.1</td>
</tr>
<tr>
<td>Length of roads [km]</td>
<td>20.1</td>
</tr>
<tr>
<td>Length of stormwater network [km]</td>
<td>15.3</td>
</tr>
<tr>
<td>Length of sewer network [km]</td>
<td>13.6</td>
</tr>
</tbody>
</table>

3.4.6.1 Overall State of Unit 6

Table 3.15 illustrates the overall ecological condition within Unit 6.
The overall scores indicate that Unit 6 is in the best ecological condition in comparison to the upstream units observed. The ecological condition ranges between the good and fair regions. Figure 3.40 provides a summary of the individual ecological conditions which, therefore, allows common problems throughout Unit 6 to be identified.
The introduction and spread of alien vegetation is a result of individual homeowners who have brought the alien vegetation into the area and have not controlled its growth. There have been a few other factors which have significantly altered the ecological condition of Unit 6. However, Unit 6 has the lowest levels of infrastructure development when compared to the upstream units, including in its riparian zone. Therefore, the better ecological condition exhibited in Unit 6, whilst not ideal due to the alien vegetation, can be attributed to the substantially lower levels of built infrastructure along the Palmiet River.

However, moving downstream of waypoint P3, the numerous sewer lines play a role in degrading the Palmiet Rivers water quality. The water quality has been negatively affected at two areas observed in Unit 6:

- **Waypoints P1 to P0 and P3-P2 (Water Quality)** - There appears to be regular contamination of the Palmiet River in-between these waypoints due to the overflowing of the sewer networks. Raw, untreated sewage flows into the Palmiet River affecting the water quality of all areas downstream.

3.4.7 **Unit 7 – Varsity Drive Bridge to uMgeni River**

Unit 7 is primarily focused on the impacts around the Quarry Road informal settlement. There are numerous other informal settlements in the area, however, the Quarry Road informal settlement borders directly the Palmiet River, thus, impacts along this area provides a good indication, potentially a worst case scenario, for other informal settlements bordering rivers. Access to the other informal settlements was not possible due to safety issues.

The eThekwini Municipality has recognized that the residents, of some informal settlements, are not willing to move out of the area in the near future. Therefore, basic services have been provided to them such as electricity. Unfortunately, the Quarry Road informal settlement, due to its proximity to
the Palmiet River, has not been fully recognized by the eThekwini Municipality and electricity is not provided at all. As a result, there are numerous illegal electricity cables crossing the area and even along the riverbanks. This poses a serious safety risk which led to the death of a small boy after his fishing rod touched the electric wire. The residents are fully aware of the risks, however, they are powerless as they need electricity.

There have been basic sanitation facilities provided to the residents of Quarry Road. These are often inadequate and the precarious position between the residents and municipal officials has led to significant problems.

All the upstream impacts, such as flow modifications, pollutants and rubbish dumping to name a few, have had significant negative impacts along the Palmiet River encompassed by Unit 7. In terms of hard infrastructure impacts within Unit 7, the main infrastructure impacting the river are the roads which cross the Palmiet River.

3.4.7.1 Overall State of Unit 7

Table 3.16 - Representation of the overall ecological condition, in-between each waypoint, of Unit 7

<table>
<thead>
<tr>
<th>Observation Point</th>
<th>*Overall Rating [ /40]</th>
<th>*Percentage Change [%]</th>
<th>*Overall Ecological Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q8</td>
<td>15.5</td>
<td>38.75</td>
<td>Fair</td>
</tr>
<tr>
<td>Q8-Q7</td>
<td>30</td>
<td>75</td>
<td>Very Poor</td>
</tr>
<tr>
<td>Q7-Q6</td>
<td>28</td>
<td>70</td>
<td>Very Poor</td>
</tr>
<tr>
<td>Q6-Q5</td>
<td>27</td>
<td>67.5</td>
<td>Poor</td>
</tr>
<tr>
<td>Q5-Q4</td>
<td>26.5</td>
<td>66.25</td>
<td>Poor</td>
</tr>
<tr>
<td>Q4-Q2</td>
<td>18</td>
<td>45</td>
<td>Fair</td>
</tr>
<tr>
<td>Q2-Q1</td>
<td>25</td>
<td>62.5</td>
<td>Poor</td>
</tr>
<tr>
<td>Q1-Q0</td>
<td>21</td>
<td>52.5</td>
<td>Poor</td>
</tr>
</tbody>
</table>

*Inundation and Water Abstraction have been omitted from the “Overall Rating”, “Percentage Change” and in calculating the “Overall Ecological Condition” as they are not applicable in this area. The inclusion of them decreases the score, therefore, it doesn’t accurately portray the conditions of the area.

presents data relating to the overall ecological condition of the Palmiet River and riparian zone, encompassed by Unit 7. The ecological condition averages in the poor region.
There are numerous areas, within Unit 7, which require immediate interventions to be implemented. Therefore, critical areas have been defined based on visual observations and the severity of the impact. The areas which require immediate attention are:

- Waypoint Q8 to Q4 and Q2 to Q0 (Bank Erosion) - There riverbanks have been subject to increased scouring resulting in severe erosion of the riverbanks. The majority of the riverbanks are in varying degrees of failure. This is a direct result of the accumulated factors which have increased the flow rate of the Palmiet River.

- Waypoints Q8 to Q7 and Q5 to Q4 (Channel Modification) - Of particular concern is the bridges which cross the river in-between the above mentioned waypoints. The supports of these bridge structures are problem areas as they have caused waste items to accumulate, therefore, acting as an obstruction to the flow of the Palmiet River. Whilst they do aid in retaining the flow, they may also cause the back flooding of the river. In addition, the channel downstream of the Varsity Drive Bridge has been significantly widened by the increased scouring ability of the Palmiet River.

- Waypoints Q8 to Q5 (Water Quality) - The excessive rubbish dumping along the riverbanks, has had a large impact on the quality of the water. In addition, some of the sanitation services have pipes discharging onto the banks of the Palmiet River. There are also areas, in-between the above mentioned waypoints were people have defecated along the riverbanks.

- Waypoints Q8 to Q4 and Q2 to Q0 (Rubbish Dumping) - Rubbish dumping is a major problem in Unit 7. Everything from building rubble, discarded by private contractors, to solid waste items, discarded by residents from the Quarry Road informal settlement, can
be seen along the riverbanks of the Palmiet River. In addition to affecting the water quality, the rubbish has attracted pests to the area including black mambas.

The previous paragraph details individual problems which require immediate attention. Figure 3.41, illustrates the average ecological condition of the impacts within Unit 7.

![Figure 3.41 - Average Ecological Impact Scores for Unit 7](image)

Waypoint Q0 is the mouth of the Palmiet River, therefore, Unit 7 bears the brunt of all the upstream problems. Unit 7 shares no patterns in terms of impacts with the upstream areas.

Rubbish dumping is a critical problem within Unit 7, with the main contributors being the residents of the informal settlement as well as private contractors. The increased flow is also a major problem within Unit 7 significantly scouring the riverbanks, as previously explained. However, whilst there are factors within Unit 7 which affect the flow rate of the river, the major contributors to the flow rate are a culmination of the factors from the upstream areas. In addition, exotic vegetation, bank erosion, channel modification and bed modification can all be attributed to upstream impacts which have resulted in downstream impacts.

3.5 Conclusion – Palmiet catchment

The analysis of the E.coli, organic loading and turbidity results as well as the miniSASS observations indicate that the Palmiet River is not at safe standards for human and environmental health. The river walks and analysis of the infrastructure present within the catchment indicate that the poor water quality is the result of sewer blockages and the illegal discharge of wastewater from industries in the Pinetown and New Germany industrial areas. Litter was not a major problem across most of the catchment but is a significant contributor to the state of the river in the region of the Quarry Road informal settlement. The urbanisation of the catchment has led to an increase in hardened surfaces which leads to greater run-off to the river. This, along with hard infrastructure along the river channel itself has led to increased flow in the river. There is a need for further, detailed
investigation into the sources of degradation of the Palmiet Catchment and rehabilitation of the river. It is evident that the majority of interventions that have been implemented in the Palmiet Catchment have addressed the symptoms of pollution, whilst the sources remain unaddressed.
4 Pathogenic impact of the Palmiet River on the wider catchment

River basins polluted by faecal discharges from humans and animals may transport a variety of human pathogenic microorganisms (viruses, bacteria, protozoa and helminths) (Teklehaimanot et al., 2014). The human exposure risk relates both to direct contact with faecal material as well as oral transmission mediated both by drinking water, after recreational exposure and through crops that may be irrigated with polluted water (WHO, 2003).

Riverbed sediments have been reported to serve as reservoirs of pathogenic microorganisms of faecal origin (Alm et al., 2003, Luna et al., 2012, Luna et al., 2010). Sediments often undergo re-suspension due to natural events such as heavy rainfall or anthropogenic activities (Abia et al., 2017a). During these events, microorganisms may re-enter the water phase, thus increasing the microbial load of the surface water, which implies that sediment resuspension is a source of water quality deterioration (Griffith et al., 2010, Luna et al., 2012).

While the concentration of pathogens in surface water is a major health risk, the impact of sediment and the necessary sediment monitoring is still not considered in many developing countries, including South Africa (Abia et al., 2015c). Thus, the monitoring programme in place may underestimate the actual microbial load of a drinking water source and may constitute a potential human health risk, especially in the event of sediment resuspension (Donovan et al., 2008, Obasohan et al., 2010, Abia et al., 2016b). During routine monitoring, sediment analysis has often been neglected in relation to the microbiological water quality and if tested, emphasis is on the chemical contaminants (Guerra et al., 2009).

In this study, E. coli and Enterococci were monitored in surface water and sediment samples in order to provide an insight into the level of faecal contamination in the Palmiet River and indicate the potential presence of waterborne faecal pathogens at the sampling points of interest.

4.1 Experimental methods

4.1.1 Sample collection and preparation

Surface water and sediment samples were collected along the Palmiet River at the sites identified in Table 4.1. Samples were collected bi-monthly over a period of 12 months (February 2015- February 2016).

Surface water grab samples were collected, in triplicate using 1L sterilized bottles at each site. The containers were rinsed with the water from the river prior to collection and filled to a certain point, leaving about 30 mm of headspace in order to allow mixing during laboratory analysis. Surface water samples were collected by holding the sterilized container by the handle and plunging it 0.5 m below the water surface, against the water current. In the absence of a current, one had to create a current artificially by pushing the container forward. All samples were protected from direct sunlight and transported on gel ice packs to the laboratory where they were stored at 4 °C until further analysis (APHA, 2005). Samples were analysed within 24 hours of collection.

Sediment samples were collected in accordance to Singh et al. (2010) with a sterile stainless steel scoop and placed in sterile plastic bags and transported on ice to the laboratory for further analysis. Each sample represented a composite of 10-20 sub-samples. Samples were analysed within 24 hours of collection.
One gram of each sediment sample was transferred to a test tube and suspended in 4 mL of 1× phosphate-buffered saline (PBS) to obtain a 1:5 (w/v) dilution. Each sample was vortexed for 90 s to disassociate and suspend bacteria from the sediment. Aliquots of the resulting supernatant for each sample were handled aseptically for further analysis based on site specific 10-fold dilutions (Singh et al., 2010).

Table 4.1 - Sampling point description, location, and potential pollution influences

<table>
<thead>
<tr>
<th>Site ID</th>
<th>Site location (coordinates)</th>
<th>Site description</th>
<th>Potential pollution source(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methven Road (SP4 in previous study)</td>
<td>-29°49'7.2228&quot; S 30°54'36.8964&quot; E</td>
<td>Upstream Palmiet River, surrounded by suburbs</td>
<td>Methven pump station</td>
</tr>
<tr>
<td>Upstream Quarry Road Informal Settlement (QRI) (SP1 in previous study)</td>
<td>-29°48'16.4304&quot; S 30°57'57.1968&quot; E</td>
<td>Where Palmiet River begins to flow through informal settlement</td>
<td>Anthropogenic activities (from informal settlement)</td>
</tr>
<tr>
<td>Downstream Quarry Road Informal Settlement (QRI) (no equivalent in previous study, SPa)</td>
<td>-29°48'16.218&quot; S 30°58'0.0552&quot; E</td>
<td>Downstream of the informal settlement</td>
<td>Anthropogenic activities (from informal settlement)</td>
</tr>
<tr>
<td>Before Palmiet River joins uMgeni River (no equivalent in previous study, SPb)</td>
<td>-29°48'11.3508&quot; S 30°58'38.316&quot; E</td>
<td>Downstream, right before the Palmiet River joins the uMgeni River</td>
<td>Pollution from the Quarry Road Informal Settlement</td>
</tr>
</tbody>
</table>

4.1.2 Physicochemical characteristics of surface water

Physicochemical characteristics of surface water at the Isipingo and Palmiet Rivers were determined in-situ. Temperature (°C), electrical conductivity (µS·cm⁻¹), total dissolved solids (TDS; g/L), dissolved oxygen (DO; mg/L) of the river water was measured by YSI model 556 MPS equipped with multi-parameter sensor 5563 MPS (Yellow Springs, Ohio, USA). This was deployed at each sampling site in parallel with the collection of water and sediment samples.

4.1.3 Enumeration of bacterial indicators

The presence and absence test as well as enumeration of total coliforms, fecal coliforms, _E. coli_, and _Enterococci_ were achieved using the IDEXX Colilert 18 and Enterolert test method for enterococci (according to manufacturer’s instructions). The Colilert-18 reagent (IDEXX Laboratories) was added to samples decimal diluted with distilled water (final volume 100 mL) and mixed well to dissolve. The dilution is site specific and sediment samples are diluted further than the water samples. The mixture was poured into a Quanti-tray/2000 (IDEXX Laboratories, Westbrook, USA), sealed and incubated at 37°C for 18 hours. The Colilert-18 method simultaneously detects total coliforms by counting the number of yellow coloured wells. This is achieved when coliform bacteria metabolize the nutrient-indicator, giving a yellow coloration through the action of the enzyme β-galactosidase on ortho-nitrophenyl- β-D-galactopyranoside (ONPG). When _E. coli_ metabolizes a second nutrient-indicator through β-glucuronidase on 4- methylumbelliferyl-β-D-glucuronide (MUG) yellow coloured wells fluoresce at 365 nm which enables the detection of _E. coli_. The MPN was then calculated using the MPN chart provided by IDEXX (IDEXX Laboratories, Westbrook, USA). The Enterolert was prepared as described above and incubated at 44.5°C for 24 hours. Positive _Enterococci_ were determined by counting the yellow coloured wells that were fluorescent at 365 nm, and read against the MPN chart.
4.2 Statistical data analysis

All microbiological data were log-transformed to fit a normal distribution. All surface water and sediment samples were statistically analysed using Microsoft Excel and GraphPad prism. Log transformation and graphs were conducted on Microsoft Excel and GraphPad prism. ANOVA, Pearson correlation analysis, and unpaired t-tests were performed using GraphPad prism software with significance set at (α) 0.05.

4.3 Organisms in surface water and sediment

Table 4.2 shows the mean physicochemical parameters at sampling points along the Palmiet River. Table 4.3 shows the mean indicator organisms in surface water and in sediment samples.

**Table 4.2 - Physicochemical parameters**

<table>
<thead>
<tr>
<th>Physicochemical parameter</th>
<th>Mean ± standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td>22.6 ± 5.2</td>
</tr>
<tr>
<td>Electrical conductivity (µS/cm)</td>
<td>367 ± 32.5</td>
</tr>
<tr>
<td>Total dissolved solids (g/L)</td>
<td>0.24 ± 0.02</td>
</tr>
<tr>
<td>Dissolved oxygen (mg/L)</td>
<td>6.11 ± 1.6</td>
</tr>
<tr>
<td>pH</td>
<td>7.4 ± 0.1</td>
</tr>
</tbody>
</table>

**Table 4.3 - Mean indicator organisms in surface water versus sediment along the Palmiet River, N.B. QRI = Quarry Road Informal Settlement**

<table>
<thead>
<tr>
<th>Sampling site</th>
<th>E. coli (mean log10 MPN/100 mL ± SD)</th>
<th>Enterococci (mean log10 MPN/100 mL ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface water</td>
<td>Sediments</td>
</tr>
<tr>
<td>Methven (SP4)</td>
<td>3.4 ± 0.9</td>
<td>4.6 ± 1.2</td>
</tr>
<tr>
<td>Upstream of QRI (SP1)</td>
<td>4.3 ± 0.8</td>
<td>4.7 ± 1.1</td>
</tr>
<tr>
<td>Downstream of QRI (SPa)</td>
<td>4.7 ± 0.6</td>
<td>5.9 ± 0.9</td>
</tr>
<tr>
<td>Before Palmiet joins uMngeni River (SPb)</td>
<td>3.7 ± 0.7</td>
<td>5.4 ± 1.0</td>
</tr>
</tbody>
</table>

In surface water samples, *E. coli* mean concentration ranged between 3.4 log10 MPN/100 mL (Methven) and 4.7 log10 MPN/100 mL (Downstream QRI). The *Enterococci* range was 2.8 log10 MPN/100 mL (Methven) and 4.6 log10 MPN/100 mL (Downstream QRI). For sediment samples, for *E. coli* mean concentration ranged between 4.6 log10 MPN/100g (Methven) and 5.9 log10 MPN/100 g (Downstream QRI). The *Enterococci* range was between 3.5 log10 MPN/100 g (Methven) and 5.2 log10 MPN/100 g (Downstream QRI).

Overall, Methven sampling site was the least contaminated, both for *E. coli* and *Enterococci* in surface water and sediment samples, whereas Downstream QRI was consistently the most polluted with high indicator concentrations in both surface water and sediment samples (Table 3.6). Higher concentrations (±1 log10 MPN/100 g greater) of *E. coli* and *Enterococci* were found in sediment samples compared to surface water samples.

4.4 Discussion

As expected, and as previously shown (Ishii et al., 2007, Whitman and Nevers, 2003, Abia et al., 2016a), *E. coli* and *Enterococci* were highest in sediment samples. In this study, *E. coli* and *Enterococci* concentrations were routinely ±1 Log greater in sediments samples when compared to surface water samples at all sampling points. Similar relationships were also shown by Alm et al.,
(2003), Ishii et al., (2007), Sithebe et al., (2016), Ekwanzala et al., (2017), Whitman and Nevers, (2003), in comparable studies. Different types and size ranges of sediments will impact the microbial abundance, where finer sediment particles were found to have a positive correlation to higher microorganism populations (Kunkel et al., 2013, Howell et al., 1996, Gao et al., 2011, Abia et al., 2015a). Particle associated microorganisms may also survive longer in sediments as compared to surface water, partly due to protection from UV rays and from predators (Kunkel et al., 2013, Liang et al., 2013).

The Methven sampling point (continuously showed lower concentrations of the indicator organisms due to the cleaner nature of this part of the catchment. The neighbourhood where this point is located is involved in a “River Watch” initiative which is conducted by a stakeholder group from Westville North led by Lee D’Eathe. Community members monitor undesirable activities and pollution and report it to the municipality. The community members gather occasionally to clean up the river around the Westville North area. The other three sampling points are surrounded by the Quarry Road informal settlements (QRI) which is a major pollution source, especially downstream as pollution sources in the informal settlements contribute to the state of the river downstream but not those upstream. The people from the informal settlements use the river to dispose of household waste, faecal material and domestic greywater. Sadly, the residents who are situated far from the community ablution blocks sometimes opt to use this river water for domestic purposes and children play in and along this part of the river. This poses a major health risk to the community of the Quarry Road informal settlements.

The presence of high numbers of indicator organisms in sediments from the Palmiet River indicates that the river receives high loads of faecal pollution; hence, there is a high likelihood of the presence of other pathogens posing a major health risk. As such, there is a need to further investigate the presence of pathogens in surface water and sediments as well as to use sediment traps in order to assess particle associated microorganisms and determine the impact and corresponding risks associated with faecal contamination of surface water.

Based on the findings of this study, it is recommended that sediment testing should be incorporated into the monthly surface water microbial quality monitoring programme conducted by the municipality on South African rivers.

Seasonal variations have an indirect impact on the abundance of indicator organisms in water and sediments with the wet season having a greater negative influence on the river water quality. Therefore, event monitoring programmes using auto-samplers over longer time periods during rainy seasons should be employed in order to better understand this phenomenon and the linked variability in concentrations and risks.

4.5 Quantitative Microbial Risk Assessment
The quantitative microbial risk assessment (QMRA) approach was used to carry out a health risk assessment. This tool has been used extensively in assessing the health risk associated with several scenarios, such as the health risk involved in wastewater use in agriculture (WHO, 2006) and the recreational use of surface water (Abia et al., 2016b). The four interrelated steps (Haas et al., 2014) are presented as follows:

1. Hazard identification
2. Exposure assessment
3. Dose-response assessment
4. Risk characterisation
4.5.1 Hazard identification

In this study, *E. coli* spp, *Salmonella* spp, *Campylobacter* spp and *Shigella* spp were chosen as the main hazards for the risk assessment, based on their prevalence and potential high concentrations in the surface water studied. The concentration of *E. coli* spp and *Salmonella* spp used for this risk assessment were based on results obtained in this study, while that of *Campylobacter* spp and *Shigella* spp were based on concentrations reported in Diergaardt et al., (2004), and Wose, King and Mbewe, (2010). Several studies have demonstrated the relationship between pathogen contamination of surface water and adverse health outcomes for exposed populations (Doreen et al., 2015; Coffey et al., 2007; Oliver et al., 2016; Jacob et al., 2015; Yilia et al., 2009; Abbott et al., 2011 Abia et al., 2016b). Irrigation of crops (especially vegetables) with faecally contaminated surface water has been shown to lead to higher risk of infections for farmers as well as consumers of these crops (Amoah, 2014, Qadir et al., 2010, Fuhrimann et al., 2016, Gemmell and Schmidt, 2013).

4.5.2 Exposure assessment

Exposure assessment involves the determination of the “amount or number of organisms that correspond to a single exposure (termed the dose) or the concentration of *E. coli* spp, *Salmonella* spp, *Campylobacter* spp and *Shigella* spp that will constitute a set of exposures” (Haas et al., 1999). In this study, three pathways were assessed:

- a. Accidental ingestion of surface water by exposed community members during bathing, swimming and similar activities where direct contact with water occurs. For this exposure scenario three sub-populations were considered: men, women and children.
- b. For women, additional exposure scenarios were considered; for example the use of the surface water for household applications such as laundry.
- c. Consumption of vegetables irrigated with surface water by consumers. The different exposed populations and exposure scenarios as well as the volume of water ingested by each exposed group are presented in Table 4.4.

<table>
<thead>
<tr>
<th>Group</th>
<th>Volume (mL)</th>
<th>Frequency</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men</td>
<td>27</td>
<td>7</td>
<td>Schets et al., 2011</td>
</tr>
<tr>
<td>Women</td>
<td>18</td>
<td>7</td>
<td>Schets et al., 2011</td>
</tr>
<tr>
<td>Children</td>
<td>37</td>
<td>8</td>
<td>Schets et al., 2011</td>
</tr>
<tr>
<td>Women (Laundry)</td>
<td>10</td>
<td></td>
<td>Steyn et al., 2004</td>
</tr>
</tbody>
</table>

4.5.3 Dose-response assessment

The dose-response assessment involves the determination of the relationship between the dose of the chosen pathogen ingested by the different exposed populations and the probability of infection. The beta-poisson dose-response model represented by the following equation below was chosen for this study (Haas et al., 1999):

\[ p(d) = 1 - \left( 1 + \left( \frac{d}{N_{50}} \right)^{\frac{1}{\alpha}} \right)^{-\alpha} \]

where \( p(d) \) is the risk of infection, \( d \) is the concentration of pathogen ingested in a known volume of surface water or crops, \( N_{50} \) is the median infection dose representing the number of organisms that will infect 50% of the exposed population and \( \alpha \) is the dimensionless infectivity constant.

\( N_{50} \) is calculated using the formula:
\[ N_{50} = \beta \times \left( \frac{1}{2a} - 1 \right) \]

The \( \beta \) values are presented in table 5.2 below.

The dose response parameters used for each of the pathogens considered are presented in table 5.2. These were adopted from dose response studies and have been used extensively in literature for quantifying risk of infections for these pathogens (Abia et al., 2016a, Eregno et al., 2016, Delignette-Muller et al., 2008, Gale, 2001, Schijven, 2011).

<table>
<thead>
<tr>
<th>Organism</th>
<th>( \beta )</th>
<th>A</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>E.coli</td>
<td>2473</td>
<td>0.395</td>
<td>Strachan et al., 2005</td>
</tr>
<tr>
<td>Salmonella</td>
<td>49.78</td>
<td>0.21</td>
<td>Meynell and Meynell, 1958</td>
</tr>
<tr>
<td>Campylobacter</td>
<td>0.011</td>
<td>0.024</td>
<td>Teunis et al., 2005</td>
</tr>
<tr>
<td>Shigella</td>
<td>1480</td>
<td>0.265</td>
<td>DuPont et al., 1972</td>
</tr>
</tbody>
</table>

### 4.5.4 Risk characterisation

In the risk characterization, all the outcomes of the hazard identification, exposure assessment and dose-response assessment were combined to characterize the probability of infection for exposed populations. The risk of infection \( (P1(A)) \) associated with multiple exposures was determined using the formula:

\[ P1(A) = 1 - (1 - P1(d))^n \]

where \( P1(d) \) is the risk of infection from a single exposure to a dose \( d \) of the pathogen; and \( n \) is the number of days of exposure to the single dose, \( d \) (Sakaji and Funamizu, 1998). It is evident that the river contains high microbial loads, and thus poses a human health risk to the community members that rely on it for different activities.

### 4.5.5 Quantification of invA and stx 2 gene copies in Palmiet River

The quantitative real-time polymerase chain reaction (qPCR) assays designed in this study had the detection limit of 10 genomic copies of invA gene (PCR efficiency 99.8%) and stx2 (PCR efficiency 99%) genes respectively (Figure 4.1 A & B; Figure 4.2 A & B). The limit of detection of the qPCR assays has been shown in Figure 4.1 A and Figure 4.2 A whereas formation of a single PCR product is indicated in Figure 4.1B and Figure 4.2B for inv A gene of Salmonella and stx2 gene of pathogenic E. coli respectively.
PCR efficiency: 99.8%, R²=0.995, Slope=-3.326, y-int=36.033

Figure 4.1 - Melt curve analysis of qPCR amplification product (A-B), A: standard curve, B: Melt curve of qPCR amplified product from 10-fold serially diluted genomic DNA of Salmonella Typhimurium ATCC 13076 targeting invA gene

PCR efficiency: 99%, R²=0.996, Slope=-3.346, y-int=36.546

Figure 4.2 - Melt curve analysis of qPCR amplification product (A-B), A: Amplification curve, B: Melt curve of qPCR amplified product from 10-fold serially diluted culture of E.coli ATCC 35150 targeting stx2 gene

It was found that the Salmonella invA gene was more dominant thus yielded higher concentrations than the stx2 gene in the Palmiet rivers’ surface water samples.

Table 4.6 - Quantitative analysis of Salmonella and E.coli through invA and stx2 gene based qPCR in surface water samples over a 6 month period

<table>
<thead>
<tr>
<th>Sampling site</th>
<th>Salmonella invA GC/ 100 mL</th>
<th>E.coli stx2 GC/ 100 mL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methven Road (SP4)</td>
<td>78 ± 43.4</td>
<td>36.3 ± 26.4</td>
</tr>
<tr>
<td>Upstream QRI (SP1)</td>
<td>45.1 ± 14.4</td>
<td>448 ± 18.1</td>
</tr>
<tr>
<td>Downstream QRI (SPa)</td>
<td>112 ± 70.9</td>
<td>95.5 ± 41.3</td>
</tr>
<tr>
<td>Joining uMngeni (SPb)</td>
<td>51.7 ± 12</td>
<td>30.7 ± 16.5</td>
</tr>
</tbody>
</table>
The sampling point Downstream QRI was the most contaminated with both the *Salmonella* (112 invA GC/ 100 mL) and *E. coli* (95.5 stx2 GC/ 100 mL). The lowest concentrations were observed at sampling site Upstream QRI (invA gene) and before joining uMngeni (stx2) as shown in Table 4.6. *Salmonella invA* gene was more prevalent compared to pathogenic *E. coli* stx2. invA concentrations ranged between 45.1 to 112 invA GC/ 100 mL.

4.5.6 Quantitative microbial risk assessment approach to determine risk of infection posed by *Salmonella* and pathogenic *E. coli* exhibiting invA and stx2 genes respectively as well as *Campylobacter* and *Shigella* spp.

The probability of infection expressed as a function of ingested surface water from the Palmiet River at various sampling points are shown in Figure 4.3. The invA and stx2 gene copies were used to estimate the risk of infection based on exposure values ranging from 1-100 mL at the sampling sites of interest. Sampling point identities are given in Table 4.6.

![Figure 4.3 - Probability of infection based on E.coli stx2 gene along the Palmiet River at sampling sites of interest](image)

In Figure 4.3, it is shown that the sampling point SPa (Downstream QRI) has the highest risk and SPb (just before the Palmiet River joins the uMngeni River) has the lowest. Assuming that a person would be exposed to 1 mL upon accidental ingestion (single exposure) of the polluted surface water from the Palmiet River, there would be no risk (P_{inf} = 0) at all sampling points. However, if the concentration that an individual is exposed to was 100 mL, the P_{inf} range would be 0.005 - 0.015 (SPb, SPa) upon a single exposure of the untreated surface water.

Figure 4.4 summarises the risk of infection upon accidental or intentional exposure to surface water containing *Salmonella invA* gene from the Palmiet River. The risk of infection is estimated for exposure values ranging between 1-100 mL.
For the Palmiet River, the $P_{\text{inf}}$ ranged between 0.13-0.22 (SP1, SPa). The number of gene copies of invA gene (Figure 4.4) is much higher than stx2 (Figure 4.3). This means that the risk of infection is high even with relatively low exposure volumes. For example, assuming that an individual is exposed to 1 mL of water from the Palmiet River, downstream of the QRI, the probability of infection would be $P_{\text{inf}} = 0.0046$.

Figure 4.5 illustrates the probability of infection relating to exposure of polluted untreated surface water contaminated with Campylobacter and Shigella spp. The concentrations used in this QMRA were adopted from Diergaardt et al., (2004) and Wose, Kinge and Mbewe, (2010).

The risk of infection will differ from person to person depending on the volume that they are exposed to as well as the dose-response. Therefore, the graph tells us the potential risk of infection
in relation to a volume of exposure ranging between 1-100 mL. If one person is exposed to 1mL we can deduce that the risk of infection will be 0.15 (Campylobacter) and 0.0017 (Shigella) at each exposure. Assuming that an individual is exposed to the surface water more frequently, for example, farmers using the water for crop irrigation then multiple exposure occurs, e.g. at least 3 times in a week, hence the probability of infection is increased. This means that the probability of infection of Campylobacter spp. or Shigella spp. can be obtained from Figure 4.5, if the volume of exposure (upon single exposure) and the frequency of exposure are known, in order to calculate probability of infection relating to multiple exposures.

4.5.6.1 Sub-population risk in relation to recreational and occupational activities

When the three different groups (men, women and children) were analysed according to exposure volumes based on literature (Table 4.4) and exposed through recreational activities, it was found that children were at the highest risk of being infected. Assuming that children were exposed to polluted surface water from the Palmiet River, upon a single exposure (37 mL) then the $P_{inf}$ is as high as 0.122 $P_{inf}$ invA and 0.006 $P_{inf}$ stx2 for children at the sampling point Downstream QRI as shown in Figure 4.3 and Figure 4.4. Assuming that the water would be contaminated with Campylobacter and Shigella, the risk of infection on children per one time exposure would be 0.22 $P_{inf}$ Campylobacter spp. and 0.057 $P_{inf}$ Shigella spp as shown in Figure 4.5.

The women had the lowest probability of infection upon single exposure during recreational activities but since they also use surface water for domestic/occupational purposes additional exposure is considered. An unpaired t-test was used to compare the risk of infection of women before and after the additional exposure and a significantly higher risk (p-value <0.05) resulted. Although there was additional exposure for the women, children were still at a higher risk of infection upon exposure due to recreational activities alone.

4.5.7 Stx2 and invA gene data and risk related to sampling sites

The high Salmonella and E. coli concentrations in the form of invA and stx2 genes observed at the sampling site Downstream QRI (Table 4.6) serve as a major human health risk to the community members that are exposed to surface water from the Palmiet River. This was proven by the high probability of infection values at the sampling point. Sampling points that had the lowest risk of infection based on the two pathogens tested were Upstream QRI and before joining uMngeni.

The use of the river water for domestic activities e.g. laundry, is much more common at the sampling point Downstream QRI (SPa). Numerous factors such as agriculture (Walters et al., 2011), WWTWs (Naidoo and Olaniran, 2013, Abia et al., 2015c, Teklehaiananot et al., 2014, Sibanda et al., 2015) and informal settlements (Sithebe et al., 2016, Abia et al., 2016b, Abia et al., 2017b) are known to be contributors to the poor microbial quality of surface water within aquatic environments. The high microbial concentrations observed were as a result of either one or a combination of these factors.

Informal settlements also played a role in enhancing the microbial concentrations and thus the risks in general as observed in the Palmiet River at the sampling point Downstream QRI. Considering the limited sanitation facilities, the inhabitants within this informal settlement sometimes use the river water and its banks for household and faecal waste disposal which naturally also results in unfavourable effects on the microbial quality of the river (Chidamba 2015, Abia et al. 2016a, Sithebe et al. 2016, Abia et al. 2017a).

4.5.7.1 Campylobacter spp and Shigella spp

It is important to note that current practices to determine a possible risk of infection related to the microbiological quality of water include the assessment of the volume of water ingested and the
concentration of pathogenic microorganisms in the water (Gerba et al., 1996). Probability of infection in relation to *Shigella* and *Campylobacter* were simulated using Figure 4.5, given that the volume of exposure is known. For the purpose of these simulations, volumes of 1mL and 100 mL were selected as representative of the best-case and worst-case scenarios respectively. Assuming that these volumes could be ingested accidentally or intentionally in the course of direct or indirect exposure, the daily combined risk of *Shigella spp.* (0.0017) and *Campylobacter spp.* (0.15) resulted due to ingestion of 1 mL of river water. The corresponding high-risk scenario of 100 mL ingested resulted in the corresponding figures of 0.13 (*Shigella*) and 0.24 (*Campylobacter*). The results obtained are higher than the lowest acceptable risk limit of $10^{-4}$ estimated by the World Health Organization (WHO, 2001) for recreational water.

### 4.5.7.2 Sub-population risk in relation to recreational and occupational activities

There are various factors that contribute to the outcome of the risk based on the different exposures as applied within QMRA. Amongst these are the general approach which assumes that the same volume of untreated water will be ingested by every individual using the water, thus the risk of infection is equal over a given population. Secondly a variability in sensitivity occurs when considering the exposures and factors like age, gender, immune status as well as previous disease history. On the other hand, researchers from different parts of the world have reported various average volumes that an individual can ingest during recreational activities, depending on the sex and age of the individual: 128 mL during long distance swimming (Allen et al., 1982); 170 mL amongst surfers (Stone et al., 2008); 50 mL for recreational exposure (Abia et al., 2016b). In this study the volumes of women (18 mL), men (27 mL) and children (37 mL) were used based on Schets et al., (2011).

When sub-population risks were determined along the Palmiet River, the highest risk due to recreational activities was observed at the sampling point Downstream QRI for men, women and children, with children having the highest risk. Risk exposure in relation to *Campylobacter* and *Shigella* also showed a relatively high risk for children. The results obtained were above the WHO recreational guidelines ($10^{-4}$) (WHO, 2001) for all pathogens. Thus, the Palmiet River is not a safe places for children to partake in recreational activities.

Additional exposure was accounted for in the women sub-population. This is because it was observed in this study that women within the informal settlements use the river water for laundry. There was significantly higher differences in the risk of women prior to the additional exposure and after the additional exposure (p-value <0.05). Although the women’s risk increased, the risk amongst children was continuously the highest at all the sampling points of interest. This is because more water is ingested by children compared to adults during recreational activities (Wade et al., 2008).

The higher sensitivity of children is also an additional factor that puts the children at a higher risk during an event of consuming untreated river water (Abia et al., 2016b). In many parts of the world fetching water from the river for household purposes is a chore set aside for children; this was observed to be the case for the Palmiet River. Ultimately this poses a relatively high risk of infection for children (Abia et al., 2016b, Musah, 2013, WHO/UNICEF, 2009).

### 4.6 Conclusion

The pathogens detected in the Palmiet River pose a relatively high risk, which was proven by the probability of infection calculations and results in this study. The sampling point downstream of QRI on the Palmiet River is highly polluted, and thus poses the highest risk.

Amongst the women, men and children sub-populations, children are at the highest risk of infection if they are exposed to surface water from the Palmiet River, especially at the sampling point
downstream of QRI. The surface water from the Palmiet River is above the WHO recommended target value for risk of infection.
5 Description of the Baynespruit catchment

The Baynespruit River is a tributary of the Msunduzi River, located in Pietermaritzburg, KwaZulu-Natal (Figure 5.1). The Baynespruit River originates in the residential area of Northdale and flows approximately 9 km through the Willowton Industrial Area before reaching its confluence with the Msunduzi River just east of the residential community of Sobantu (Figure 5.1). The upper catchment of the Baynespruit River consists of high-density formal residential developments, the middle reaches are comprised of numerous trade effluent regulated industries and downstream are high-density formal and informal residential areas.

Figure 5.1 - Location of the Baynespruit River and the Sobantu community in KwaZulu-Natal, South Africa
The Baynespruit Catchment is located within the Msunduzi municipal boundary and thus, its characteristics can be associated with this municipal area (Figure 5.1). Table 5.1 summarizes a variety of factors which characterise the Msunduzi municipal area i.e. climatology, geology, topography, soils, hydrology, biodiversity, sanitation and solid waste, storm water and the socio-economic environment. It is evident from Table 5.1 that the relationship between the slope and geology in the municipal area is complex, which may result in erosion and the transportation of sediments and soil into water bodies. In addition, the municipal area has great potential for agriculture due to the topography, rainfall, geology and soils characteristics; however, much of this land is utilised for industrial and residential purposes. Table 5.1 highlights characteristics such as hydrology and biodiversity, which have been compromised as a result of anthropogenic activities in the municipal area. According to Table 5.1, solid waste and sanitation in the catchment, as well as the storm water characteristics of the municipal area, may significantly impact water quality. Finally, with regard to the socio-economic environment of the municipal area, there may be a poor standard of living and economic losses experienced, as a result of insufficient municipal capabilities and the degradation of ecosystems.

Table 5.1 - Characteristics of the Msunduzi municipal area and the catchment of the Baynespruit

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Climatology</strong></td>
<td>MAP (mm): 900 – 999 per annum</td>
</tr>
<tr>
<td></td>
<td>Average temperature (OC): 24.8</td>
</tr>
<tr>
<td><strong>Topography</strong></td>
<td>Altitude: 495 -1795 m above sea level</td>
</tr>
<tr>
<td></td>
<td>Slope: West to East</td>
</tr>
<tr>
<td><strong>Geology</strong></td>
<td>The municipal area is dominated by sedimentary rocks of the Ecca Group</td>
</tr>
<tr>
<td></td>
<td>and Dwyka Formation. These sediments are intruded by Jurassic post-Karoo</td>
</tr>
<tr>
<td></td>
<td>dolerite sheets, dykes and sills that outcrop across the municipal area.</td>
</tr>
<tr>
<td></td>
<td>Thus, the relationship between the slope and geology in the municipal area is regarded as complex.</td>
</tr>
<tr>
<td><strong>Soils and Vegetative Cover</strong></td>
<td>According to Ramburran (2014), the soils within the municipal area vary</td>
</tr>
<tr>
<td></td>
<td>significantly.</td>
</tr>
<tr>
<td></td>
<td>Northdale: The vegetative cover comprises of Moist Coast Hinterland</td>
</tr>
<tr>
<td></td>
<td>Ngongoni Veld, with soils, which are acidic and leached.</td>
</tr>
<tr>
<td></td>
<td>Willowton: The vegetative cover comprises of Dry Coast Hinterland</td>
</tr>
<tr>
<td></td>
<td>Ngongoni Veld.</td>
</tr>
<tr>
<td></td>
<td>Sobantu: The vegetative cover comprises of Coast Hinterland Thornveld.</td>
</tr>
<tr>
<td><strong>Hydrology</strong></td>
<td>Runoff (mm): 150 – 199 mm per annum</td>
</tr>
<tr>
<td></td>
<td>Rivers in the municipal area form part of the riparian corridors that may be vulnerable to flooding (Ramburran, 2014).</td>
</tr>
<tr>
<td></td>
<td>Wetlands have been transformed and are currently degraded as a result of inappropriate land use and inadequate catchment management (Ramburran, 2014).</td>
</tr>
<tr>
<td><strong>Biodiversity</strong></td>
<td>There are diverse habitats and species richness within the municipal area, for example, 56 animal species, 20 plant species and 8 vegetation types.</td>
</tr>
<tr>
<td></td>
<td>However, due to anthropogenic transformations, there is a major loss of biodiversity, especially in the Baynespruit River (Ramburran, 2014).</td>
</tr>
<tr>
<td><strong>Solid Waste and Sanitation</strong></td>
<td>Solid waste is disposed of at the New England Road landfill. However, this site may soon reach its carrying capacity. Illegal dumping poses a threat to storm water and sewer reticulation in addition to the water quality of water sources such as the Baynespruit River. The sanitation network requires</td>
</tr>
</tbody>
</table>
replacement and upgrading of infrastructure along the middle reaches of the Baynespruit River.

| Storm Water | The expansion of high-density settlements has given rise to hardened surfaces that increase storm water runoff. Thus, the risk of downstream (i.e. the Sobantu community) flooding and transportation of numerous constituents has increased over time. |
| Social Environment | Rapid population growth has resulted in the inappropriate development and land degradation. Furthermore, the municipality has insufficient resources and capacity to provide the required services to these expanding high-density settlements, which results in a poor standard of living in the area. |
| Economic Environment | The ecosystems goods and services within the municipal area generate economic benefits. For example, untransformed regions of the municipal area comprise of grassland plants, indigenous trees and indigenous animals that are utilised by traditional healers and medicinal plant collectors for informal trading. Thus, the loss of such species will diminish financial prospects. |

A specific site of interest within the Baynespruit Catchment is the Sobantu community (29°35'33.86"S, 30°25'12.73"E), which is located toward the lower reaches of the Baynespruit River, as depicted in Figure 5.1. The Sobantu community is described as a high-density formal and informal residential area, situated on a floodplain with high agricultural potential (Ramburran, 2014). The Baynespruit River serves as an irrigation source for subsistence and small-scale market farming sites in this area. Irrigation is carried out manually and directly onto the crops, using watering cans and/or an electric water pump. The crops that are grown in the Sobantu community usually consist of *Spinacia oleracea* (spinach), *Daucus carota* (carrot), *Brassica oleracea* (cabbage) and *Zea mays* (maize), as well as various other crops depending on the farmers’ preference. The current study considered three farming sites located on the floodplain of the river, within the Sobantu community, i.e. farming site 1, farming site 2 and farming site 3 (Figure 5.2). All three sites were maintained by farmers in the community in order to keep the field conditions for each site unchanged. The characteristics of each site have been summarized in Table 5.2. Each farming site contained different crops grown in both summer and winter; spinach was common across all farming sites in both seasons (Table 5.2). It is important to note that these three farming sites have different forms of irrigation, i.e. polluted water from the Baynespruit river, water from a nearby wetland pond and water from a communal tap. Farming site 1 has never been irrigated with water from the Baynespruit River (Table 5.2). Farming site 2 was last irrigated with water from the river in 2005 but due to poor water quality, the irrigation source is currently a nearby wetland pond (Table 5.2).
Figure 5.2 - Location of farming sites (green) in the Sobantu community, and water sampling points (red) along the Baynespruit River and wetland pond

Table 5.2 - Characteristics of the three farming sites studied

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Farming Site 1</th>
<th>Farming Site 2</th>
<th>Farming Site 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-ordinates</td>
<td>290 35°33.88′ S : 300 25′ 22.63′ E</td>
<td>290 35°37.38′ S : 300 25′ 17.99′ E</td>
<td>290 35°37.38′ S : 300 25′ 17.99′ E</td>
</tr>
<tr>
<td>Area (m²)</td>
<td>84</td>
<td>10 200</td>
<td>2700</td>
</tr>
<tr>
<td>Irrigation Source</td>
<td>Communal tap</td>
<td>Wetland pond</td>
<td>Baynespruit river</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Comments</td>
<td>Site 1 is considered the reference site since it has never been irrigated with water from the Baynespruit river Crops grown annually, last irrigated with water from the Baynespruit river in 2005 The wetland pond is not connected to the Baynespruit river Irrigation applied as the farmer sees fit</td>
<td>Crops grown annually. Last irrigated with water from the Baynespruit river in 2005 The wetland pond is not connected to the Baynespruit river Irrigation applied as the farmer sees fit</td>
<td>Crops grown annually. Irrigation applied as the farmer sees fit</td>
</tr>
</tbody>
</table>

In South Africa, the use of polluted river water for activities such as crop irrigation, washing clothes and recreation, is a common practice in many rural and urban communities. The Baynespruit River, in the province of KwaZulu-Natal, South Africa, is a typical example as it serves as a vital water...
source to the Sobantu community. There have been numerous reports of extremely poor water quality in this river and suggestions that this may pose health risks to the community.
6 The effects of water quality in the Baynespruit River on small-scale agriculture in the catchment

6.1 Water quality in the Baynespruit River

It may be assumed that a wide range of physical, chemical and microbiological constituents are present in the Baynespruit River. The Msunduzi municipality and Umgeni Water have reported that illegal effluent discharges and poor sewage disposal infrastructure significantly contribute to water quality degradation of the Baynespruit River.

Industrial effluent is a rich source of heavy metals, which may have harmful effects on the environment, as well as human health (Khan et al., 2013a). Thus, a confidential industrial effluent report, provided by Umgeni Water, was used in this study to determine which physicochemical constituents, including heavy metals, to monitor. This report contained an inventory of pollutants in the effluent from industries in the Baynespruit Catchment.

The microbial constituent considered for the water quality assessment needed to be an overall indicator of contamination, since conducting individual tests for monitoring specific bacteria and pathogens was considered beyond the scope of this study. It was therefore decided that E.coli would be a suitable indicator to measure the level of microbial contamination in the Baynespruit River because of broken sewage infrastructure.

The constituents were chosen based on their volumes in the effluent, their ability to adversely affect crops, as well as their level of health risks to humans. Ultimately, the following constituents were monitored: pH, electrical conductivity (EC), arsenic (As), cadmium (Cd), copper (Cu), lead (Pb), mercury (Hg), zinc (Zn) and E.coli, at four sampling points (Figure 5.2).

The first point was selected to represent the water quality before the point of irrigation extraction. The second point represented the water quality at the point of irrigation extraction used at farming site 3. The third point represented the water quality of lower reaches of the river. Finally, the fourth point represented the water quality of the wetland pond, which is used to irrigate farming site 2.

Water sampling was conducted weekly for the duration of one year (June 2015 – June 2016) to show variations over time, including seasonal variations. The days on which water samples were collected were random and usually occurred between 9am and 11am for safety reasons. The type and the volume of bottles used for sampling varied according to the constituent being analysed. A 500 ml plastic bottle with a sodium thiosulphate preservative was used to submit samples for E.coli analysis. A 500 ml plastic bottle with a nitric acid preservative was used for the analysis of cadmium, copper, lead and zinc. A 250 ml plastic bottle with a hydrochloric acid preservative was used for the analysis of arsenic. A 250 ml glass bottle with a hydrochloric acid preservative was used for the analysis of mercury. Thus, one sample was obtained from each point in different collection bottles. All samples were transported to the Umgeni Water laboratory immediately after sampling. The chemical and microbial analyses were conducted by Umgeni Water laboratories, whereas the pH and electrical conductivity (EC) were measured on site using a Hanna combination pH and electrical conductivity meter.

Literature has stipulated that constituents may not always be detected in overlying water and may show a greater presence in the river’s surface sediments (Tshibanda et al., 2014). Hence, a sediment analysis was carried out in order to compliment the water quality monitoring. Twenty three
elements were analysed, including routine heavy metals, in order to obtain a thorough screening of the river sediment and determine which constituents exceeded the maximum permissible limits for contaminants in freshwater sediments, according to USA Freshwater Sediment Guidelines (USEPA, 1996). Therefore, the following constituents were considered in the sediment analyses: Ag, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, total P, V, volatile solids (VS) and Zn. The sediment sampling occurred at the end of August 2015 and at the end of February 2016, in order to represent the winter and summer periods, respectively. A scoop was used to collect the surface sediments from an approximate depth of 5 cm, which was then bottled into 250 ml plastic containers. A total of eight samples were collected from point 1, 2 and 3 in the river (Figure 5.2). At point 1, one composite sample containing five sub-samples was collected. At point 2, six composite samples comprising of five sub-samples were collected to thoroughly assess the sediments at the point of irrigation extraction for farming site 3 and achieve representativeness. Finally, at point 3, one composite sample consisting of five sub-samples was collected. The sediment analysis was conducted by Umgeni Water laboratories.

Literature has highlighted the importance of considering rainfall when conducting water quality monitoring, which may be related to the constituent dilution capacity. Rainfall data was therefore obtained from the weather station at the Darvill Wastewater Treatment Works (29°36’05.21”S and 30°25’45.10” E), which is located on the outskirts of Sobantu. The rainfall record consisted of daily data for the duration of the sampling period and was made available by Umgeni Water.

The GenStat (18th ed.) statistical package was used to determine the significance of the water quality and sediment results, where applicable.

The water quality monitoring revealed that most of the physicochemical constituents, i.e. pH, EC and heavy metals, were below the permissible limits for crop irrigation, as stipulated by the South African Water Quality Guidelines (DWAF, 1996). However, the microbial constituent that was measured, i.e. E.coli, greatly exceeded the permissible limit.

It is important to note that the concentration of constituents expressed in the South African Water Quality Guidelines (DWAF, 1996) are based on average values over a crop-growing season. The current study represents infrequent high values of heavy metals rather than elevated average concentrations over a period of one year. Thus, for the purpose of this study, it was assumed that the guideline values were an absolute limit.

6.1.1 pH and electrical conductivity
The majority of pH values across all sampling points conformed to the standard range pH 6.5 – 8.4 (DWAF, 1996) (Figure 6.1). However, a number of cases below the lower pH limit occurred. The detection of acidic water quality generally occurred between September and November 2015 and August and November 2015 in the river and in the wetland pond respectively. However, there were two cases that exceeded the upper pH limit, i.e. 8.44 at point 1 (8/10/2015) and 9.47 at point 2 (8/10/2015). The pH was not influenced by rainfall as displayed in Figure 6.1. According to the box plot in Figure 6.3, there was no statistically significant difference in pH across the sampling points (n-value = 52).
The greater portion of the EC measurements at points 1 and 3, excluding a few occurrences, were below the permissible limit of 40 mS/m (DWAF, 1996) (Figure 6.2). It was observed that all EC measurements at point 2 fell below the permissible limit. In contrast, the majority of the EC measurements at point 4 were above the permissible limit (Figure 6.2). The EC generally increased from point 1 to point 3 in the river with point 4 recording the highest EC of all the sampling points. The EC was not influenced by rainfall as shown in Figure 6.2. Figure 6.3 established that the EC at point 1, 2 and 3 in the river did not differ significantly (n-value = 52). However, point 1 and 2 in the river did differ significantly from point 4 in the wetland pond (Figure 6.3).
6.1.2 Heavy metals

The heavy metal results provided by Umgeni Water included limits of detection, which were considered by the laboratory to be the maximum acceptable concentrations to report for each analysis. Thus, the limits were as follows: As <2.00 (µg/L), Cd <1.00 (µg/L), Cu <0.05 (mg/L), Hg <0.50 (µg/L), Pb <4.00 (µg/L) and Zn <0.03 (mg/L). The GenStat software does not accept data with limits and therefore was not used to analyse the heavy metal results.

The majority of the heavy metals detected in the water quality assessment were below the permissible limits for crop irrigation (DWAF, 1996), except for the cases noted below. The concentrations of As, Cd and Hg detected at all four points were less than the permissible limits, i.e. 100 µg/L, 10 µg/L and 50 µg/L, respectively (Figure 6.4 to Figure 6.6). It was found that Cu values exceeded the permissible limit, i.e. 0.2 mg/L, with values of 0.63 mg/L at point 1 (28/08/2015), 0.74 mg/L at point 2 (28/08/2015), 0.36 mg/L at point 4 (04/08/2015) and 0.43 mg/L at point 4 (21/08/2015) (Figure 6.7). The levels of Pb at point 4 in the wetland pond greatly exceeded the permissible limit i.e. 200 µg/L, with values such as 2,557 µg/L (04/08/2015), 1,371 µg/L (12/08/2015) and 3,599 µg/L (21/08/2015) (Figure 6.8). It was also observed that Zn was greater than the permissible limit, i.e. 1 mg/L, with concentrations of 1.03 mg/L at point 3 (04/09/2015) and 1.90 mg/L at point 4 (21/08/2015) (Figure 6.9). It can be seen in Figure 6.4 to Figure 6.9 that the concentrations of heavy metals detected were not influenced by rainfall, based on the weekly sampling routine over a period of one year. A summary of the number of heavy metals detected at each point that exceeded the limits of detection provided by Umgeni Water has been compiled (Table 6.1). It can be seen that when comparing sampling points in the river, point 3 incurred the greatest number of heavy metal detections. Overall, the wetland pond had the highest number of heavy metal detections when compared across all sampling points. The frequency of heavy metal detections and the sporadic detections that exceeded the MPL were low in the river water, which suggested that heavy metal pollution was not problematic for the purpose of crop irrigation.
Figure 6.4 - Comparison of As across sampling points (permissible limit: 100 µg/L)

Figure 6.5 - Comparison of Cd across sampling points (permissible limit: 10 µg/L)

Figure 6.6 - Comparison of Hg across sampling points (permissible limit: 50 µg/L)
Figure 6.7 - Comparison of Cu across sampling points (permissible limit: 0.2 mg/L)

Figure 6.8 - Comparison of Pb across sampling points (permissible limit: 200 µg/L)

Figure 6.9 - Comparison of Zn across sampling points (permissible limit: 1 mg/L)

Table 6.1 - Summary of heavy metal detections above permissible limits at each sampling point

<table>
<thead>
<tr>
<th>Element</th>
<th>As</th>
<th>Cd</th>
<th>Cu</th>
<th>Hg</th>
<th>Pb</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point 1</td>
<td>7</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Point 2</td>
<td>7</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Point 3</td>
<td>12</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>28</td>
</tr>
<tr>
<td>Point 4</td>
<td>14</td>
<td>4</td>
<td>7</td>
<td>4</td>
<td>27</td>
<td>15</td>
</tr>
</tbody>
</table>
6.2 Sediment analysis

The total concentration of elements in the Baynespruit river sediment samples for winter and summer are presented in Table 6.2. The sediment results provided by Umgeni Water included limits of detection, which were considered by the laboratory to be the maximum acceptable reporting concentrations for each analysis. The GenStat software does not accept data with limits and was therefore not used to analyse the sediment results.

Table 6.2 indicates that the limits of detection for Cd, Cu, Co, Hg, Zn and Ag exceeded the maximum permissible limits (MPL) for elements in freshwater sediments. However, the exact concentrations are unknown and may therefore be incomparable with the MPL. Furthermore, the summer analysis for Cu, Co and Ag could not be accredited by Umgeni Water due to analytical issues and caution should be taken when interpreting these results.
Table 6.2 - Total concentration (mg/kg) of elements from the Baynespruit river sediment samples for winter (W) and summer (S) with concentrations exceeding the respective MPL highlighted in yellow

<table>
<thead>
<tr>
<th></th>
<th>MPL</th>
<th>Point 1W</th>
<th>Point 1S</th>
<th>Point 2W</th>
<th>Point 2S</th>
<th>Point 3W</th>
<th>Point 3S</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>As</td>
<td>6</td>
<td>21.80</td>
<td>16.50</td>
<td>21.13</td>
<td>24.30</td>
<td>24.60</td>
<td>26.20</td>
<td>As exceeded the MPL at all three points with point 2 and 3 having higher concentrations in summer and point 1 having higher concentrations in winter</td>
</tr>
<tr>
<td>Cd</td>
<td>0.6</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>Cd exceeded the MPL only at point 1 in the summer</td>
</tr>
<tr>
<td>Cr</td>
<td>26</td>
<td>202</td>
<td>351</td>
<td>220.50</td>
<td>654.50</td>
<td>253</td>
<td>699</td>
<td>Cr exceeded the MPL at all three points for both seasons with summer having higher concentrations</td>
</tr>
<tr>
<td>Cu</td>
<td>16</td>
<td>9008</td>
<td>&lt;200</td>
<td>6319.50</td>
<td>&lt;200</td>
<td>5809</td>
<td>&lt;200</td>
<td>Cu greatly exceeded the MPL for winter</td>
</tr>
<tr>
<td>Hg</td>
<td>0.2</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>-</td>
<td>-</td>
<td>Hg detected in unknown concentrations of &lt;1 mg/kg at all three points in winter.</td>
</tr>
<tr>
<td>Ni</td>
<td>16</td>
<td>39.90</td>
<td>62.10</td>
<td>43.37</td>
<td>71.95</td>
<td>40.50</td>
<td>73.20</td>
<td>Ni exceeded the MPL at all three points in both seasons with summer having higher concentrations</td>
</tr>
<tr>
<td>Pb</td>
<td>31</td>
<td>51.70</td>
<td>62.90</td>
<td>48.50</td>
<td>48.75</td>
<td>46.50</td>
<td>61.20</td>
<td>Pb exceeded the MPL at all three points for both seasons with summer having higher concentrations</td>
</tr>
<tr>
<td>VS</td>
<td>-</td>
<td>5.49</td>
<td>3.37</td>
<td>6.01</td>
<td>3.61</td>
<td>5.53</td>
<td>3.51</td>
<td>VS% was low across all three points but was found to be greater in winter when comparing seasons</td>
</tr>
<tr>
<td>TP</td>
<td>600</td>
<td>1343</td>
<td>257</td>
<td>1443.83</td>
<td>336</td>
<td>1481</td>
<td>393</td>
<td>TP exceeded the MPL in winter and recorded below the MPL in summer at all three points</td>
</tr>
<tr>
<td>Zn</td>
<td>120</td>
<td>&lt;200</td>
<td>&lt;200</td>
<td>278</td>
<td>&lt;200</td>
<td>&lt;200</td>
<td>&lt;200</td>
<td>Zn exceeded the MPL only at point 2 in winter</td>
</tr>
<tr>
<td>Ba</td>
<td>-</td>
<td>205</td>
<td>175419</td>
<td>234.25</td>
<td>139538</td>
<td>&lt;200</td>
<td>126272</td>
<td>Ba was higher in summer at all three points</td>
</tr>
<tr>
<td>Ca</td>
<td>-</td>
<td>1402</td>
<td>4697</td>
<td>1531.67</td>
<td>5734.67</td>
<td>941</td>
<td>5551</td>
<td>Ca was higher in summer at all three points</td>
</tr>
<tr>
<td>Co</td>
<td>50</td>
<td>21.30</td>
<td>&lt;2</td>
<td>25.03</td>
<td>&lt;2</td>
<td>25.00</td>
<td>&lt;2</td>
<td>Co recorded below the MPL at all three points for both seasons but had a higher detection concentration in winter</td>
</tr>
<tr>
<td>Fe</td>
<td>2</td>
<td>117722</td>
<td>91487</td>
<td>108201</td>
<td>154040</td>
<td>123433</td>
<td>152706</td>
<td>Fe exceeded the MPL at all three points for both seasons with point 2 and 3 having higher concentrations in summer and point 1 having a higher concentration in winter</td>
</tr>
<tr>
<td>K</td>
<td>-</td>
<td>2988</td>
<td>2736</td>
<td>2972.33</td>
<td>2225</td>
<td>2665</td>
<td>2582</td>
<td>K was higher in winter at all three points</td>
</tr>
<tr>
<td>Mg</td>
<td>-</td>
<td>3356</td>
<td>2655</td>
<td>3511.50</td>
<td>3083.83</td>
<td>3102</td>
<td>2826</td>
<td>Mg was greater in winter at all three points</td>
</tr>
<tr>
<td>Mn</td>
<td>460</td>
<td>776</td>
<td>713</td>
<td>899.50</td>
<td>924.83</td>
<td>734</td>
<td>673</td>
<td>Mn exceeded the MPL at all three points for both seasons with point 1 and 3 having higher concentrations in winter and point 2 having a higher concentration in summer</td>
</tr>
<tr>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>--------</td>
<td>--------</td>
<td>-----</td>
<td>-----</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>Mo</td>
<td>-</td>
<td>3.40</td>
<td>2.49</td>
<td>3.72</td>
<td>3.91</td>
<td>3.20</td>
<td>4.17</td>
<td>Mo was higher at point 2 and 3 in summer but higher at point 1 in winter</td>
</tr>
<tr>
<td>Na</td>
<td>-</td>
<td>935</td>
<td>1074</td>
<td>1196</td>
<td>3560.20</td>
<td>955</td>
<td>3396</td>
<td>Na was greater in summer at all three points</td>
</tr>
<tr>
<td>Sb</td>
<td>-</td>
<td>2.95</td>
<td>2.46</td>
<td>2.12</td>
<td>2.72</td>
<td>2.19</td>
<td>2.64</td>
<td>Sb was higher at point 2 and 3 in summer but higher at point 1 in winter</td>
</tr>
<tr>
<td>Se</td>
<td>-</td>
<td>4.16</td>
<td>5.15</td>
<td>4.41</td>
<td>4.82</td>
<td>4.29</td>
<td>5.67</td>
<td>Se was higher in summer at all three points</td>
</tr>
<tr>
<td>V</td>
<td>-</td>
<td>163</td>
<td>143</td>
<td>188.50</td>
<td>213.67</td>
<td>221</td>
<td>254</td>
<td>V is greater at point 2 and 3 in summer and greater at point 1 in winter</td>
</tr>
<tr>
<td>Ag</td>
<td>0.5</td>
<td>1780</td>
<td>&lt; 200</td>
<td>&lt; 200</td>
<td>2293</td>
<td>&lt; 200</td>
<td>418</td>
<td>&lt; 200</td>
</tr>
</tbody>
</table>
There are no sediment quality guidelines derived for South Africa thus the MPL were adopted from the USA Freshwater Sediment Guidelines (USEPA, 1996). It is important to note that the values represent an average of the six composite samples taken for each analysis at point 2. The analysis for Hg was not conducted for the summer sediment samples due to the failure of analytical equipment and procurement issues experienced at the Umgeni Water laboratory.

Table 6.2 reveals that As, Cr, Ni, Pb, Fe and Mn in sediments were problematic at all three points for both seasons since their concentrations exceeded the respective MPL. The Cu and Ag concentrations exceeded the MPL at all three points in winter only. The Cd and Zn concentrations were only greater than the MPL at point 1 in summer and at point 2 in winter, respectively.

The concentrations of As, Fe, Mo, Sb and V were higher at point 2 and 3 in summer but higher at point 1 in winter. It was found that the concentrations of Cr, Ni, Pb, Ba, Ca, Na and Se were greater at all three points in summer, whereas the concentrations of Cu, VS, TP, Co, K, Mg and Ag were higher at all three points in winter. It was observed that Mn was greater at point 1 and 3 in winter but greater at point 2 in summer. Overall, the concentration of analysed elements was greater at point 2 and 3 in summer, whereas point 1 had a greater concentration of analysed elements in winter (Table 6.2).

6.3 Soil analysis

The CRM (ERA 540 Heavy Metals in Soil) experimental concentrations (mg/kg) for Cr, Cu and Zn fell within the certified quality control performance acceptance limits (mg/kg), with Cd and Pb following closely to the respective lower limits (Table 6.3). The recovery (%) values were calculated based on the lower limits of the certified quality control performance acceptance limits, i.e. Recovery (%) = (Experimental Concentration/Lower Limit of Certified Value)*100 (AOAC, 1998). According to AOAC (1998), the accuracy of the methodology was confirmed by the acceptable recovery values, i.e. 80 – 123%.

Table 6.3 - Experimental concentrations of heavy metals in the CRM compared to the certified ranges and the respective recovery percentages

<table>
<thead>
<tr>
<th>Heavy Metal</th>
<th>Experimental Concentration (mg/kg)</th>
<th>Certified Quality Control Performance Acceptance Limits (mg/kg)</th>
<th>Recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd</td>
<td>97.48</td>
<td>116 - 169</td>
<td>84</td>
</tr>
<tr>
<td>Cr</td>
<td>78.28</td>
<td>69.30 - 104</td>
<td>113</td>
</tr>
<tr>
<td>Cu</td>
<td>251.23</td>
<td>219 - 317</td>
<td>115</td>
</tr>
<tr>
<td>Pb</td>
<td>64.25</td>
<td>80 - 116</td>
<td>80</td>
</tr>
<tr>
<td>Zn</td>
<td>130.10</td>
<td>106 - 155</td>
<td>123</td>
</tr>
</tbody>
</table>

The results in Figure 6.11 show the mean concentrations (mg/kg) of Cd, Cr, Cu, Pb and Zn, as well as the standard errors (SE), in the soil of the respective farming sites. A statistical analysis of heavy metal variability in soil was carried out using a general structure treatment ANOVA in GenStat (18th ed.). According to Figure 6.11, Cd (P<0.001), Cr (P=0.035), Cu (P<0.001), Pb (P<0.001) and Zn (P<0.001) differed significantly between each of the three farming sites. The highest concentrations of Cd (6.97 mg/kg), Cu (79 mg/kg), Pb (442 mg/kg) and Zn (306 mg/kg) were observed at farming site 2, while the lowest concentrations were observed at farming site 3, i.e. Cd (4.20 mg/kg), Cu (6.90 mg/kg) and Pb (1 mg/kg). The concentration of Cr differed significantly (P=0.035) with farming site 1 and 3 having the highest (44.30 mg/kg) and lowest (31.50 mg/kg) concentrations, respectively. The maximum permissible limits (MPL) for heavy
metals in soils were obtained from WRC (1997). As shown in Figure 6.11, the concentration of Cd, Cu and Zn exceeded the maximum permissible limit (MPL), i.e. 2, 6.6 and 46.5 mg/kg respectively, for heavy metals in soil at all three farming sites. The concentration of Pb exceeded the MPL, i.e. 6.6 mg/kg, at farming site 1 and 2 only. The concentration of Cr was below the MPL, i.e. 80 mg/kg, at all three farming sites.

![Graphs showing mean concentration (mg/kg) of heavy metals found in soil at three farming sites](image)

6.4 Crop analysis

The results in Table 6.4 show the mean concentrations of Cd, Cr, Cu, Pb and Zn in spinach, carrots, maize, pumpkin and cabbage. An unbalanced ANOVA design was used in GenStat (18th ed.) to determine the heavy metal variability between different crops. The statistical analysis suggested that the concentrations of Cd, Cr, Cu, Pb and Zn varied significantly (P<0.001) between the different crops. Table 6.4 illustrates the MPL of heavy metals in crops according to FAO/WHO (2001) and where concentrations have exceeded the MPL these have been highlighted in yellow.

<table>
<thead>
<tr>
<th>Cd in Crop</th>
<th>Farming Site 1</th>
<th>Farming Site 2</th>
<th>Farming Site 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPL = 0.2 mg/kg</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 6.4 - Mean concentration (mg/kg) of heavy metals in crops with concentrations exceeding MPL highlighted in yellow*
<table>
<thead>
<tr>
<th></th>
<th>Farming Site 1</th>
<th>Farming Site 2</th>
<th>Farming Site 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spinach</strong></td>
<td>0.26</td>
<td>0.31</td>
<td>0.94</td>
</tr>
<tr>
<td><strong>Carrots</strong></td>
<td>0.27</td>
<td>0.58</td>
<td>-</td>
</tr>
<tr>
<td><strong>Maize</strong></td>
<td>-</td>
<td>-</td>
<td>0.01</td>
</tr>
<tr>
<td><strong>Pumpkin</strong></td>
<td>-</td>
<td>0.04</td>
<td>-</td>
</tr>
<tr>
<td><strong>Cabbage</strong></td>
<td>-</td>
<td>-</td>
<td>0.27</td>
</tr>
<tr>
<td><strong>Cr in Crop</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MPL = 0.05 mg/kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Spinach</strong></td>
<td>0.23</td>
<td>4.42</td>
<td>7.71</td>
</tr>
<tr>
<td><strong>Carrots</strong></td>
<td>1.01</td>
<td>5.34</td>
<td>-</td>
</tr>
<tr>
<td><strong>Maize</strong></td>
<td>-</td>
<td>-</td>
<td>2.76</td>
</tr>
<tr>
<td><strong>Pumpkin</strong></td>
<td>-</td>
<td>0.46</td>
<td>-</td>
</tr>
<tr>
<td><strong>Cabbage</strong></td>
<td>-</td>
<td>-</td>
<td>6.26</td>
</tr>
<tr>
<td><strong>Cu in Crop</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MPL = 73.3 mg/kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Spinach</strong></td>
<td>12.00</td>
<td>8.38</td>
<td>9.62</td>
</tr>
<tr>
<td><strong>Carrots</strong></td>
<td>6.15</td>
<td>4.35</td>
<td>-</td>
</tr>
<tr>
<td><strong>Maize</strong></td>
<td>-</td>
<td>-</td>
<td>2.36</td>
</tr>
<tr>
<td><strong>Pumpkin</strong></td>
<td>-</td>
<td>3.47</td>
<td>-</td>
</tr>
<tr>
<td><strong>Cabbage</strong></td>
<td>-</td>
<td>-</td>
<td>5.71</td>
</tr>
<tr>
<td><strong>Pb in Crop</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MPL = 0.3 mg/kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Spinach</strong></td>
<td>1.89</td>
<td>3.45</td>
<td>0.94</td>
</tr>
<tr>
<td><strong>Carrots</strong></td>
<td>3.45</td>
<td>3.76</td>
<td>-</td>
</tr>
<tr>
<td><strong>Maize</strong></td>
<td>-</td>
<td>-</td>
<td>1.07</td>
</tr>
<tr>
<td><strong>Pumpkin</strong></td>
<td>-</td>
<td>1.54</td>
<td>-</td>
</tr>
<tr>
<td><strong>Cabbage</strong></td>
<td>-</td>
<td>-</td>
<td>0.80</td>
</tr>
<tr>
<td><strong>Zn in Crop</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MPL = 100 mg/kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Spinach</strong></td>
<td>112.22</td>
<td>210.72</td>
<td>209.46</td>
</tr>
<tr>
<td><strong>Carrots</strong></td>
<td>54.80</td>
<td>94.18</td>
<td>-</td>
</tr>
<tr>
<td><strong>Maize</strong></td>
<td>-</td>
<td>-</td>
<td>39.67</td>
</tr>
<tr>
<td><strong>Pumpkin</strong></td>
<td>-</td>
<td>33.53</td>
<td>-</td>
</tr>
<tr>
<td><strong>Cabbage</strong></td>
<td>-</td>
<td>-</td>
<td>66.35</td>
</tr>
</tbody>
</table>

Table 6.4 indicates that Cd internalization occurred in spinach, carrots and cabbage at concentrations greater than the MPL, i.e. 0.2 mg/kg, whereas the concentrations in maize and pumpkin were below the MPL. The Cr and Pb concentrations in all crops across all farming sites exceeded the MPL, i.e. 0.05 mg/kg and 0.3 mg/kg, respectively. The concentration of Cu in all crops was below the MPL, i.e. 73.3 mg/kg. The concentration of Zn in spinach across all farming sites was above the MPL, i.e. 100 mg/kg. Overall, it can be seen from Table 6.4 that spinach, carrots and cabbage were more favourable to heavy metal internalization than maize and pumpkin.

Table 6.5 - Comparison of mean concentrations (mg/kg) of heavy metals in spinach between farming sites and seasons with concentrations exceeding MPL highlighted in yellow

<table>
<thead>
<tr>
<th>Farming Site</th>
<th>Cd MPL = 0.2 mg/kg</th>
<th>Cr MPL = 0.05 mg/kg</th>
<th>Cu MPL = 73.3 mg/kg</th>
<th>Pb MPL = 0.3 mg/kg</th>
<th>Zn MPL = 100 mg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.26</td>
<td>0.23</td>
<td>12.00</td>
<td>1.89</td>
<td>112.00</td>
</tr>
</tbody>
</table>
The results in Table 6.5 compare the difference of heavy metal internalization by spinach between the farming sites, as well as between summer and winter. The standard errors of differences of means (SED) are also displayed in Table 6.5. It is important to note that spinach was used individually for this comparison since it was the only common crop grown across all three farming sites in both summer and winter. A general ANOVA design was undertaken in GenStat (18th ed.) to determine the variability of heavy metal internalization by spinach between the farming sites and the seasons.

The statistical analysis indicated that the concentrations of Cd (P<0.001), Cr (P<0.001), Cu (P<0.001), Pb (P<0.001) and Zn (P=0.055) in spinach were significantly variable across the three farming sites. The concentrations of Cd (0.942 mg/kg) and Cr (7.710 mg/kg) were the highest in spinach grown at farming site 3. The concentration of Cu (12 mg/kg) was the highest in spinach grown at farming site 1. The concentrations of Pb (3.450 mg/kg) and Zn (209 mg/kg) were the highest in spinach grown at farming site 2. It was found that spinach grown at all three farming sites contained levels of Cd, Cr, Pb and Zn that exceeded the MPL, i.e. 0.2, 0.05, 0.3 and 100 mg/kg, respectively. The concentration of Cu in spinach was below the MPL, i.e. 73.3 mg/kg, at all three farming sites.

The statistical analysis showed that the concentrations of Cd (P<0.001), Cr (P<0.001), Pb (P<0.001) and Zn (P<0.001) in spinach differed significantly between the seasons, whereas Cu concentrations (P=0.343) were not significantly different. Table 6.5 shows that the concentration of Cd, Cr and Zn in spinach was highest during the winter, while the Cu and Pb concentrations in spinach presented higher in summer. The concentrations of Cd, Cr, Pb and Zn in spinach exceeded the MPL, i.e. 0.2, 0.05, 0.3 and 100 mg/kg, in both summer and winter. It was observed that the Cu concentration in spinach was below the MPL, i.e. 73.3 mg/kg, during both seasons.

### 6.5 Discussion

The objectives of this research were to monitor the water quality of the Baynespruit River by conducting a water quality assessment and sediment analysis of problematic pollutants, as well as determining the effects of these pollutants on soil and crops that were irrigated with water from the river.

The water quality assessment suggested that the majority of the physicochemical constituents, i.e. pH, EC and heavy metals, in the river, were below the maximum permissible limits (MPL) according to the South African Water Quality Guidelines for Crop Irrigation (DWAF. 1996). There were however, sporadic occasions between August and November 2015 where acidic water quality was detected and heavy metal concentrations exceeded the MPL, which may be defined as single pollution events. The frequency of heavy metal detections and the sporadic detections that exceeded the MPL were low, which suggested that long-term heavy metal pollution in the
river water was not problematic for the purpose of crop irrigation. The water quality results of the wetland pond indicated high concentrations of EC, whereas pH conformed to the MPL. It was also observed that the wetland pond incurred more heavy metal detections and exceeded the MPL for these more often than in the river. The wetland pond is situated at the bottom of a steep slope containing illegally disposed litter. It is therefore possible that contamination may have originated from this slope through runoff. The *E. coli* greatly exceeded the MPL for crop irrigation throughout the year, at all three points in the river, while the *E. coli* recorded in the wetland pond infrequently exceeded the MPL. The *E. coli* results obtained in the current study corresponded with work conducted by Gemmell and Schmidt (2011), which concluded that the faecal coliform count frequently exceeded the MPL for crop irrigation in the Baynespruit River. It can be confirmed that reports of broken sewage infrastructure surrounding the Baynespruit River have resulted in severe microbial contamination (Ramburran, 2014).

The sediment analysis revealed that As, Cd, Cr, Cu, Ni, Pb, Zn, Fe, Mn and Ag exceeded the MPL for elements in freshwater sediments according to the USA Freshwater Sediment Guidelines (USEPA, 1996). It must be reiterated that As, Cd, Cu, Pb and Zn that were monitored in the water quality assessment frequently presented in concentrations below the detection limit or occasionally in low concentrations. According to Tshibanda *et al.* (2014), river sediments act as a reservoir for heavy metals and have the ability to accumulate higher concentrations than the surface water, which is apparent in this study. In general, during summer the concentration of elements was highest at the downstream region of the river, i.e. point 2 and 3; this may relate to water volume and high flows during the wet season, which allows for transportation of elements downstream. During winter however, the concentration of elements was higher upstream, i.e. point 1, which may relate to the decrease in water volume and low flows associated with the dry season, resulting in low transportation downstream. The water quality assessment showed that the highest number of heavy metal detections above the MPL was found at point 2 and 3, which corresponds to the high concentrations of elements found at point 2 and 3 in the river sediment. A study by Shanbehzadeh *et al.* 2014, observed that where there was an increase in heavy metals in water samples downstream, the concentration of heavy metals in the river sediment downstream increased as well, a situation which is reflected in the present study. The sediment analysis suggested that the routine heavy metals, i.e. As, Cd, Cu, Pb and Zn, as well as other elements, presented as problematic in the Baynespruit River.

The accuracy of the soil results was confirmed by the acceptable recovery values (80 – 123%) retrieved from the CRM. The soil analysis showed that Cd, Cu and Zn presented as problematic by exceeding the MPL for heavy metals in soil at all three farming sites, while Pb exceeded the MPL at farming site 1 and 2 only. The concentration of Cr remained below the MPL at all three sites but concentrations were still relatively high. In general, the order of highest to lowest concentrations of heavy metals was found at farming site 2, 1 and 3. It must be reiterated that water from the wetland pond was used for irrigation at farming site 2 and the Pb concentrations in this pond were at times well above the MPL, which can be linked to the high concentration of Pb in the soil at farming site 2. The water quality results occasionally detected concentrations of Cu and Zn at point 2 in the river, while the sediment analysis detected very high concentrations of Cd, Cu and Zn at point 2 in the river. These results therefore relate to the high concentrations of Cd, Cu and Zn in the soil at farming site 3, since irrigation for this site is extracted from point 2 in the river. The area of farming site 1 was never irrigated with water from the Baynespruit River yet this site had the second highest concentration of heavy metals in the soil when compared to
the others. This suggests that since all three farming sites are located on the primary floodplain of the river, as a result of historical flooding, which mobilized contaminants from river sediments; heavy metal accumulation has occurred in the floodplain soils over time. Ramburran (2014) highlighted that rivers, i.e. the Baynespruit River, within the Msunduzi municipal boundary are vulnerable to flooding. A study by Ciszewski and Grygar (2016) has verified the channel-to-floodplain transfer of heavy metals, whereby flooding mobilized heavy metals that were stored in river sediments and subsequently transported these onto the floodplain, which may be apparent in the current study. Sardar et al. (2013) reported that long-term irrigation with polluted water containing low concentrations of heavy metals resulted in the build-up of heavy metals in the soil, which may be plausible in the current study as contaminated irrigation is used at farming sites 2 and 3. It must be reiterated that farming site 2 was last irrigated with water from the Baynespruit River in 2005, which may have resulted in an accumulation of heavy metals in the soil.

The crop analysis indicated that heavy metal internalization occurred in a variety of crops grown across all three farming sites. It was found that elevated concentrations of Cd, Cr, Pb and Zn internalization was more favourable in spinach, carrots and cabbage than in maize and pumpkin when comparing different crops, while Cu was internalized in low concentrations by all crops. These findings correspond with literature which stipulates that spinach, carrots and cabbages are considered hyper-accumulators of heavy metals (Moreno-Jimenez et al., 2012; Abah et al., 2014; Alia et al., 2015). This is due to their broad and leafy crop structures in the case of spinach and cabbages, whereas carrots are considered edible roots which concentrate high levels of heavy metals. An individual comparison of spinach was conducted in order to compare heavy metal internalization across all three farming sites and in both seasons. This comparison showed that spinach grown at farming site 3 contained the highest concentrations of Cd and Cr, which both exceeded the respective MPL for heavy metals in crops. The spinach grown at farming site 2 contained the highest concentrations of Pb and Zn, which also exceeded the respective MPL. The concentration of Cu in spinach grown across all three farming sites was below the MPL. According to Aliyu (2014), crops grown in soils containing elevated concentrations of heavy metals enhance uptake and have high heavy metal content. This phenomenon was observed in the current study where the soil at farming site 3 contained excessive concentrations of Cd, which resulted in high concentrations in spinach. The Cr concentration in the soil at farming site 3 was substantial, i.e. 31.5 mg/kg, even though it was below the MPL, i.e. 80 mg/kg, which resulted in high uptake by spinach. A similar observation can be made at farming site 2 where the Pb and Zn concentrations were excessive in the soil, resulting in elevated uptake in spinach. The concentration of Cu in spinach grown across all three farming sites was below the MPL, even though the concentration of Cu in soil exceeded the MPL. However, as alluded to above, none of the crops grown on any of the three farming sites internalized extreme concentrations of Cu. The comparison of heavy metal internalization in spinach between summer and winter suggested that Cd, Cr and Zn had the greatest concentrations in winter. It was observed that Pb and Cu had the highest concentrations in summer. The concentrations of Cd, Cr, Pb and Zn exceeded the respective MPL in both seasons, with Cu remaining below the MPL in both seasons.

6.6 Conclusion
The water quality of the Baynespruit River presented as problematic with regards to *E. coli* contamination. There were infrequent low concentrations of heavy metals detected, i.e. As, Cu, Hg, Pb and Zn, with sporadic detections of Cu and Pb pollution events, as well as acidic water, which suggested that these did not result in long-term toxicity of surface water. The majority of
the water quality results, excluding *E. coli*, conformed to the South African Water Quality Guidelines for Crop Irrigation throughout the year. The water quality of the wetland pond was found to be a concern since heavy metals and high measurements of EC were detected more frequently than in the river. While the water quality assessment suggested that the routine heavy metals were not problematic in the river, the sediment analysis showed otherwise, presenting As, Cd, Cr, Cu, Ni, Pb, Zn, Fe, Mn and Ag in high concentrations, possibly reflecting historical events. In essence, the contaminants residing in the river sediment may contribute to water quality degradation. The soil and crop analysis showed high heavy metal internalization, not only at the farming site irrigated with water from the river but across all three farming sites on the floodplain of the river. These findings were confirmed by an experimental pot trial which also included a control site away from the farming sites showing minimal or no heavy metal contamination. This may imply that the floodplain has been compromised, due to historical flooding, which allowed the accumulation of heavy metals in soils through channel-to-floodplain transfer. Long-term irrigation with water from the river and wetland pond, which contain low concentrations of heavy metals, may have also contributed to the build-up of heavy metals in the respective farming sites. Ultimately, this study has concluded that the water quality of the Baynespruit River has been compromised by *E. coli* and heavy metals. Furthermore, this poor water quality has contributed to high concentrations of heavy metals in the soil and crops grown in the Sobantu community, all of which may have the potential to adversely affect human health.
7 Conclusions

Both the Palmiet and the Baynespruit Rivers suffer from poor water quality.

In the Palmiet River, the presence of E.coli at levels of 2 000 cfu/100 ml and above and organic loading that regularly exceeds 5 mg/l and often spikes to over 36 mg/l demonstrate that the water quality in the river is poor. Turbidity has also increased between 2013 and 2015. The sources of this water pollution include sewage from sewerage failures and blockages in the catchment which can include high levels of fats and grease from shopping centres and fast food outlets as well as high bacterial content. Additionally, illegal industrial discharge from local industry has a negative impact on the river.

miniSASS results for the Palmiet River similarly demonstrate that the water quality is poor based on the macroinvertebrates that are present. River walks confirm that there are numerous impacts on the river from urbanisation and identifies key areas where improvements are needed, including downstream of the Quarry Road Informal Settlement and downstream of the New Germany / Pinetown industrial area.

Analysis of the pathogenic content of the surface water and sediments in the Palmiet River show that pathogenic content is also highest downstream of the Quarry Road Informal Settlement. As has been shown in other literature, E.coli and Enterococci concentrations are higher in sediment samples than in surface water samples. A QMRA was carried out for the Quarry Road Informal Settlement to assess the potential health effects of exposure to the river through swimming, washing laundry and consuming vegetables irrigated from the river. Children were shown to be at highest risk of infection.

One of the lowest pathogenic contents was found at the most upstream sampling location where the “River Watch” initiative takes place. This attempt to clean up the river by reporting pollution incidents and performing occasional clean-ups appears to have a positive effect on the river and may provide some guidance for investments in catchment Ecological Infrastructure.

A similar analysis of the water quality in the Baynespruit River was carried out considering the heavy metal and bacterial content (using E.coli as an indicator organism). This focused on the water used by the Sobantu community to irrigate their crops, sediment from the same part of the river, soil from the fields and the crops themselves. Whilst there were sporadic exceedances of the maximum permissible limits of heavy metals in the water, E.coli greatly exceeded the maximum permissible limit. This may be caused by faecal contamination of the river from sewerage failure in the upstream catchment.

However, the sediment analysis revealed that several of the heavy metals exceeded the maximum permissible limits given by the USA Freshwater Sediment Guidelines (USEPA, 1996). The presence of heavy metals was also observed in soil samples. This could be due to build-up of heavy metals over many years of irrigation with polluted water or may be due to sediments left on the fields after the river floods.

The presence of heavy metals in the water and sediments of the Baynespruit River has contributed to high concentrations of heavy metals in the soil and also in the crops grown by the Sobantu community which may have a negative impact on human health in the community.
This report shows that the poor water quality of the two rivers considered in these case studies plays a central role in the catchment. The water quality is poor due to the urbanisation of the catchment with sewerage pipes in residential areas, effluent discharge from industrial areas, and the daily interactions with the water in informal settlements all having an effect on the river. However, the poor water quality also has an impact on the state of the catchment and the people who live there. The pathogenic load of the water leads to an increased risk of disease for people who use the water for crop irrigation, laundry and recreational swimming in informal settlements whilst heavy metals in the water accumulate in the soil of fields on the floodplain and in the crops grown there. These interactions with the river can all have negative effects on human health in the catchment.
References


BOTH, C. A. 2016. Type to NAIDOO, S.


Ramburran, E. 2014. 1st draft to rehabilitate the Baynespruit River for increased water supply to improve the water quality, Msunduzi Municipality, Pietermaritzburg, South Africa.


Appendix 1

The attached diagrams show maps of the units along the Palmiet River and details of each Unit as follows:

- Appendix 1-1 shows each of the units along the Palmiet River
- Appendix 1-2 shows the detailed description of Unit 1
- Appendix 1-3 shows the detailed description of Unit 2
- Appendix 1-4 shows the detailed description of Unit 3
- Appendix 1-5 shows the detailed description of Unit 4
- Appendix 1-6 shows the detailed description of Unit 5
- Appendix 1-7 shows the detailed description of Unit 6
- Appendix 1-8 shows the detailed description of Unit 7

Appendix 2

The attached diagram (Appendix 2-1) shows a summary of the impacts with colour coding according to the rating in each unit.
UNIT 7
Quarry Road Informal Settlement
Description of the Area

Legend
Unit 7 Palmiet River
Accessible
Yes
No

Unit 7 Tributaries
Accessible
Yes
No

- Unit 7 Roads
- Unit 7 Stormwater Pipes
- Unit 7 Stormwater Manholes
- Unit 7 Sewer Pipes
- Unit 7 Sewer Manholes

1 cm = 25 meters

Figure 5-23
Drawn by: Somesh Naidoo
Checked by: Somesh Naidoo
Date: 26/11/2016
UNIT 6
Palmiet Nature Reserve to University Road
Description of the Area
Cowies Hill/ Westville North Residential Area

Description of the Area

Legend

UNIT 3 Palmiet River
Accessible

Yes
No

UNIT 3 Tributaries
Accessible

Yes
No

UNIT 3 Roads

UNIT 3 Stormwater Pipes

UNIT 3 Stormwater Manholes

UNIT 3 Sewer Pumps

UNIT 3 Sewer Manholes

1 cm = 40 meters

Figure 5-19

Drawn By: Semeshan Naidoo

Checked by: Semeshan Naidoo

Date: 20/08/2016
UNIT 1
Wyebank/Kloof Residential Area
Description of the Area

Legend
- Unit 1 Palmeir River
- Unit 1 Stormwater pipes
- Unit 1 Tributaries
- Unit 1 Stormwater Manholes
- Unit 1 Roads
- Unit 1 Sewer pipes
- Unit 1 Sewer Manholes

Figure 5-17
Drawn By: Semchan Nokaco
Page 5-21
Checked by: Semchan Nokaco
Date: 09/09/2018
Please refer to individual descriptive maps of each area which details the accessible areas of each unit.