

**THE RELATIONSHIP BETWEEN THE INFRASTRUCTURE, WITHIN THE PALMIET  
CATCHMENT, AND THE CONDITION OF THE PALMIET RIVER WATER QUALITY AND  
RIPARIAN ZONE**

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EXAMINERS COPY

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## PREFACE

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## ABSTRACT

The construction and daily operation of infrastructure systems, has imposed significant negative consequences on the natural environment. The primary aim of this study was to explore the relationship between the infrastructure, within the Palmiet Catchment, and the condition of the river water quality and riparian zone. It was hypothesized that the Palmiet Catchment has been significantly impacted by the development of the surrounding land.

Visual observations of the accessible areas of the Palmiet River, and its associated tributaries, were undertaken with the following key impacts assessed: indigenous vegetation removal, exotic vegetation, channel modification, inundation, water abstraction, flow modification, bed modification, water quality and rubbish dumping. The recorded impacts were then represented onto Geographic Information Systems forming baseline maps of the current ecological condition of the Palmiet River, relative to the above-mentioned impacts.

Results indicated that the Palmiet River and its riparian zone were in various degrees of degradation. The river channel has been extensively modified by hard infrastructure, thus reducing the infiltration ability resulting in the channelling of the river water. In addition, the impervious surfaces, numerous stormwater outlets and obstructions, i.e. infrastructure supports within the river channel, has significantly modified the flow rate causing the scouring of both the riverbed and riverbank. Numerous blockages and failures in the sewer system as well as illegal activities of industries, in the Pinetown and New Germany areas, has resulted in sewage, containing trade effluent, being discharged directly into the Palmiet River, affecting the water quality. The informal settlements, located near the mouth of the Palmiet River, are another major contributor to the degradation of the Palmiet catchment. Service delivery problems and trust issues in this area has resulted in the accumulation of waste items along the riverbank.

The results obtained validate the hypothesis that urbanisation, and infrastructure development in particular, has led to the degradation of the natural environment. By understanding the extent and severity of the impacts imposed on the Palmiet Catchment,

remedial interventions can be implemented. These interventions include: retention ponds, weirs and wetlands to regulate and slow down the flow of the Palmiet River; geotextile engineering solutions as opposed to hard infrastructure solutions to stabilise collapsing riverbanks; rainwater tanks and retention areas in industries and households to reduce the amount of runoff entering the Palmiet River, the rainwater tanks can potentially also serve as a supplement to the water needs, thereby, reducing the water bills; improved service delivery and the potential hiring of members from the informal settlement to reduce and remove the accumulation of waste and promote trust between different members of the community, and wider municipal area.

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# TABLE OF CONTENTS

PREFACE .....	II
ABSTRACT.....	III
ACKNOWLEDGMENTS .....	V
Chapter 1 : INTRODUCTION .....	1-1
1.1    Background .....	1-1
1.2    Motivation.....	1-2
1.3    Research Question .....	1-3
1.4    Aims and Objectives.....	1-3
1.4.1    Aims.....	1-3
1.4.2    Objectives.....	1-4
1.5    Measurable Results and Outcomes .....	1-4
1.6    Structure of the Dissertation .....	1-5
Chapter 2 : LITERATURE REVIEW .....	2-1
2.1    Introduction .....	2-1
2.2    General Views of the Environment .....	2-1
2.3    The Built Environment .....	2-2
2.4    Current Infrastructure Development in South Africa .....	2-3
2.5    Importance of Infrastructure .....	2-4
2.6    The Relationship between Infrastructure and the Environment.....	2-4
2.7    The Natural Environment.....	2-5

2.7.1	The National Environmental Management Act (Act 107 of 1998).....	2-5
2.8	What is Sustainable Development.....	2-6
2.9	South Africa’s Natural Environment .....	2-7
2.9.1	Environmental Systems.....	2-7
2.10	Water Situation in South Africa .....	2-7
2.11	Water Sources.....	2-9
2.11.1	Surface Water .....	2-9
2.11.2	Groundwater Sources .....	2-9
2.11.3	Recycled Water .....	2-9
2.12	Water Pollution.....	2-10
2.12.1	Surface Water Pollution .....	2-11
2.12.2	Groundwater Pollution .....	2-11
2.13	Water Quality Problems in South Africa .....	2-12
2.13.1	Eutrophication.....	2-12
2.13.2	Suspended Solids.....	2-13
2.13.3	Microbiological Contamination.....	2-13
2.13.4	Salinity.....	2-13
2.13.5	Acid Mine Drainage.....	2-14
2.14	Poor Maintenance of Infrastructure in South Africa .....	2-14
2.15	Importance of Policies and Legislations in the Water Sector .....	2-15
2.15.1	The National Water Policy.....	2-15
2.15.2	The National Water Act.....	2-16

2.16	Rivers.....	2-17
2.16.1	Importance of Rivers.....	2-17
2.17	Rivers in South Africa and the uMngeni River .....	2-18
2.18	Buffer Zones .....	2-19
2.19	General Impacts on River Systems by Urbanisation and Infrastructure Development .	2-20
2.19.1	Industrial Pollution.....	2-20
2.19.2	Informal Settlements .....	2-22
2.19.3	Freshwater Pipe Bursts .....	2-22
2.19.4	Urban Runoff.....	2-23
2.19.5	Waste Disposal.....	2-25
2.19.6	Invasive Alien Plants and Animals.....	2-26
2.19.7	Land Fragmentation .....	2-27
2.20	Importance of Investing in Ecological Infrastructure.....	2-28
2.21	Wetlands .....	2-28
2.21.1	Current Status of Wetlands.....	2-29
2.21.2	Working for Wetlands .....	2-30
2.21.2.1	Legislative Framework .....	2-30
2.22	Interventions in Line with Sustainable Development.....	2-31
2.22.1	Rainwater Harvesting Systems.....	2-31
2.22.2	Pervious Pavements .....	2-32
2.22.3	Filter Drains .....	2-34
2.22.4	Gabion Baskets and Masonry Drop Works .....	2-35

2.22.5	Decentralized Wastewater Treatment Plants.....	2-36
2.23	The River Health Program in South Africa .....	2-36
2.23.1	River Health Indices and Monitoring Techniques .....	2-37
2.23.1.1	Water Quality Index .....	2-37
2.23.1.2	South African Scoring System .....	2-37
2.23.1.3	Index of Habitat Integrity .....	2-38
2.23.1.4	Riparian Zone Assessment .....	2-38
2.23.1.5	Fish Assemblage Integrity Index .....	2-39
2.23.1.6	Land Remote-Sensing Satellite Data .....	2-39
2.24	Summary .....	2-40
Chapter 3 : CASE STUDY .....		3-1
3.1	Introduction .....	3-1
3.2	Focus of this Study .....	3-1
3.3	Study Area .....	3-1
3.4	Areas of Impact along the Palmiet River.....	3-2
3.5	Rainfall in the Palmiet Catchment .....	3-5
3.6	Prior Pollution Incidents Recorded in the Palmiet River.....	3-5
3.7	River Monitoring .....	3-8
3.7.1	Unicity River Quality Indices .....	3-8
3.7.2	miniSASS Observations .....	3-9
3.8	The Palmiet Nature Reserve .....	3-10
3.8.1	Flora and Fauna.....	3-10

3.8.2	Threats to the Palmet Nature Reserve.....	3-11
3.9	Summary .....	3-11
Chapter 4 : METHODOLOGY.....		4-1
4.1	Introduction .....	4-1
4.2	Research Approaches.....	4-1
4.2.1	Theoretical Approach.....	4-1
4.2.2	Case Study Approach .....	4-1
4.3	Overall Methodological Approach .....	4-2
4.4	Defining the Scope of the Study.....	4-2
4.5	Data Collection .....	4-3
4.5.1	Data Record Sheets .....	4-4
4.6	Data Analysis .....	4-9
4.6.1	Land Cover Analysis.....	4-9
4.6.1.1	Limitations.....	4-10
4.6.2	Rainfall Data .....	4-11
4.6.3	Analysis of Microbiological and Chemical Testing .....	4-11
4.6.3.1	Limitations to the Chemical and Microbiological Results .....	4-12
4.6.4	miniSASS.....	4-12
4.6.4.1	Limitations to the miniSASS Results.....	4-12
4.6.5	River Walks.....	4-13
4.6.5.1	Limitations to the River Walks .....	4-15
4.6.6	Analysis of Observational Data .....	4-16

4.6.7	Understanding the Results.....	4-17
4.7	Summary .....	4-18
Chapter 5 : RESULTS AND DISCUSSIONS .....		5-1
5.1	Introduction .....	5-1
5.2	Land Cover Analysis.....	5-1
5.3	Analysis of the Rainfall within the Palmiet Catchment.....	5-4
5.4	Analysis of the Palmiet River Water Quality .....	5-7
5.4.1	Chemical and Microbiological Analysis .....	5-7
5.4.2	minSASS Analysis.....	5-13
5.4.3	Overview of the Chemical, Microbiological and miniSASS Sampling.....	5-19
5.5	Areas of the Palmiet River Observed .....	5-19
5.6	Impact of Infrastructure within the Palmiet Catchment.....	5-28
5.7	Unit 1 – Wyebank and Kloof Residential Area .....	5-31
5.7.1	Overall State of Unit 1.....	5-31
5.8	Unit 2 – Industrial Area .....	5-33
5.8.1	Overall State of Unit 2.....	5-34
5.9	Unit 3 – Cowies Hill/ Westville North Residential Area .....	5-37
5.9.1	Overall State of Unit 3.....	5-37
5.10	Unit 5 – Methven Road Pump Station to PNR .....	5-39
5.7.1	Overall State of Unit 5.....	5-40
5.11	Unit 6 – Palmiet Nature Reserve to University Road Bridge.....	5-42
5.11.1	Overall State of Unit 6.....	5-43

5.12	Unit 7 – Varsity Drive Bridge to uMngeni River .....	5-44
5.9.1	Overall State of Unit 7 .....	5-45
5.13	Unit 4 - The Kingfisher Catchment .....	5-47
5.13.1	Overall State of Unit 4 .....	5-49
5.14	Infrastructure at the Source.....	5-50
5.14.1	Flow Modification .....	5-51
5.14.2	Water Quality.....	5-53
5.14.3	Alien Vegetation.....	5-57
5.14.4	Service Delivery and Human Ignorance .....	5-57
5.14.5	Enforcement of Laws and Regulations.....	5-58
5.15	Potential Remedial Interventions .....	5-58
5.15.1	Short-Term Interventions – Municipal Driven Projects .....	5-58
5.15.1.1	Gabion Baskets and Masonry Drop Works .....	5-58
5.15.1.2	Gabion Baskets, Geo-textile Bags, Vetiver Grass .....	5-59
5.15.1.3	Alien Vegetation Removal.....	5-60
5.15.1.4	Education .....	5-61
5.15.2	Short-Term Interventions – Individual/Community Driven Projects .....	5-61
5.15.2.1	Palmiet River Watch.....	5-61
5.15.3	Short-Term Interventions – Co-operation between the Municipality and Individuals/Community.....	5-62
5.15.3.1	Promotion of Recycling .....	5-62
5.15.3.2	Solid Waste Clean-up .....	5-62

5.15.4	Long-Term Interventions – Municipal Driven Projects .....	5-63
5.15.4.1	Detention Pond .....	5-63
5.15.4.2	Pervious Pavement .....	5-64
5.15.4.3	Stormwater Drains .....	5-65
5.15.4.4	Sewer Network Monitoring Systems .....	5-65
5.15.4.5	Decentralized Wastewater Treatment Plants.....	5-66
5.15.4.6	Wetland.....	5-66
5.15.5	Long-Term Interventions – Co-operation between the Municipality and Individuals/Community.....	5-68
5.15.5.1	Pervious Pavements .....	5-68
5.15.5.2	Gravity Fed Rainwater Harvesting System.....	5-69
5.15.5.3	Decentralized Wastewater Treatment Plants.....	5-69
5.15.5.4	Buffer Zones .....	5-70
5.15.5.5	Employment .....	5-70
Chapter 6 : CONCLUSIONS AND RECOMMENDATIONS .....		6-1
6.1	Introduction .....	6-1
6.2	Summary of Results .....	6-1
6.3	Improvements.....	6-3
REFERENCES .....		A
APPENDIX A.....		A-1
APPENDIX B.....		B-1
APPENDIX C.....		C-1

APPENDIX D.....	D-1
APPENDIX E.....	E-1
APPENDIX F.....	F-1
APPENDIX G.....	G-1

## TABLE OF FIGURES

Figure 2-1: The average rainfall across South Africa (Source: Water Wise, 2015). .....	2-8
Figure 2-2: Typical pre-development and post-development runoff scenarios (Source: Armitage et al., 2013).....	2-23
Figure 2-3: Typical pre-development and post-development hydrographs (Source: Armitage et al., 2013). .....	2-23
Figure 2-4: Gravity fed rainwater harvesting system (Source: CIRIA, 2015c). .....	2-32
Figure 2-5: Pervious pavement allowing for stormwater to infiltrate into the underlying soil layers only (Source: CIRIA, 2015b).....	2-33
Figure 2-6: Pervious pavement allowing for stormwater to infiltrate into the underlying soil layers or be re-used for non-potable applications (Source: CIRIA, 2015b). .....	2-33
Figure 2-7: Pervious pavement that allows stormwater to be collected and re-used (Source: CIRIA, 2015b). .....	2-34
Figure 2-8: Example of a filter drain implemented along a road (Source: CIRIA, 2015a). .....	2-34
Figure 2-9: Layout of a typical filter drain (Source: CIRIA, 2015a). .....	2-34
Figure 2-10: An example of a masonry drop implemented along the Akechi River in Japan (Source: Sasaki, 2016). .....	2-35
Figure 2-11: Schematic of the Clarus Fusion WWTP (Source: MaskamAfrica, 2016). .....	2-36
Figure 3-1: Tributaries of the Palmiet River.....	3-2
Figure 3-2: Palmiet River course from its source to the Westville North residential area. ....	3-3
Figure 3-3: Palmiet River course from the Westville North residential area to its source at uMngeni River. ....	3-4
Figure 3-4: Location of the Dunkeld Road and Kennedy Road rainfall stations in relation to the Palmiet River (Source: Google Earth, 2016).....	3-5
Figure 3-5: Previous pollution incidents in the Palmiet River.....	3-7
Figure 3-6: Location of the sampling points undertaken by the EWS, Pollution and Environment branch. ....	3-8

Figure 3-7: Location of the existing miniSASS sampling points. .... 3-10

Figure 4-1: Sample data collection sheet. .... 4-6

Figure 5-1: 1975 estimated urban coverage. .... 5-2

Figure 5-2: 1985 estimated urban coverage. .... 5-2

Figure 5-3: 1995 estimated urban coverage. .... 5-2

Figure 5-4: 2006 estimated urban coverage. .... 5-2

Figure 5-5: 2016 estimated urban coverage. .... 5-2

Figure 5-6: Land area of the Palmiet Catchment encompassed by industrial, residential and natural areas from 1975 to 2016. .... 5-3

Figure 5-7: Dunkeld Road station rainfall data. .... 5-5

Figure 5-8: Kennedy Road station rainfall data. .... 5-5

Figure 5-9: Changes in E.coli and organic loading over the length of the Palmiet River. .... 5-9

Figure 5-10: Mean turbidity results at the 5 sampling points along the Palmiet River. .... 5-12

Figure 5-11: 2013 miniSASS observation results. .... 5-15

Figure 5-12: 2014 miniSASS observation results. .... 5-16

Figure 5-13: 2015 miniSASS observation results. .... 5-17

Figure 5-14: 2016 miniSASS observation results. .... 5-18

Figure 5-15: Units of the Palmiet River observed. .... 5-20

Figure 5-16: Description of Unit 1. .... 5-21

Figure 5-17: Description of Unit 2. .... 5-22

Figure 5-18: Description of Unit 3. .... 5-23

Figure 5-19: Description of Unit 4. .... 5-24

Figure 5-20: Description of Unit 5. .... 5-25

Figure 5-21: Description of Unit 6. .... 5-26

Figure 5-22: Description of Unit 7. .... 5-27

Figure 5-23: Ecological condition along the length of the Palmiet River. .... 5-30

Figure 5-24: Average Ecological Impact Scores for Unit 1. .... 5-32

Figure 5-25: Average Ecological Impact Scores for Unit 2. .... 5-35

Figure 5-26: Average Ecological Impact Scores for Unit 3. .... 5-39

Figure 5-27: Average Ecological Impact Scores for Unit 5. .... 5-41

Figure 5-28: Average Ecological Impact Scores for Unit 6. .... 5-44

Figure 5-29: Average Ecological Impact Scores for Unit 7. .... 5-46

Figure 5-30: Ecological condition along the Kingfisher Stream. .... 5-48

Figure 5-31: Average Ecological Impact Scores for Unit 4. .... 5-50

Figure 5-32: Impacts that have resulted due to flow modification. .... 5-51

Figure 5-33: Relationship between the impacts with focus on water quality. .... 5-54

## INDEX OF TABLES

Table 2-1: Impact of varied buffer widths on pollutant removal and habitat value (Source: Desbonnet and Pogue, 1994). .....	2-19
Table 2-2: Recommended buffer widths based on the surrounding land usage (Source: Macfarlane et al., 2009). .....	2-20
Table 3-1: Pollution incidents recorded by members of the PRW during the year 2016 (Source: D'Eathe, 2016). .....	3-6
Table 3-2: miniSASS score limits for rocky rivers (Source: miniSASS, 2016). .....	3-9
Table 4-1: Accuracy assessment of the land cover maps. ....	4-10
Table 4-2: EWS thresholds for E.coli and organic loading (Source: EWS, 2016). .....	4-11
Table 5-1: Percentage coverage of "Urban" and "Natural" class. ....	5-3
Table 5-2: Mean annual rainfall data for the Palmett catchment. ....	5-6
Table 5-3: Mean E.coli and organic loading results from 2007 to 2015 at the various sampling locations. ....	5-7
Table 5-4: Brief description of the land use at the various sample points along the river. ....	5-14
Table 5-5: Details regarding some of the infrastructure within Unit 1. ....	5-31
Table 5-6: Overall ecological condition at each observation point in Unit 1. ....	5-31
Table 5-7: Details regarding some of the infrastructure within Unit 2. ....	5-34
Table 5-8: Overall ecological condition at each waypoint in Unit 2. ....	5-34
Table 5-9: Details regarding some of the infrastructure within Unit 3. ....	5-37
Table 5-10: Overall ecological condition at each waypoint in Unit 3. ....	5-38
Table 5-11: Details regarding some of the infrastructure within Unit 5. ....	5-40
Table 5-12: Overall ecological condition at each waypoint in Unit 5. ....	5-40
Table 5-13: Details regarding some of the infrastructure within Unit 6. ....	5-42
Table 5-14: Overall ecological condition at each waypoint in Unit 5. ....	5-43
Table 5-15: Overall ecological condition at each waypoint in Unit 7. ....	5-45

Table 5-16: Details regarding some of the infrastructure within Unit 4..... 5-47

Table 5-17: Overall ecological condition at each waypoint in Unit 4. .... 5-49

Table 5-18: Infrastructure associated with modifying the Palmiet Rivers flow rate. .... 5-51

Table 5-19: Infrastructure associated with decreasing the water quality of the Palmiet River. ... 5-54

Table 5-20: Impact the Palmiet River water quality has on the uMngeni River..... 5-56

## LIST OF ABBREVIATIONS

CIRIA	Construction Industry Research and Information Association
CSIR	Council of Scientific and Industrial Research
CW	Constructed Wetlands
DEA	Department of Environmental Affairs, previously known as the Department of Environmental Affairs and Tourism
DSW	Durban Solid Waste
DUCT	Duzi-uMngeni Conservation Trust
DWS	Department of Water and Sanitation, previously known as the Department of Water Affairs
E.coli	Escherichia coli
EPA	Environmental Protection Agency
EPCPD	Environmental Planning and Climate Protection Department
ETM+	Enhanced Thematic Mapper Plus
EWS	eThekweni Water and Sanitation
GIS	Geographical Information Systems
IHI	Index of Habitat Integrity
INTOSAI	International Organization of Supreme Audit Institutions
Landsat	Land Remote Sensing Satellite
miniSASS	Miniature South African Scoring System
MSS	Multi-spectral Scanner
NCSU	North Carolina State University

NEMA	National Environmental Management Act
NGO	Non-Governmental Organization
NRC	National Research Council
NWA	National Water Act
NWF	National Wildlife Federation
NWP	National Water Policy
OLI	Operational Land Manager
PICC	Presidential Infrastructure Coordinating Commission
RDP	Reconstruction Development Program
RGB	Red-Green-Blue
PNR	Palmiet Nature Reserve
PRW	Palmiet River Watch
PV4	Organic Loading/Permanganate value after 4 hours
RHA	Riparian Health Audit
RHP	River Health Program
SAHRC	South African Human Rights Commissions
SANBI	South African National Biodiversity Institute
SASS	South African Scoring System
SIP	Strategic Integrated Projects
STATS SA	Statistics South Africa
SUDS	Sustainable Urban Drainage Systems
TDS	Total Dissolved Salts

TM	Thematic Mapper
UEIP	uMngeni Ecological Infrastructure Project
UKZN	University of KwaZulu-Natal
UNESCO	United Nations Educational, Scientific and Cultural Organization
USGS	United States Geological Survey
WBCSD	World Business Council for Sustainable Development
WHO	World Health Organization
WMA	Water Management Area
WRC	Water Research Commission
WWF-SA	World Wildlife Fund South Africa
YPTE	Young People's Trust for the Environment

# CHAPTER 1 : INTRODUCTION

## 1.1 Background

Water is an important component of all forms of life, 50-97 % of the mass of plants and animals is made up of water and about 70 % of the human body consists of water (Buchholz, 1998 cited in Phiri et al., 2005). Water also plays a critical role in agricultural activities, transportation and many other human activities. Even though water is a highly valued resource, it remains one of the most poorly managed resources worldwide (Fakayode, 2005).

Rivers, streams, estuaries and the oceans can all be contaminated by a variety of sources. In informal settlements, river water is used for bathing, drinking, cooking and washing. The placement of toilets along the riverbanks can result in human faeces contaminating the water (Umgeni Water, 2016). In urban areas, factories use rivers, in most cases illegally, as a means to dispose of industrial effluent and other wastes generated. If these industrial effluents are not properly treated and controlled, the ground water sources may also be contaminated (Olayinka, 2004). Household owners who live nearby or alongside rivers add to the pollution by using the rivers as a means to dispose of their rubbish and garden refuse. In the current era, the majority of urban areas have water borne sewerage systems. Failures in the pump stations and blockages in the sewer pipes result in the discharge of sewage into the surrounding environment eventually ending up in nearby water sources (D'Eathe, 2016). In addition to the degradation of the environment and the reduced water quality, there is also a risk imposed on human health.

There is a high demand for money to be invested in infrastructure in order to replace existing, degrading infrastructure and to implement new infrastructure to cater for our ever-growing population needs (INTOSAI, 2013). This infrastructure includes buildings, factories, houses, roads and water pipelines. The implementation of new infrastructure has many social and economic benefits, however, at significant cost to the environment (INTOSAI, 2013). Urban areas are characterized by their hard, impermeable surfaces, which prevents infiltration of stormwater into the soil, and increases runoff and stormwater discharge into rivers (Waters et al., 2011). Therefore, research has been conducted into Sustainable Urban Drainage Systems (SUDS) as a means of reducing the volume of water entering stormwater drains and being discharged into rivers, thereby, reducing the one of the impacts imposed on river systems.

This study will provide an inventory of the impacts, resulting from infrastructure, along the observable areas of the Palmiet River. Using imagery from satellite data, the changes in land cover over the years will be analysed. In addition, water quality data, obtained from the eThekweni Water and Sanitation (EWS) Pollution and Environment Branch, and miniSASS samplings, were used to derive a relationship between the surrounding infrastructure and the decrease in water quality and environmental degradation, within the Palmiet Catchment. The surrounding infrastructure is hypothesised to have an effect on the high flows of the Palmiet River, the water quality as well as the channel morphology. The current condition of rivers, worldwide, is due to an accumulation of the numerous negative impacts over the years. **Chapter 3** and **Appendix B** will provide more details relating to the numerous pollution incidents occurring within the Palmiet Catchment, the focus area of this study.

## 1.2 Motivation

With the ever-increasing population, the needs of the environment often come second best to the need for urbanisation (Joshi and Sukumaran, 1987). The contamination of air, water and soil arising from poor agricultural practices, industrial activities and the exploitation of the natural resources are some of the problems that require attention (Joshi and Sukumaran, 1987). The desire for urbanisation has overshadowed the importance of the environment. If there is no balance between the environment and infrastructure, there could be serious negative impacts on future life (Joshi and Sukumaran, 1987). The critical fact remains, humans need the Earth, its environment and its resources to survive, however, the Earth does not need humans to survive.

South Africa is currently facing a major water crisis (The Water Project, 2015). There are several factors, brought on by our daily consumption patterns, which compromise the water resources in South Africa and these include urbanisation, afforestation, mining, agriculture and power generation (CSIR, 2010). Climatic changes have also had a negative effect on water supplies in the region. The dam levels are significantly lower than previous years. The water level at Midmar Dam is at 45 % whilst the water level at Albert Falls Dam is at 27.58 % as of 21<sup>st</sup> July 2016 (Umraw, 2016).

Many people are unaware of the large impact urbanization has on the river water quality. Every building erected, road built and pipeline implemented in some way contributes to the pollution in our rivers. This pollution is caused both by the daily operation of the various facilities as well as during the development of the infrastructure (Rand Water, 2015).

The quality of water present in rivers and streams, is reflected by the activities of the surrounding areas and, is generally a good indication of the conditions present within the surrounding communities (Rand Water, 2015). The uMngeni River, being one of the most important rivers, is also one of the most polluted rivers in the country and studies show the presence of cholera, shigella and salmonella germs in the river (Carnie, 2013). Poor water quality, in addition to reducing its utilisation, also adds unnecessary economic strain on society by both the primary treatment costs and the secondary impacts on the economy. The more pollutants present in water sources, the higher the costs needed to treat the water. Human health can also be negatively affected by poor water quality arising from the water borne diseases mentioned above. It can thus be concluded that the major threat to a sustainable supply of water in South Africa is the contaminants polluting the water sources (CSIR, 2010).

There is increasing pressure to implement systems to reduce the negative impacts incurred on the rivers, streams and surrounding environment (Armitage et al., 2013). An example of this would be the implementation of buffer zones. Buffer zones are naturally occurring areas alongside rivers and streams, which can significantly reduce the negative impacts brought on by development, protect human health and enhance the surrounding environment (Macfarlane et al., 2014).

This sparked the author's interest in the topic, as it required an inventory to be compiled of the impacts of infrastructure along the Palmiet River. Once completed, the severity of the impacts could be assessed resulting in the investigation of further mitigation measures. The results obtained will provide a clear indication of the current ecological condition of the Palmiet River resulting in the identification of areas requiring immediate attention.

### **1.3 Research Question**

What is the relationship between the infrastructure, within the Palmiet Catchment, and the condition of the Palmiet River water quality and riparian zone?

### **1.4 Aims and Objectives**

#### **1.4.1 Aims**

- Provide an inventory of the impacts imposed on the river by the surrounding infrastructure.
- Derive a relationship between the state of the river and the surrounding infrastructure.

- Provide potential mitigation measures that can reduce/prevent the impacts of the surrounding environment.

#### **1.4.2 Objectives**

- Use Land Remote-Sensing Satellite Systems (Landsat) to explore the changes in land cover over time.
- Obtain existing chemical and microbiological water quality data, from EWS, as well as miniSASS observations to provide an indication of the water quality within the Palmiet River. In addition, key areas along the Palmiet River that are prone to continuous pollution should be explored.
- Use Geographic Information Systems Software (GIS) and visual observations in order to assess how infrastructure has affected the Palmiet River.
- Consider components like factories, pump stations, roads, sewage pipes, recreational facilities, informal settlements and dumping sites, which may be in close proximity to the Palmiet River and could potentially add to the pollution in the river.
- Draw conclusions on how the above-mentioned components affect the Palmiet River.
- Investigate whether the impacts of the surrounding infrastructure affect only the water quality or are there other factors which have also been negatively impacted i.e. high/low flows and channel morphology.

#### **1.5 Measurable Results and Outcomes**

This dissertation provides a foundation for the interaction between the built and natural environment focusing particularly on how the infrastructure, surrounding the Palmiet River, affects the river. The following outputs are envisaged:

- A detailed inventory of the impacts imposed on the Palmiet River by the surrounding infrastructure.
- A short analysis of water quality in the Palmiet River.
- A relationship between the infrastructure and the degradation of the water quality in the Palmiet River.

- An improvement analysis stating potential recommendations addressing the source problems and critical areas along the Palmiet River.
- Recommendations for further study.

## 1.6 Structure of the Dissertation

**Chapter 1** is an introductory chapter containing information relating to the why the study was undertaken as well as the aims and objectives to be met on completion of the study.

**Chapter 2** is a literature review, which summarises the literature relating to the study as well as providing clarity on various concepts and definitions.

**Chapter 3**, the Case Study Chapter, provides background information on the Palmiet River. This chapter also serves to put the study into context.

**Chapter 4**, the Methodology Chapter, describes the approach used to undertake the study as well as the sequence of events that occurred in order to complete the study.

**Chapter 5**, the Results and Discussions Chapter, contains the results obtained as well as discussion on the various results. Recommendations to reduce the source problems within the Palmiet Catchment will be explored and discussed.

**Chapter 6**, the Conclusion and Recommendations Chapter, will summarize the findings of the study and provide relevant conclusions. Recommendations for further study will also be explained.

*“Earth provides enough to satisfy every man’s needs, but not every man’s greed.” – Mahatma Gandhi*

## CHAPTER 2 : LITERATURE REVIEW

### 2.1 Introduction

This chapter develops the theoretical framework of this study and provides an understanding as to why there needs to be a balance between the natural and built environment. The importance of both the natural and built environment will be explored. The positive and negative impacts of the natural and built environment are also concepts, which will be discussed. In addition, policies and legislations around water, the uses of water as well as the current water situation in South Africa will be discussed. The impact on river systems, in South Africa, forms the basis of this study and will be discussed in detail. Monitoring techniques, the importance of investing in the restoration, rehabilitation and conservation of the ecological infrastructure will also be detailed in this chapter.

### 2.2 General Views of the Environment

The environment encompasses all living things and everything that surrounds them including all the physical, chemical and other naturally occurring processes. All biotic and abiotic factors constantly interact with each other, this includes interactions between plants, animals, water, light and the soil (Roof and Oleru, 2008).

The environment can be divided into two main categories namely the natural environment, sometimes referred to as the “green environment” and the built environment, sometimes referred to as the “brown environment” (Strydom and King, 2009). Colby (1989) proposed a definition of the “green environment” which stated that:

*“The environment is the complex of biotic, climatic, soil and other conditions which comprise the immediate habitat of an organism; the physical, chemical and biological surroundings of an organism at any time.”*

The natural environment consists of the living and non-living things which are naturally occurring on Earth and which co-exist with one another. The built environment, however, refers to everything that is man-made (Roof and Oleru, 2008). This can include buildings, cities, roads, parks and other infrastructure.

The National Environmental Management Act (NEMA), Act 107 of 1998, presents a legal definition of the environment:

*“Environment means the surroundings within which humans exist and are made up of –*

- i) the land, water and atmosphere of the earth;*
- ii) micro-organisms, plant and animal life;*
- iii) any part or combination of (i) and (ii) and the interrelationships among and between them: and*
- iv) the physical, chemical, aesthetic and cultural properties and conditions of the foregoing that influence human health and well-being.”*

### **2.3 The Built Environment**

The built environment constitutes everything that man has made or altered in some way. The existing and upcoming infrastructure plays an important role in improving the way of life for humans (JP Morgan Asset, 2009). Infrastructure are the systems, which are implemented in order to provide goods and services to inhabitants of an area (Lockrem and Lugo, 2013). The Oxford Dictionary of Economics (2009) defines infrastructure as:

*“The capital equipment used to produce publicly available services, including transport and telecommunications, and gas, electricity and water supplies. These provide the essential background for other economic activities in modern economies: the fact that they are not available or reliable is a characteristic of less developed countries (LDC’s), and handicaps their development. Infrastructure services are generally either provided or regulated by the state.”*

Infrastructure development in South Africa was limited to the coastal areas, prior to the discovery of diamonds in the Kimberley-region, in 1867, and gold on the Witwatersrand, in 1886. Following these discoveries, there was an increased rate of development focused on the interior of South Africa, which led to large investments in infrastructure (Perkins et al., 2005). The increased development in mining infrastructure and activities led to greater profits, some of which was used for the construction of rail infrastructure. In 1896, the rail network extended from Johannesburg to Durban (Perkins et al., 2005).

The 1930’s saw rail infrastructure reaching its peak. Therefore, some of the profits from the mining activities was used to improve the transport infrastructure namely the ports and roads. The national road system, in South Africa, was significantly extended and improved in the 1970’s (Feinstein,

2005). However, the majority of the infrastructure development, during the apartheid years, was focused on advancing the key objectives of the apartheid government. Therefore, South Africa is under strain to improve the existing infrastructure and municipal service delivery. The present inequalities in South Africa, brought on by the apartheid era, are widely known (Holicki and Tladinyane, 2000). During this period, the segregation of the different races occurred resulting in emphasis being placed on developing “white areas” with little/no attention paid to the other areas. Considering this, The Reconstruction and Development Programme (RDP) started an initiative, focusing, on boosting the country’s economy and meeting the basic needs of the population. This was deemed possible by focusing on infrastructure development. This, in turn, had the potential to reduce the inequalities present between people from different areas within the country and improve the overall service delivery of many South Africans (Holicki and Tladinyane, 2000).

The government viewed infrastructure development as a fixed asset or a permanent facility (Holicki and Tladinyane, 2000). Schools, roads, water pipes, sewer and stormwater infrastructure, hospitals and recreational facilities are some of the things that the South African Government encompassed as infrastructure development. The external donors to the programme, however, included the activities and processes relating to infrastructure development in their definition (Holicki and Tladinyane, 2000). These activities and processes include technical assistance, resources and skills training of the public.

Therefore, it is clear that the implementation, improvement and development of infrastructure not only has a physical and economic impact on the country, but also a positive social impact. Infrastructure is not considered as a discrete sector as it supports activities from different sectors (Holicki and Tladinyane, 2000).

## **2.4 Current Infrastructure Development in South Africa**

In 2012, the South African Government initiated a National Infrastructure Plan. The primary aim of this plan was to boost the economy, create more job opportunities and improve on basic services (PICC, 2010).

During the next 3 years from, years 2013/2014, R827 billion Rand is to be invested by the government in building new and upgrading existing infrastructure. Investment into the construction and renovation of ports, roads, railway systems, electricity plants, hospitals, sanitation systems and

dams were done in order to benefit the economy by boosting growth and improve access, by South Africans, to basic services (South African Government, 2012).

18 Strategic Integrated Projects (SIPs) were initiated by South African Government in order to increase growth and development by focusing on infrastructure across all the provinces (PICC, 2010). The SIPs comprise of 5 geographically focused SIPs, 3 energy SIPs, 3 spatial SIPs, 3 social infrastructure SIPs, 2 knowledge SIPs, 1 regional integration SIP and 1 water and sanitation SIP (PICC, 2010).

## **2.5 Importance of Infrastructure**

Infrastructure services namely communications, power and transportation as well as stormwater and sewer systems are very important activities and utilised by the occupants of every household in South Africa (Holicki and Tladinyane, 2000). These services are essential to the daily survival needs of households.

The deterioration and lack of regular maintenance on the existing infrastructure facilities can become a major constraint on economic development (Sum, 2008). South Africa's transport, water supply, wastewater transport and treatment infrastructure provides services for both industries and individuals. As a result, communities with deteriorating, inadequate infrastructure will be less likely to attract new businesses, which will lead to a stunt in that areas development (Sum, 2008). The negative effects of inadequate infrastructure are not constrained to economic development and individual growth, but extend to the environment.

The implementation and upgrading of infrastructure has incurred many challenges in South Africa. These include slow approval processes for projects, delays in the starting of projects, poor quality of projects carried out, corruption and abuse of power in the tendering process, payment to contractors is not given on time and changes in design leading to unplanned costs and delays (PICC, 2010). However, in spite of these challenges, the South African Government's endorsement of the National Development Plan (NDP) is expected to increase the level of infrastructural development (Gordhan, 2014).

## **2.6 The Relationship between Infrastructure and the Environment**

The economic growth of an area is directly dependant on the goods and services provided by the implementation of infrastructure. Infrastructure also plays a role in reducing the inequality, brought

on during the apartheid era, between different members in society. Infrastructure is also critical in creating job opportunities (United Nations Economic Commission for Africa, 2013).

Infrastructure, however, is directly dependant on the space provided by the natural environment as well as the resources it has. In order for a country to develop and grow, part of the environment needs to be sacrificed. The flora and fauna, in areas where infrastructure is implemented, will have their natural habitats altered or destroyed and rivers and streams may have their courses altered. In addition, there will be many pollutants to the air, land and water brought on during the construction and operation of infrastructure. Careful planning is required to ensure the safety and preservation of the environment. Economic growth is directly linked to urbanisation, which in turn results in the deterioration of the natural environment (CSIR, 2010).

## **2.7 The Natural Environment**

### **2.7.1 The National Environmental Management Act (Act 107 of 1998)**

Many of the people living in South Africa live in an environment, which is detrimental to their health and well-being, however, everyone has the right, according to the South African Constitution, to live in a safe and healthy environment. An unhealthy environment will result in an unhealthy population (ETU Local Government Toolkit, 2003). The core principles of the National Environmental Management Act (NEMA) include:

- To use and conserve the natural resources in a sustainable manner so that both the present and future generations can benefit from them.
- To maintain stable functioning relationships between the living and non-living components of the environment by preserving biodiversity.
- To implement sufficient environmental protection systems to safeguard the environment and continuously monitor the changes in the quality of the environment.
- To publish data relating to the well-being of the environment resulting in the increase in environmental awareness.
- To ensure that the costs of polluting the environment are borne by the polluter.

However, a large number of people feel that the needs of humans outweigh the needs of the environment. Much focus has been placed on economic growth through the implementation of infrastructure. These changes have resulted in the destruction or alteration of a significant portion of the natural environment (ETU Local Government Toolkit, 2003).

The exploitation of the natural environment has brought on a series of negative impacts, which at the time appeared to be insignificant, however, the impacts have affected the natural environment to such an extent that it can no longer be ignored. These noticeable changes have resulted in a larger majority of people becoming aware of the consequences to the environment and in order to prevent further exploitation, great emphasis has been placed on sustainable development (Caldwell, 1990).

## **2.8 What is Sustainable Development**

The World Commission on Environmental Development (Brundtland Commission), in 1987, posed the following definition on sustainable development:

*“Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”*

South Africa has signed important conventions, which aim to keep the environment safe and free from exploitation. These conventions include the Convention on Biological Diversity, the Ramsar Convention and the Cartagena Protocol on Biosafety (DEA, 2016a). Further details regarding the numerous conventions can be found on the Department of Environmental Affairs (DEA) website (DEA, 2016a).

Sustainable resource management requires the biosphere to be treated as an entity consisting of three components, namely social, economic and environmental, with no one component being sacrificed for another. For example, in the water sector, water quality was historically focused on human health standards, disregarding the wellbeing of the surrounding eco-systems. Many of the benefits, which humans have achieved from water resources, are directly dependant on healthy, functioning aquatic eco-systems (Macleod, 2016 cited in eThekweni Municipality, 2010). Hence, balanced eco-systems are critical for the sustained use of water resources. As a result, governments, worldwide including South Africa, have developed policies to protect aquatic eco-systems. Water quality managers are required to adopt integrated eco-system management systems as opposed to the previous systems based on chemical water quality management (Macleod, 2016 cited in

eThekweni Municipality, 2010). Thus, eco-system management is not limited to human health, rather it takes into account the health of the aquatic organisms. Bio-monitoring techniques, such as the South African Scoring System (SASS), have been conducted on a regular basis on numerous rivers throughout South Africa.

## **2.9 South Africa's Natural Environment**

The environment promotes biodiversity and it is this biodiversity, which is essential for the sustainability of life on Earth. South Africa, ranked as one of the top biologically diverse countries in the world, represents just 2 % (1.2 million square kilometres) of the Earth's total land surface (South African Government, 2016). However, South Africa contains almost 10 % of the world's known bird, plant and fish species. The country also has more than 6 % of the world's reptile and mammal species (Wynberg, 2002). South Africa's rich diversity supports the livelihood of many of its inhabitants and makes a significant contribution to the country's economy (Wynberg, 2002).

### **2.9.1 Environmental Systems**

Certain environmental systems and resources present in the environment may appear to be degraded through natural conditions whilst others may appear to be degraded due to human activities. According to a publication by the DEA, in 2002, these human activities result in the exploitation of the natural resources and pollutants being released into the environment. A comprehensive list of the variables and indicators which are used to indicate the state of South Africa's environmental systems can be found in the following publication by the DEA: "Environmental Indicators for National State of the Environment Reporting: South Africa".

These environmental systems need to be continuously monitored so that mitigation measures can be immediately implemented should the need arise. Environmental systems and resources include water, air, land and biodiversity. Activities, which lead to economic growth, can influence these systems in numerous ways (DEA, 2012). Currently, impacts on the water resources have come to the forefront due to the recent water shortages.

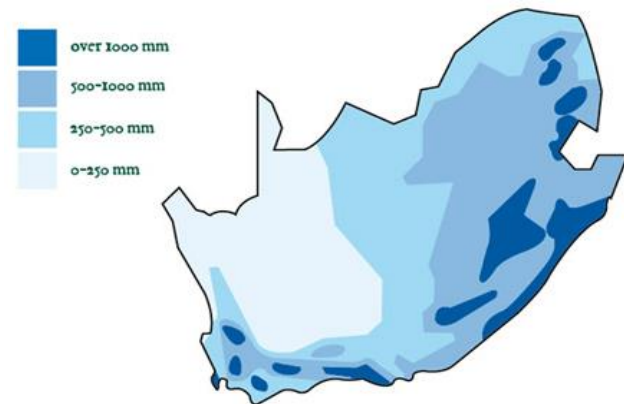
### **2.10 Water Situation in South Africa**

There are currently 51 million people living in South Africa. About 60 % of the people (31 million) live in urban areas while the remaining 40 % (20 million) live in rural settlements (STATS SA, 2010). In South Africa, 77 % of our water is obtained from surface water sources, 9 % from groundwater

sources and 14 % from recycled water (UNESCO, 2006). However, the water usage throughout South Africa varies between different areas. People living in rural areas obtain the majority of their water (77 %) from groundwater sources namely wells and pumps (UNESCO, 2006). This is the opposite for people living in urban areas as they rely on surface water to supply them with the majority of their water demands. Surface water sources include rivers, such as the uMngeni River, the Limpopo River and the Komati River, and this water, after undergoing numerous treatment processes, is then supplied to the cities by water distribution systems (UNESCO, 2006).

South Africa, classified as a semi-arid country, experiences varying degrees of rainfall ranging from a minimum of less 100 mm per annum in the west of the country to a maximum of greater than 1 500 mm in the east of the country (DWS, 2015). South Africa experiences an average rainfall of 450 mm per annum. This is significantly smaller in comparison to the world's average of 860 mm per annum (DWS, 2015).

**Figure 2-1** illustrates the rainfall distribution across South Africa, variations between the Eastern and Western parts of South Africa can clearly be seen. The current rainfall patterns present in South Africa is inconsistent and currently South Africa is facing one of the worst droughts. Coupled with climate change, the effects of drought worsens. Water is being rationed



*Figure 2-1: The average rainfall across South Africa (Source: Water Wise, 2015).*

in many parts of South Africa, there is also no grass to be grazed and livestock are dying due to water shortages (de Kock, 2016).

Over the years, there has been a significant increase in population growth, which has placed stress on South Africa's water supply and resources. The increasing number of people immigrating into the country is also another major contributor to the stress on the water supply. 19 % of the people living in rural areas do not have access to a reliable water supply (UNESCO, 2006).

In South Africa, 1 100 cubic meters of water is available to each person per annum (STATS SA, 2010). According to the United Nations Environmental Programme (UNEP), countries, which have less than 1 700 cubic meters of water available per person per annum, are classified as water stressed

countries. A water scarce country is where less than 1 100 cubic meters of water is available per person per annum, this statistic emphasises the fact that South Africa is bordering on being a water scarce country (WBCSD, 2006).

The water demand is expected to increase over the next few years. Population growth, new developments such as mines and power plants, irrigation developments and poor water quality are a few factors which are expected to increase the strain on the water supply (WBCSD, 2006).

## **2.11 Water Sources**

Surface water sources are generally high in quantity but low in quality in comparison to groundwater sources, which are generally high in quality but low in quantity (DEA, 2007).

### **2.11.1 Surface Water**

Surface water sources are renewable as they are naturally replenished by precipitation. Humans are able to increase the storage capacity by creating artificial reservoirs. In addition, they can increase runoff quantities by paving areas and channelizing stream flow. The total amount of surface water available for use at any time is an important factor that needs to be considered when allocating water resources (DEA, 2007). Surface water is mainly used for drinking, irrigation, power generation and mining (DEA, 2007).

### **2.11.2 Groundwater Sources**

Groundwater sources can be found underground in spaces in the sand, soil and rock. Groundwater is usually used for irrigation activities. Groundwater has the potential to be an essential component in industrial processes. Groundwater also supplements the water present in lakes, rivers and wetlands (DEA, 2007). Groundwater moves slowly underground through the rocks and it, therefore, undergoes a filtration process, which reduces the amount of certain contaminants (DEA, 2007).

### **2.11.3 Recycled Water**

Wastewater, which has been purified so that it can be used again, is called recycled water. Water can be recycled from numerous sources, including rainwater caught on roofs of buildings, stormwater which is considered rainwater that has reached the ground or any other hard surface and drains into watercourses and treated effluent from sewage plants. All the above-mentioned recycled water sources are suitable for a wide range of non-potable applications after it has been

treated. This has the potential to decrease the stress placed on surface and groundwater sources, reduce the amount of pollutants entering watercourses and can be considered a very valuable resource. The initial set up costs of the recycling plants will be expensive, however, it will be beneficial in the long run as it will improve the sustainability of water use (DEA, 2007).

## 2.12 Water Pollution

In urban areas, access to clean water, used for cleaning, washing dishes, drinking and other recreational activities, is taken for granted. However, sources of water such as lakes, streams, rivers, ponds and the ocean can become polluted by a variety of pollutants. Pollutants can be introduced into the watercourses by sewage leaks, agricultural runoff or chemical spills. When this water becomes polluted, it becomes unsafe for human consumption. It is essential for South Africa, being a water scarce country, to have measures in place to remove pollutants from effluents and waste material before it can enter any water resource. Measures also need to be implemented to remove pollutants already present in the country's water resources (Strydom and King, 2009).

Pollution can be caused by natural sources or human activities. The presence of pollutants in water bodies can have detrimental effects on aquatic eco-systems as well as on humans who depend on that source of water (Strydom and King, 2009).

Pollution is defined by the National Water Act (Act 36 of 1998) as:

*“the direct or indirect alteration of the physical, chemical or biological properties of a water resource so as to make it –*

*(a) Less fit for any beneficial purpose for which it may reasonably be expected to be used;*

*or*

*(b) harmful or potentially harmful –*

*i) to the welfare, health or safety of human beings;*

*ii) to any aquatic or non-aquatic organisms;*

*iii) to the resource quality; or*

*iv) to property.”*

Polluted bodies of water do not have many observable indicators as the pollutants are not always visible, scientists, therefore, need to use a variety of tests to determine the quality of water and level of contamination. Water pollution may occur from either point sources or non-point sources (Strydom and King, 2009). Point sources are pollution from a discrete location such as a factory or from a sewage pipe (DEA, 2007). Non-point source pollution is pollution from different points over a large area. A water body may be contaminated by a numerous sources like agricultural runoff and construction sites. These sources do not release contaminants from the same point each time, however, each point where contaminants are released contributes to the pollution of the water body (DEA, 2007).

### **2.12.1 Surface Water Pollution**

Surface water pollution is the pollution of aquatic systems, which are found above ground. These water bodies become polluted when water, containing pollutants, enters watercourses (DEA, 2007). There are a variety of pollutants contaminating stormwater including salts and chemicals from towns and new developments and nutrients and fertilizers from farms (DEA, 2007).

A River Health Programme (RHP) was implemented by South Africa's Department of Water and Sanitation (DWS) in 1994. This programme provided information relating to the ecological status of aquatic eco-systems in South African rivers. Initial analysis of individual rivers, from source to mouth, revealed the following:

- 6 % of the rivers studied are in natural condition.
- 22 % of the rivers studied are in good condition.
- 44 % of the rivers studied are in fair condition.
- 28 % of the rivers studied are in poor condition (DWS, 1994).

### **2.12.2 Groundwater Pollution**

Groundwater can be polluted by a variety of sources and this is problematic to monitor as it is below ground. Groundwater pollution can be caused by chemicals from spills, agricultural runoff and pathogens. These sources of pollution are similar to the sources of pollution to surface water pollution. Underground septic tanks and oil tanks can also pollute groundwater sources. If these

tanks develop a leak, chemicals and waste can seep into the groundwater supply and pollute it (DEA, 2007).

## **2.13 Water Quality Problems in South Africa**

Watercourses naturally contain organic matter due to the large variety of organisms and decaying matter present. However, the natural levels of organic matter are increased by stormwater discharge, industrial pollution, pipe bursts, pipe blockages and atmospheric fallout. It is important to note that it is not the high levels of organic loading that are detrimental to human health, rather it is the nature of the organics and the uses of the water, which affect human life (Botha, 2016).

The South African Government has a standard for potable water quality known as the Blue Drop Certification. There are 153 municipalities and 1 036 water systems in South Africa. Only 44 municipalities were given the Blue Drop Certification in 2014. The Green Drop Report provided information regarding the sewage systems in South Africa. Out of the 824 sewage systems, only 60 were given the green drop certification (Pawson, 2016).

A survey conducted by the DWS indicated that 60 % of the country's water service officials do not have the correct licences for their treatment plants and nearly one third of them do not monitor the water quality of the treated water on a monthly basis (DWS, 2010). Some of the major pollution challenges in South Africa includes eutrophication, nitrification, microbiological contamination, salinity and acid mine drainage (Strydom and King, 2009).

### **2.13.1 Eutrophication**

Eutrophication is due to the accumulation of nutrients, consisting mainly of nitrogen and phosphorus compounds, in water (DEA, 2007). The major causes of eutrophication in a water body are:

- Inefficient sewage disposal and treatment methods.
- The uncontrolled use of household detergents that contain phosphate and other harmful chemicals.
- Poor agricultural practices, which result in excess fertilizer washing into river systems or seeping into groundwater sources (Strydom and King, 2009).

Eutrophication commonly affects surface water. Eutrophication of water bodies can also occur downstream of large urban areas or in rural areas where there is inadequate sanitation facilities (Strydom and King, 2009). A common effect of eutrophication is an increase in the organic matter within water bodies. When the organic matter starts to decompose, oxygen is needed which results in a decrease in the dissolved oxygen levels within the water body. The flora and fauna are negatively affected, as they require oxygen to survive (Strydom and King, 2009). Nitrification of a water body, classified under the wider eutrophication heading according to a publication by the DEA in 2007, occurs when the water body has increased nitrate levels and has the same sources as eutrophication.

### **2.13.2 Suspended Solids**

Suspended solids are insoluble sediments that are transported within water bodies. They arise from excessive erosion, the destruction of riparian vegetation, construction activities as well the discharge of domestic and industrial waste (DEA, 2007). The increase in suspended solids reduces the amount of light able to penetrate the surface of the water body. As a result, plant growth becomes stunted, in-stream habitats are negatively affected and the gills of fish and respiratory tracts of other aquatic species become damaged (Kerr, 1995).

### **2.13.3 Microbiological Contamination**

Microbiological contamination can affect the water quality of both surface and groundwater sources. This is usually caused by inefficient sanitation methods together with the inadequate treatment of drinking water (Strydom and King, 2009).

Water supplies, which have been inadequately treated, will have noticeable levels of total coliform bacteria, which is indicated by the presence of *Escherichia coli* (E.coli). This is an indication that the water body is polluted by faecal matter from humans and other warm-blooded animals (DWS, 1996). In addition, there may be pathogenic bacteria present in the water body, however, the pathogenic bacteria alone may not be harmful (NRC, 1977).

### **2.13.4 Salinity**

This term refers to the salt content of water. Increased salinity is a major problem for the biota present in surface water. It is an expensive procedure to remove salts from water in order for it to be fit for human consumption. Salination is usually associated with mining operations as well as

industrial activities such as metal and mineral processing plants. The Total Dissolved Salts (TDS) levels provides an indication of the various salts dissolved in the water (Strydom and King, 2009).

### **2.13.5 Acid Mine Drainage**

Acid mine drainage occurs from large-scale mining activities (McCarthy, 2011). Acid mine drainage is currently one of the main pollutants of surface water. Acid mine drainage, also known as acid rock drainage, occurs naturally in certain environments as part of the rock weathering process. The process of acid mine drainage is, however, magnified by mining and other large construction activities which bring about large-scale earth disturbances. These activities usually occur within rocks containing large quantities of sulphide minerals (McCarthy, 2011).

## **2.14 Poor Maintenance of Infrastructure in South Africa**

The water treatment plants together with the pipes supplying water to the various areas in South Africa are in various stages of degradation. A large number of municipal sewerage systems in South Africa, which are about 50 years old, have leaks. In addition, there are numerous blockages and overflowing incidents in sewer networks. This results in the contamination of the surrounding water in lakes, rivers and groundwater systems. Many people are aware of the Duzi Canoe Marathon, but it is unlikely that the public and even some of the canoeist realise condition of the river. Tests conducted on the river revealed that there were high levels of bacterial contamination within the uMsunduzi River. Concentrations of indicator bacteria have been recorded as high as 2 419 000 cfu/100 ml (Zacharie, 2011). After numerous tests were conducted, it was declared that the uMgungundlovu district has the highest diarrhoea infection rate in the country. This largely caused by sewage spills, which have resulted from blockages, in the sewer pipes, and overflowing incidents, at the sewer manholes (Zacharie, 2011).

However, water pipelines have also been susceptible to leaks, both major and minor. Whilst major leaks are easily spotted and fixed, minor leaks can remain undetected and are a major problem. An estimated 40 % of the total municipal potable water supplied to South Africa is lost before it reaches the customers. A quarter of this is attributed to physical leaks and reservoir overflows (Strydom and King, 2009).

## 2.15 Importance of Policies and Legislations in the Water Sector

The decrease in environmental health affects both the economy and society. The management of pollution and waste products is a key component in ensuring that development is economically, environmentally and socially friendly (Li et al., 2016). In accordance with this, legislations and policies have been implemented by the South African government and enforced by parties such as the DWS and the DEA.

These legislations and policies serve to stabilize environmental systems, thereby, reducing climatic changes and biodiversity losses. As a result, these new government arrangements are applicable to both the public and private sectors at national and international levels (Van Kersbergen and Van Waarden, 2004). A key component to these environmental systems is water and it is one of the most important natural resources (Tietenberg, 1992). The following is a quote by Sandra Postel (1984):

*“Water’s seeming ubiquity has blinded society to the need to manage it sustainably and to adapt to the limits of fixed supply”.*

The effects of South Africa’s poor planning of its water resources are clearly shown today by the water shortages experienced throughout the country as well as the water restriction measures implemented.

### 2.15.1 The National Water Policy

The government has primarily focused on equitable and sustainable development since 1994. However, some of the existing laws, prior to 1994, were not in accordance with this (DWS, 2004). As a result, the National Water Policy for South Africa was adopted by cabinet in 1997.

The three core objectives for managing South Africa’s water sources according to the NWP are:

- To achieve water access – This entails providing all South Africans with equal access to water services, resources and the benefits, which arise from the use of these water resources.
- To achieve sustainable water use – This was deemed possible by making continuous adjustments to water use in order to achieve a balance between water availability and requirement and to implement measures to protect these resources.

- To achieve efficient and effective water use – This objective is to provide both social and economic benefit (NWP, 1997).

### 2.15.2 The National Water Act

The primary focus of this Act is to ensure that South Africa's water resources are protected. The National Water Act (NWA) is important as it focuses on the components relating to water which have been stated in the South African Constitution (Act 108 of 1996). The NWA has also been implemented in order to guarantee that the water resources are used, managed, developed and conserved. The NWA (1996) recognised the scientific indivisibility of water resources. As such, the Minister of Water Affairs is the public trustee chosen to safeguard the water resources and ensure that decisions do not negatively affect the integrity of the resource (Strydom and King, 2009).

Waste, defined by the NWA, includes:

*“any solid material that is suspended, dissolved or transported in water (including sediment) and which is spilled or deposited on land or into a water resource in such volume, composition or manner as to cause, or to be reasonably likely to cause, the water resource to be polluted.”*

A critical aspect to take note of is that waste, as defined by the NWA, is not limited to matter disposed, discarded or discharged, but includes any matter that may cause water resources to be polluted. Sewage and trade effluent are commonly found contaminating watercourses. As a result, the DWS devised a list of by-laws and guidelines regarding the disposal and treatment of wastewater to have minimal impact on watercourses. The following are a list of some of the guidelines, the full list can be obtained from the EWS website.

- Policy Guidelines on Water Supply and Sanitation Provision to Communities.
- Monitoring and Control of Sewage Disposal and Treatment.
- Re-Use of Treated Effluent From Sewage Treatment Works.
- Guidelines for the Design and Approval of On-Site (Sub Surface) Disposal of Domestic Sewage.
- Guidelines for Building Plans Approval in Respect of Trade Effluent Control and Water Pollution Prevention in order to Comply with the Durban Metro Sewage Disposal Bylaws of February 1999.

- Guidelines for Privately Owned "Package" Sewage Treatment Plants or other "On-Site" Systems for the Treatment of Domestic Sewage in the Durban Metropolitan Unicity Area where the Treated Wastewater is to be Discharge Directly to a Natural Surface Water Course or Through Surface Irrigation.
- Guidelines for the Management of Metal Finishing Industry Effluent Developed by the Durban Chamber of Commerce Bylaws Working Group.
- Guidelines for the Design and Construction of Toilets where the Basic Level of Services is Appropriate.

## **2.16 Rivers**

A river is the naturally occurring flow of water towards oceans, seas, lakes and other rivers. However, some rivers flow into the ground and become dry. This usually occurs in smaller rivers. Small rivers are commonly referred to as streams, brooks, creeks or rivulets (One Geology, 2016).

Rivers are an important component in the hydrological cycle. Water normally collects in rivers by precipitation, surface run-off, groundwater recharge and springs. A river commonly starts at a source, or a number of sources, and follows a natural path, called a course, until it reaches its end, referred to as the river mouth or mouths. Most rivers have high flow rates in the steep areas near their source, this fast flowing water displaces the gravel, sand and mud leaving behind a rocky bottom to the river (One Geology, 2016). The water present within a river is usually restricted to flow within its channel, this is made up of the banks on either side of the river. A floodplain is the area alongside the river that is susceptible to flooding. Larger rivers usually have a larger floodplain.

The term upstream and downstream are often mentioned when talking about rivers and these terms will be used during the course of this study. Upstream refers to the direction towards the source of the river, therefore, the upstream direction is the opposite direction to which the river is flowing. Downstream refers to the direction in which the river flows.

### **2.16.1 Importance of Rivers**

The goods and services provided by river systems have either a direct or an indirect influence on the well-being of humans as well as the economic growth of the country. For example, rivers provide drinking water, water for agricultural practices and larger rivers are even used as a means to

transport goods. Rivers are also used in recreational activities and are good picnic spots due to their diversity. The goods and services provided by river systems are essential for human survival and economic growth (WRC, 2002). The quality and quantity of these goods and services may be reduced when a river system is contaminated by pollutants. In order for humans to continue to enjoy the benefits provided by river systems, it is important to ensure that the river systems remain healthy. Therefore, it is common knowledge that the quality and health of a river directly influences the surrounding communities.

## **2.17 Rivers in South Africa and the uMngeni River**

South Africa is directly dependant on rivers, dams and groundwater sources to satisfy its water demands (Strydom and King, 2009). Approximately half of South Africa's annual rainfall is stored in dams and transferred from there to the required areas. Rivers play a crucial role in this process.

The numerous rivers in South Africa are a major contributing factor to the diversity present in South Africa. The important rivers in South Africa include the Tugela River, Orange River, Vaal River, Limpopo River and the uMngeni River, of which the Palmiet River is a tributary. The Orange River takes the title of being the largest and longest river in South Africa. The Vaal River is 1 120 km long and is also a source for around 12 million consumers in and around the Gauteng area (Scott, 2011). However, in Kwa-Zulu Natal, the uMngeni River is the most important river from an economic perspective.

The uMngeni catchment covers an area of 441 square kilometres with a river length of 225 km from its source to the river mouth (WRC, 2002). The uMngeni River originates in the Midlands area, Pietermaritzburg, and flows towards Durban with its mouth being in the northern area of the Durban harbour. It flows through areas ranging from natural conservation areas to urban and industrial areas. These areas are very important in terms of the economy, ecology and culture (WRC, 2002).

The uMngeni River is widely used for cultural and spiritual activities. In addition, the reduced floodplain of the uMngeni River has provided land for the implementation of infrastructure at the cost of a reduced ecology (WRC, 2002). The uMngeni catchment consists of a number of other rivers and their tributaries. The Palmiet River, which forms the focus of this particular study, is one of the many tributaries to the uMngeni River. All the rivers, included in the larger uMngeni catchment are affected by pollution and environmental degradation. However, these impacts are not concentrated

to the rivers but extends to their buffer zones and wider terrestrial area. This reduces the overall volume of water available for use and decreases the functionality of the river system (WRC, 2002).

### 2.18 Buffer Zones

Buffer zones are strips of vegetation, consisting of riparian vegetation, riverbanks and sometimes terrestrial habitats. Buffer zones act as a barrier between human developments and aquatic resources, such as rivers (Macfarlane et al., 2009). Buffer systems provide a number of functions to river systems including:

- Sediment removal.
- Pollutant removal.
- Habitat connectivity.
- Channel stability and flood attenuation (Macfarlane et al., 2009).

**Table 2-1** presents information, which indicates how the varying widths of buffer zones affect its effectiveness.


It is evident that the greater the width of the riparian zone, the greater its effectiveness in removing pollutants and enhancing the life of the surrounding wildlife. **Table 2-2** presents minimum recommended buffer widths, calculated by Macfarlane et al.

*Table 2-1: Impact of varied buffer widths on pollutant removal and habitat value (Source: Desbonnet and Pogue, 1994).*

Buffer Width	Pollutant Removal Effectiveness	Wildlife Habitat Value
5m	Approximately 50% or greater sediment and pollutant removal	Poor habitat value, useful for temporary activity of wildlife.
10m	Approximately 60% or greater sediment and pollutant removal	Minimally protects stream habitat, poor wetland habitat, useful for temporary activity of wildlife.
15m	Greater than 60% sediment and pollutant removal	Minimum general wildlife and avian habitat value.
20m	Greater than 70% sediment and pollutant removal	May have use as a wildlife travel corridor for some species as well as minimal to fair wildlife habitat.
30m	Approximately 70% or greater sediment and pollutant removal	May have use as a wildlife travel corridor for some species as well as minimal to fair wildlife habitat.
50m	Approximately 75% or greater sediment and pollutant removal	Minimum to fair general wildlife habitat value.
75m	Approximately 80% or greater sediment and pollutant removal	Fair to good general wildlife and avian habitat value.
100m	Approximately 80% or greater sediment and pollutant removal	Good general wildlife and avian habitat value; may protect significant wildlife habitat value.
200m	Approximately 90% or greater sediment and pollutant removal	Excellent general wildlife and avian habitat value; likely to support diverse community.
600m	Approximately 99% or greater sediment and pollutant removal	Excellent general wildlife and avian habitat value; likely to support diverse community; protection of significant species.

(2009) using the step-wise approach presented by Graham and de Winnaar (2009), for different land uses around a river system.

Table 2-2: Recommended buffer widths based on the surrounding land usage (Source: Macfarlane et al., 2009).

Disturbance	Land use		Buffer width [m]	
	Primary Category	Secondary Category	River	
	Low	Protected/ Conservation areas	National park	15
			Nature reserve	15
		Conservancy	32	
	Residential developments		Eco-states	32
			Low density	32
			Medium density	32
			High density	45
			Industrial developments	Low density
	Services/ Infrastructure		High density	70
			Pipelines	32
			Communication/Power	32
			Roads	32
			Sewerage farms	45
			Septic tanks	70
			Landfills	100
High	Landfills	Landfills	100	

The increase in urbanisation has negatively affected buffer zones along river systems. The biggest problem being the reduction in width of the buffer zones due to the encroachment of the surrounding developments. In addition to adverse effects on the natural buffers, river systems are degraded due to a number of other factors. The following sections provide details of how urbanisation and the increase in infrastructure development has affected river systems.

## 2.19 General Impacts on River Systems by Urbanisation and Infrastructure Development

### 2.19.1 Industrial Pollution

Some industries have received permission to discharge their effluent into nearby rivers and streams, however, Umgeni Water tests some of the effluent prior to discharge to ensure that it will not be harmful to the environment. However, there are some industries, which do not comply with the

standards, or discharge their effluent without receiving the correct permissions. These companies are usually prosecuted, however, the effects of the discharged effluent cannot be reversed (Umgeni Water, 2016). The following are common pollutants discharged from industries:

- Nitrates and Phosphates - As fertilizers and pesticides become more commonly used, there is an increase of nitrates/phosphates washed from the soil into rivers and lakes, which results in the water body becoming eutrophic (Strydom and King, 2009).
- Mercury - Mercury is a metallic element and one of the most harmful pollutants affecting fish and other wildlife (NWF, 2016). Mercury is a neurotoxin and it affects the central nervous system of both people and wildlife (NWF, 2016).
- Lead - Lead is another metallic element that is harmful to both humans and animals as it can inhibit the action of bodily enzymes. There are no acceptable levels of lead as even a small amount can be detrimental. Lead in the body can be transferred to the brain, liver, bones and kidneys (WHO, 2016).
- Sulphur and sulphuric acid - These are non-metallic substances, which are emitted into the atmosphere, the end result being acid rain. The effects of acid rain are clearly visible in aquatic habitats. In addition to falling directly into rivers and streams, acid rain also runs off the land and eventually ends up in the rivers, lakes and streams. Acid rain causes the acidity levels of a water body to increase. This results in the deaths of aquatic animals. Freshwater shrimps and snails are very sensitive to the effects of the increased acidity in the water. The increased acidity of water can cause deformity in young fish and hinder the egg hatching process. River systems have their own individual eco-systems and if a single species is affected by the acid rain, this will lead to an imbalance in the eco-system (NCSU, 2016).
- Oil - Oil does not dissolve in water, rather, it forms a layer on the surface of the water body preventing light from entering the water body and hindering the process of photosynthesis (Gonnellia et al., 2016). In addition, oil is detrimental to aquatic animals who consume it. Together with aquatic animals, birds are also affected. Bird feathers, become matted with oil and when birds preen themselves, they end up ingesting the oil (YPTE, 2016).

- Petrochemicals - Petrochemicals can be formed from petrol or diesel. Petrochemicals together with their by-products, like dioxin, cause a variety of health problems. Some of these health problems include cancer and endocrine disruption (Wordpress, 2012).

### **2.19.2 Informal Settlements**

The inhabitants of informal settlements along rivers are directly dependant on the river to satisfy their basic needs. In general, rivers, which run through informal settlements and rural areas, are used for numerous activities including:

- Direct sanitary use - This includes bathing and washing of clothes and utensils.
- Recreational activities - This includes swimming, fishing as well as just sitting along the river edge.
- Harvesting plants - There are usually a large variety of plants and other vegetation, which grows alongside the river, these are then plucked for their medicinal properties as well as for food.
- Water source – River water is used for drinking and cooking after it has been boiled and purified to an extent.
- Solid waste disposal - Often rubbish is discarded directly into the river, as it is an easy way to get rid of the waste items. The lack of or poor service delivery in these areas are also a contributor to the disposal of solid waste along the riverbanks.
- Sewage disposal - On site toilet waste is discharged into the river due to the inadequate sanitary facilities (Vollmer and Gret-Regamey, 2013).

### **2.19.3 Freshwater Pipe Bursts**

Excess water running through the soil, from pipe leakages and bursts, reduces the integrity of the soil structure. This can lead to slope failure and soil erosion. If this occurs, near rivers, there will be an increased amount of sediment particles transported into the rivers. Pipe bursts also increase the runoff abilities and a wide variety of pollutants are transported through the environment and into river systems (D'Eathe, 2016).

### 2.19.4 Urban Runoff

Urbanization is a common pattern throughout the world as it is directly linked to economic growth. Urban areas are characterized by impervious surfaces and buildings. This prevents water from being absorbed into the soil, which results in increased runoff. The water, after flowing across driveways, rooftops and roads, eventually reaches the stormwater drains, which directs it towards rivers to be discharged.

Wildlife relies on the riparian zones to provide food, water and a habitat, however, it is into these areas which

stormwater is discharged. The increased rate of stormwater runoff results in a decrease in the groundwater's ability to recharge (Burns et al., 2005).

**Figure 2-2** illustrates what happened to runoff in developed areas as opposed to natural areas. **Figure 2-3** illustrates the resultant hydrograph. It is important to

note the high peak flow rates over a shorter duration represented by the post - development hydrograph. In natural areas, more water is able to seep into the soil resulting in the lower peak flows and a more constant flow rate, represented by the hydrograph illustrating the pre-development flow rate.

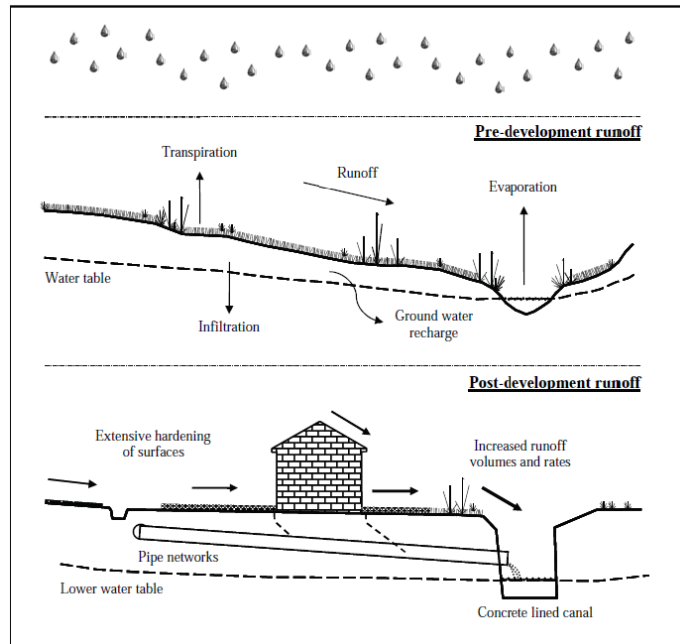


Figure 2-2: Typical pre-development and post-development runoff scenarios (Source: Armitage et al., 2013).

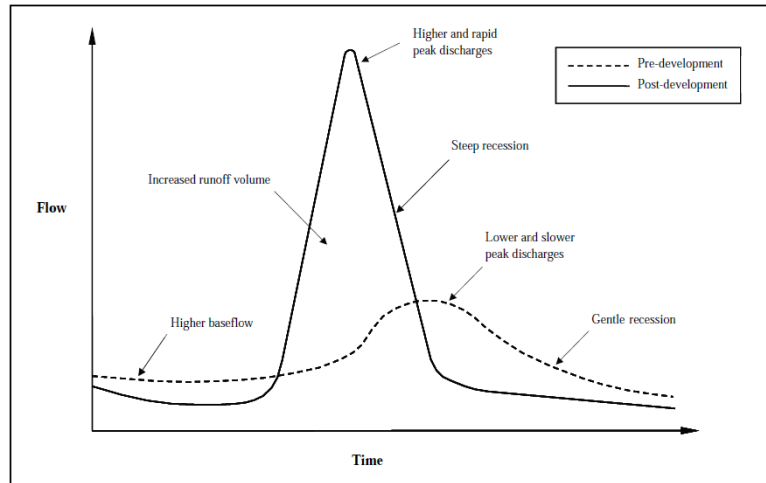


Figure 2-3: Typical pre-development and post-development hydrographs (Source: Armitage et al., 2013).

One of the most significant consequences of the increased volumes of runoff discharged into rivers is the impact it has on the rivers scouring ability. Scouring is a more specific term, which refers to erosion. The scouring impacts imposed on the land include:

- Reduces the ability of the soil to store nutrients and water.
- Results in the exposure of the subsoil, which usually has poor physical and chemical properties.
- Increases the rate of runoff.
- Silt is deposited in low-lying areas (Queensland Government, 2013).

The scouring impacts imposed on the river systems include:

- Causes siltation of rivers and storage areas.
- Reduces the water quality due to excess nutrients, pesticides and other chemicals deposited (Queensland Government, 2013).

The scouring impacts imposed on the infrastructure in and around the river include:

- In order to build roads, the natural land is disturbed. As a result, erosion and siltation can potentially occur if stabilising techniques are not used.
- Urban developments can cause scouring if the land is unsuitable to support infrastructure and if the proposed development occurs over existing drainage lines (Queensland Government, 2013).

Areas such as lawns, parks and golf courses can provide similar groundwater recharge rates to what would have naturally occurred (Lerner, 2002). In addition, these areas filter runoff, to an extent, before it enters the river system. In South Africa, there are 2 separate systems to deal with sewage and stormwater. The stormwater system collects urban runoff and directs it towards rivers and bays. The sewer system, however, collects household, industrial and commercial waste and effluent and directs it towards wastewater treatment plants. The water is then treated in these plants before being discharged into water bodies (Macleod, 2016). Therefore, urban runoff is commonly polluted when it becomes contaminated by pollutants present on the impermeable surfaces. Urban runoff is considered a nonpoint source pollution as it comes from a variety of sources. Individual households

usually have a small contribution to non-point source pollution. However, the combined effects of an entire town or city can pose a serious negative impact (Waters et al., 2011).

Before urban runoff enters the stormwater drains, it is exposed to pollutants including:

- Pesticides used in the gardens.
- Chemicals used for landscaping.
- Litter and household rubbish.
- Oil from motor vehicles.
- Waste excreted from pets.
- Chemicals used for washing cars.
- Sediment resulting from soil erosion (Waters et al., 2011).

Precipitation and urban runoff can potentially cause soil erosion, which results in loose sediment being transported into river systems. Rivers, which are polluted by sediment, appear murky and cloudy. This colour change reduces visibility resulting in animals being unable to see their food in the river. Sedimentation also greatly restricts the growth of natural vegetation, blocks the gills of fish preventing them from absorbing oxygen and creates an imbalance in the food chain. Nutrients are also bound to sediment particles and are released into the water body (Waters et al., 2011).

In landscaping activities, chemicals and nutrients are washed into stormwater drains. These pollutants end up polluting river systems. This causes the water body to become eutrophic (Waters et al., 2011).

Another common household pollutant is the faeces of pets. Pet waste, which is left on the ground, can contain E.coli bacteria, roundworm, tapeworm and toxoplasma gondii. This waste, if not picked up and disposed of, can contaminate the surface water runoff. In addition to the detrimental impacts on the rivers, these bacteria can also be transmitted to humans (Waters et al., 2011).

### **2.19.5 Waste Disposal**

Improperly discarded dry solid waste is often transported by wind or runoff to the surrounding environment and rivers. Litter and garbage such as plastics, cloths, paper, metal, cardboards and

glass are examples of dry solid waste. These items are what remains from the goods we buy and use. Even people who use rivers for recreational purposes can add to the overall pollution by littering. Domestic waste needs to be properly controlled and managed in order to prevent this (EPA, 2016). This is of particular concern in the informal settlements, as the service delivery is poor in these areas.

Aquatic organisms have been known to take refuge in the discarded items such as tyres and plastic containers. However, dry solid waste is a sign of human negligence and causes the degradation of the aesthetic and natural value of the eco-systems (Water Encyclopedia, 2016). Plastics are particularly harmful to aquatic animals and wildlife because once ingested, they can cause organ failure, suffocation and even death. Other waste items such as oil filters and lead-acid batteries are problematic as they can leak harmful chemicals, which can cause problems for the surrounding fauna as well as humans (Water Encyclopedia, 2016). Items such as plastic bags, paper and glass bottles need to be sent for recycling and not just thrown away. Plastic bottles for example can take anywhere from 450 years to 1000 years to decompose (O'Connor, 2011).

#### **2.19.6 Invasive Alien Plants and Animals**

Invasive alien species are the single greatest threat to South Africa's biodiversity and they are causing direct economic losses (DWS, 2007). Invasive alien species that have been introduced to the South African environment tend to dominate the competition for the natural resources. Invasive alien plants invade rivers, dams, wetlands and estuaries causing a number of problems including:

- Lower oxygen levels in the rivers.
- Certain invasive alien plants grow into a "thick mat-like material" which blocks pump inlets.
- The overall flow of the water and the flow in canals is reduced.
- Siltation of rivers occur.
- There is an increase in water loss caused by the process of evapotranspiration.
- Alien plants can also provide a breeding spot for mosquitos and snails. These organisms can sometimes carry diseases such as bilharzia and malaria.

- Invasive alien plants can also increase the impacts of natural disasters such as fires and floods and increase soil erosion.
- Alien plants which grow along the water surface can also prevent sunlight from penetrating the water. The entire food chain is, thus, affected which results in the deterioration of aquatic biodiversity (EPCPD, 2016).

According to the DWS (2007), there were about 9 000 plants introduced to South Africa, out of those, 198 were classified as invasive alien plants. Although this seems like a small amount, invasive alien plants cover about 10% of South Africa, this coverage is increasing exponentially.

Effective control measures, concerning alien vegetation, should take into account the surrounding indigenous vegetation as well as possible disturbances to the soil. In addition, the alien vegetation, once removed, should not be immediately discarded. Many alien plants can be used for compost, firewood, building materials and furniture. Therefore, the benefits, which arise, from removing alien vegetation needs to be considered before it is discarded. There are 3 types of control measures used to control alien vegetation namely biological control, mechanical control and chemical control (EPCPD, 2016). Certain control methods may appear more advantageous than others may, however, a combination of the three control measures is recommended by the EPCPD for the best results. Further details with regards to the different control measures obtained through brochures and pamphlets from the EPCPD.

### **2.19.7 Land Fragmentation**

Land fragmentation has a negative impact on the biodiversity of the area as it reduces the amount of available natural habitat. This can be caused by geological processes, which alter the environment over a long period, or by human activities, which can change the landscape at a significantly quicker rate (Sahney et al., 2010). Urbanization is a major contributor to land fragmentation. Due to urbanization, natural areas have been used for the implementation of infrastructure. The habitats, which were once continuous over the land, becomes divided into smaller fragments. In urban areas, each fragment is separated from the other by roads, factories, pavements and buildings (D'Eathe, 2016).

## 2.20 Importance of Investing in Ecological Infrastructure

South Africa's water security is directly dependant on the sustained use of its water resources. Therefore, it is of utmost importance that these water resources, including rivers, wetlands, estuaries, springs and aquifers, are conserved, maintained, monitored and restored where necessary (WWF-SA, 2016).

The South African National Biodiversity Institute (SANBI, 2016a) provided the following definition for ecological infrastructure:

*“Ecological infrastructure refers to naturally functioning ecosystems that deliver valuable services to people, such as water and climate regulation, soil formation and disaster risk reduction. It is the nature-based equivalent of built or hard infrastructure, and can be just as important for providing services and underpinning socio-economic development.”*

The importance of preserving and maintaining functioning ecological infrastructure is apparent when compared to the costs incurred to purify the water resources (WWF-SA, 2016). The major types of ecological infrastructure include wetlands and river systems. The investment of ecological infrastructure can also be attributed to the investment into options, which reduces the impacts of urbanisation on the environment, such as the implementation of SUDS.

## 2.21 Wetlands

The NWA (1996) defines wetlands as:

*“land which is transitional between terrestrial and aquatic eco-systems where the water table is usually at or near the surface, or the land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil”.*

South Africa is a country, which contains thousands of wetlands (Strydom and King, 2009). Inland wetlands include reedbeds, vleis, in river channels, marshes, swamps and floodplains. Coastal wetlands include mangrove swamps and tidal salt and mud flats.

Wetlands have a number of important features:

- Waterlogged soils or soils covered with a shallow layer of water, either all year round or seasonally.

- Unique types of soils
- Distinctive plants adapted to water-saturated soils (Strydom and King, 2009).

These features are the core components aiding in the functionality of wetlands. The primary functions of wetlands include:

- Flood control – Wetlands along streams and rivers aid in slowing down the flow rate by acting as sponges, covering a wide surface area. Water flowing into a wetland loses velocity and spreads out. The variety of plants co-existing in the wetland play a critical role in retaining the water. The majority of the water is stored in the wetland and is slowly released to downstream areas. This is beneficial as it reduces flood damage and erosion and ensures a steady supply of water throughout the year (WWF-SA, 2016).
- Water purification – Wetlands are effective filters, which trap sediment, nutrients and even pathogenic bacteria and, therefore, improves the water quality. There are also a number of chemical and biological processes occurring in wetlands, which can trap heavy metal pollutants, such as mercury and lead, and pesticides. As a result, the water seeping out a wetland is usually cleaner than the water, which flowed into the wetland (WWF-SA, 2016).
- Habitat protection for wildlife – The functionality of wetlands is not limited to its benefits to freshwater resources. Wetlands provide shelter for many animals. The accumulation of sediment and nutrients is beneficial for the growth of a variety of vegetation including grasses, reeds, water lillies and trees. The vegetation, in turn, provides shelter and food for a variety of animals. Some of these animals are directly dependant on wetlands, for example the Wattled Crane, whilst other animals only use the wetlands for part of their lives (WWF-SA, 2016).

### **2.21.1 Current Status of Wetlands**

All wetlands within Southern Africa are threatened. Many wetlands have been converted for agricultural activities, the implementation of dams, forestry practices, waste disposal sites and industrial activities. The Convention on Wetlands of International Importance, termed the Ramsar Convention was adopted in 1971 and implemented in 1975. This treaty outlines the framework for the conservation and use of wetlands, and their resources (Strydom and King, 2009).

The Ramsar Convention defines wetlands as:

*“areas of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres”*

The convention further states that each party, included in the treaty, is required to designate applicable wetlands, within its boundaries, for inclusion in the “List of Wetlands of International Importance”. South Africa has 17 sites, which have been recognised by the Ramsar Convention and included in the above-mentioned list (Strydom and King, 2009).

### **2.21.2 Working for Wetlands**

The increasing concern around the degradation of wetlands in South Africa has resulted in the DWS initiating a programme focused on the rehabilitation of wetlands. The Working for Wetlands programme, was implemented and consists of partnerships with a variety of organizations (Strydom and King, 2009).

The Working for Wetlands programme focuses on rehabilitation of existing wetlands as well as the wise use and protection of existing wetlands. Wetlands are able to provide a diverse range of functions, at no charge, and, therefore, their functionality and integrity needs to be maintained. Despite the numerous benefits of wetlands, they were previously considered as valueless and were converted for other uses. These activities have significantly altered the countries landscape. Studies conducted indicated that between 35 and 60% of South Africa’s wetlands have been either lost or severely degraded (DEA, 2016b).

#### **2.21.2.1 Legislative Framework**

There are numerous legislations, which have provisions to ensure that both urban and commercial development does not affect or alter the integrity and functionality of wetlands. The 1984 Conservation of Agricultural Resources Act was the first legal document, which included the protection of wetlands and remains in force to this day. The more commonly known legislations include NEMA, NWA and the Mineral and Petroleum Resources Development (MPRD) Act 28 of 2002.

## 2.22 Interventions in Line with Sustainable Development

During rainfall events, large stormwater networks transport the runoff, which is unable to infiltrate into the underlying soil, into the nearest watercourse. This was the traditional method of stormwater management (Armitage et al., 2013). The environmental consequences, such as pollution, erosion and siltation, of dealing with stormwater in this manner is evident today. As a result, research into alternative, environmentally friendly ways of dealing with stormwater, in line with sustainable development, was initiated. SUDS is one such option. SUDS interventions can reduce the amount of runoff being discharged into watercourses. In addition, SUDS interventions incorporate a small level of purification, thereby, reducing the pollutants, being transported by runoff. There are 3 categories of SUDS interventions that can be implemented:

- Source controls – These are often used to manage stormwater runoff as close to the source as possible i.e. within property boundaries.
- Local controls – These are interventions which are often used to manage stormwater runoff in public areas like parks and roads.
- Regional controls – These are generally large-scale interventions, which are constructed on municipal land (Armitage et al., 2013).

The three SUDS categories are intertwined and interventions could potentially be used at all levels, i.e. an intervention at a source control level can be magnified to the level of a regional control (Armitage et al., 2013). There are numerous interventions designed and implemented to reduce stormwater runoff and pollution of water bodies, the following sub-sections explore some of the interventions.

### 2.22.1 Rainwater Harvesting Systems

Rainwater harvesting systems can be implemented on each property, be it a residential household or an industrial factory. Water from the roofs of buildings can be directed through gutters and downpipes into the rainwater tanks. This water can be stored and used when required for activities like watering the garden, washing the cars, filling up pools and flushing the toilet. This promotes the concept of recycled water. Whilst the initial costs of implementing a rainwater harvesting system are high, the long-term benefits arising from the reduced water bills make up for it. When implementing such a system, it is recommended that the gutters be partially covered by a high

permeability filter screen to prevent contaminants from entering or clogging the system. Unless otherwise chlorinated and boiled, the rainwater collected should only be used for non-potable uses (CIRIA, 2015c).

There are two different types of rainwater harvesting systems which can be implemented namely a gravity fed system and a pumped supply system.

However, in order to keep running costs low and prevent any further increase in electricity usage, gravity fed systems are generally implemented in residential properties. **Figure 2-4** illustrates a brief schematic of a potential rainwater harvesting system, which could be implemented.

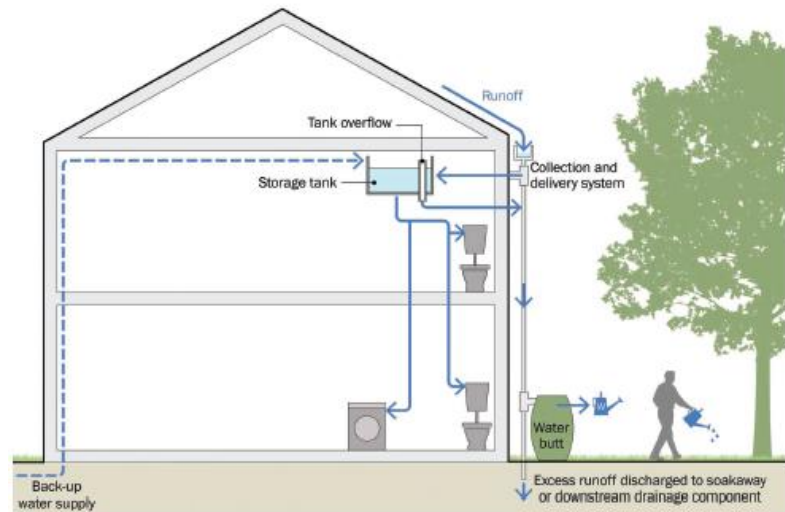


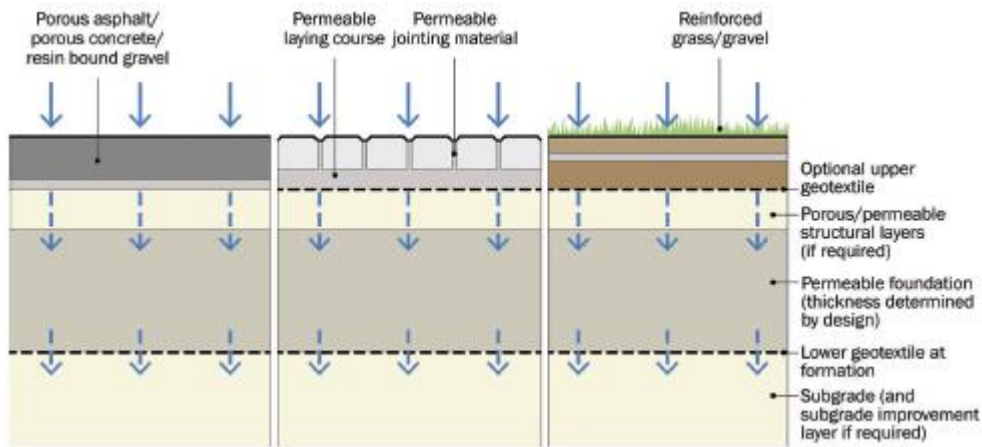
Figure 2-4: Gravity fed rainwater harvesting system (Source: CIRIA, 2015c).

### 2.22.2 Pervious Pavements

Pervious pavements allow stormwater to infiltrate through the surface and into the underlying soil layers. The stormwater can be temporarily stored before it is used, infiltrates into the ground or discharged at a controlled rate (CIRIA, 2015b). There are two types of pervious pavements:

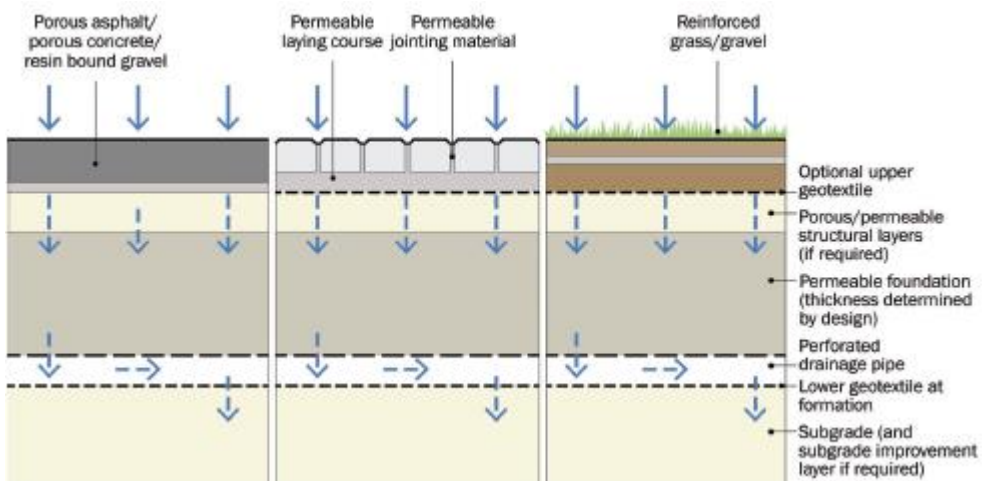
- Porous pavements – These allow water to infiltrate across their entire surface.
- Permeable pavements – Water is only able to infiltrate along the voids in-between the surface material (CIRIA, 2015b).

**Figure 2-5** to **Figure 2-7** illustrates the potential flow paths of the stormwater after infiltrating into the pervious pavement.



*Figure 2-5: Pervious pavement allowing for stormwater to infiltrate into the underlying soil layers only (Source: CIRIA, 2015b).*

Option 1 allows for all the stormwater, which falls onto the pavement surface, to infiltrate into the underlying soils, thereby, significantly aiding in the recharge of groundwater. This water will then seep at a slow, steady rate into the Palmet River.



*Figure 2-6: Pervious pavement allowing for stormwater to infiltrate into the underlying soil layers or be re-used for non-potable applications (Source: CIRIA, 2015b).*

Option 2 allows for the stormwater to infiltrate into the underlying soils as well as be used for non-potable activities. The perforated drainage pipe acts as a conduit for the stormwater to be transported into a storage area. In addition, being a perforated pipe, the stormwater is able to seep into the underlying soils.

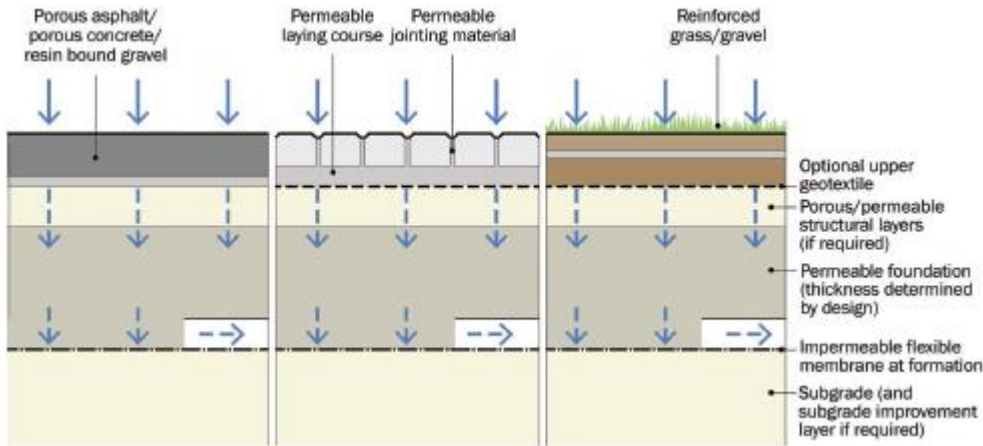


Figure 2-7: Pervious pavement that allows stormwater to be collected and re-used (Source: CIRIA, 2015b).

Option 3, due to its impermeable membrane at the base of the pavement, prevents any water from infiltrating into the underlying soil layers. The water is conveyed by a pipe into a storage facility where the water can be re-used.

### 2.22.3 Filter Drains

Filter drains are shallow trenches, which are filled with stone/gravel and can potentially replace conventional stormwater channel seen along the roads. Filter drains create a temporary storage median from which water can be filtered, conveyed and attenuated (CIRIA, 2015a). **Figure 2-8** illustrates a filter drain implemented along the road.



Figure 2-8: Example of a filter drain implemented along a road (Source: CIRIA, 2015a).

Filter drains can replace the conventional stormwater channels across the road. **Figure 2-9** is a schematic of a potential filter drain.

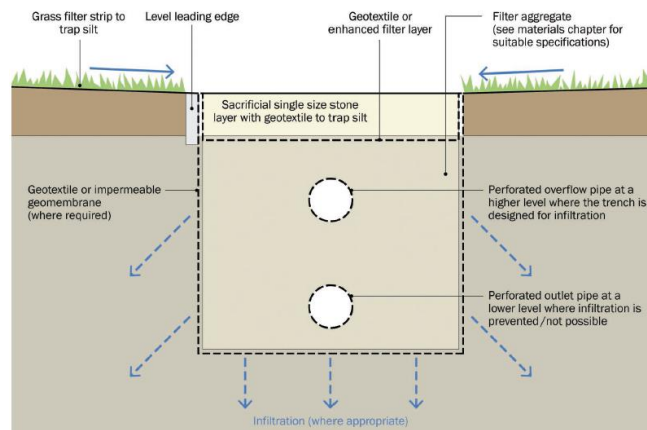


Figure 2-9: Layout of a typical filter drain (Source: CIRIA, 2015a).

The Construction Industry Research and Information Association (CIRIA) SUDS manual recommends that filter drains be used in conjunction with other pre-treatment measures to prevent sediment from clogging the system. A geotextile

layer can be used below the surface of the filter drain to trap sediment and certain pollutants, thereby, reducing the need for pre-treatment interventions (CIRIA, 2015a).

Filter drains are beneficial in attenuating stormwater runoff as well as in purifying the runoff to some degree. In addition, filter drains can potentially drain into the existing stormwater networks, which reduces the need for construction of new infrastructure to transport the runoff. Due to the variability in rainfall in South Africa, filter drains should be designed by incorporating inflow rates and volumes, which are typical of heavy rainfall events, i.e. a worst-case scenario. Ideal locations for filter drains include carparks and along roads, however, the CIRIA (2015) manual recommends that filter drains should not be placed on roads exceeding a gradient of 2 %.

#### 2.22.4 Gabion Baskets and Masonry Drop Works

Gabion baskets and masonry drop works, if correctly implemented, can be used to attenuate the flow within river systems. Gabion baskets consists of rectangular, galvanised wire cages which encloses stones. Masonry drops have been used in Japan enabling the restoration of river systems, as illustrated by **Figure 2-10**. Masonry drops consist of stones implemented across the river to create shallow pools and to re-create the slow and rapid portions, which are naturally occurring in rivers (Sasaki, 2016). This performs a similar function to a weir.

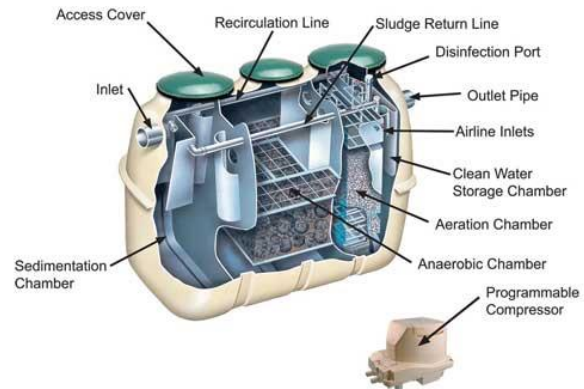


*Figure 2-10: An example of a masonry drop implemented along the Akechi River in Japan (Source: Sasaki, 2016).*

However, masonry drop works can be created from natural rocks found within the river system and it has, therefore, been termed a near natural restoration solution. Factors like the riverbed soil may affect the areas where masonry drops can be implemented. Therefore, a professional should be consulted (Sasaki, 2016).

### 2.22.5 Decentralized Wastewater Treatment Plants

Decentralized Wastewater Treatment Plants (DWWTP's), as illustrated by **Figure 2-11**, requires individuals to take care of their own wastewater. There are different types of DWWTP's available, which can be used on-site to treat wastewater (Cronje, 2016).



*Figure 2-11: Schematic of the Clarus Fusion WWTTP (Source: MaskamAfrica, 2016).*

DWWTP's are particularly suitable for installation within urban areas (Cronje, 2016). DWWTP's makes use of an Activated Sludge

Treatment system with nitrification and denitrification as integral parts of the treatment process, therefore, making it suitable for the treatment of both domestic and industrial wastewater. In addition, DWWTP's designed for urban areas have a small footprint and low electricity usage, making them ideal for residential properties.

The technology incorporated to treat the wastewater is the same as in large municipal activated sludge plants, mitigating any issues arising around sub-standard treatment. DWWTP's come in a variety of sizes. Initial construction and implementation costs of DWWTP's are comparatively higher than Centralized Wastewater Treatment Plants (CWWTP's) (Cronje, 2016).

### 2.23 The River Health Program in South Africa

The DWS is responsible for the water resources in South Africa. This includes ensuring that river systems are healthy enough to enable them to continue providing goods and services for future generations. In 1994, the DWS initiated a RHP (WRC, 2002). According to DWS, this programme provides information based on the assessment of the condition of biological communities in and around rivers. This assessment takes into account the fishes, aquatic invertebrates, riparian vegetation and river habitats.

Many factors influence the health of river systems. These factors include geomorphic characteristics, hydrological and hydraulic processes, chemical and physical water quality and the nature of the instream and riparian habitats. The RHP, however, has focused on assessing and analysing certain factors, which are good representations of the large eco-system (WRC, 2002).

### **2.23.1 River Health Indices and Monitoring Techniques**

A series of indices were used by the RHP to assess the health of rivers including the uMngeni River as well as some of the surrounding rivers (WRC, 2002). These are presented in the following sections.

#### **2.23.1.1 Water Quality Index**

The quality of water influences both the health of humans and the environment, therefore, the continuous monitoring of the resource provides invaluable information. The process of water quality monitoring involves the acquiring of samples of water, which are then analysed for specific parameters. The different municipalities take numerous samples along rivers, at pre-determined points, on a monthly basis and test these samples for microbiological, physical and chemical parameters (WRC, 2000). The EWS Pollution and Environment Branch together with the EWS GIS Department have translated eThekweni's water quality test results onto a map, which can be viewed on the EWS website. Every month the maps are updated with the latest test results, the rivers are colour coded according to the water quality status of the rivers (EWS, 2011). These maps are called Unicity River Quality Indices. These indices incorporate E.coli and organic loading, and are used to assess the effectiveness of the sanitation system in eThekweni (Fennemore, 2016). Variables which form are tested for in rivers include:

- E.coli counts.
- Turbidity.
- Conductivity.
- Nitrate percentages.
- Ammonia percentages.
- Total suspended solids.
- Total organic carbon (WRC, 2002).

#### **2.23.1.2 South African Scoring System**

This is a straightforward index, which is based on the aquatic invertebrates present along certain areas along a river. However, this only measures the macro invertebrates within the river and does not indicate whether the water is drinkable (miniSASS, 2016). From the South African Scoring System

(SASS) tool, the miniature South African Scoring System (miniSASS) tool was developed. miniSASS is a simple tool, which can be used by almost everyone to monitor the wellbeing of rivers. miniSASS observations are based on macro invertebrates. The presence or absence of macro invertebrates provides a good indication of the water quality. Macro invertebrates tend to live around vegetation in the river water or in the sediments along the riverbed (miniSASS, 2016).

The river is classified into categories ranging from natural conditions all the way to very poor conditions, according to the macro invertebrates present. The natural/good end of the category has hardly any changes in the in-stream and riparian habitats and biota. The eco-systems, which fall into these categories, are in good condition with the natural biodiversity unharmed. The categories at the lower end of the scale indicate that the river health has declined. Sensitive species may be lost. It also indicates that there is a decrease in habitat diversity and availability. Only resilient species remain. In addition, biota can sometimes no longer reproduce and alien species may have invaded the river and surrounding eco-systems (WRC, 2002).

#### **2.23.1.3 Index of Habitat Integrity**

The habitat integrity of a river system refers to the maintenance of a stable and integrated system of physio-chemical and habitual characteristics on both a spatial and temporal scale. This can then be compared to the characteristics of the natural habitats of the area (Kleynhans, 1996). The habitat integrity of an area is assessed from both an instream and riparian zone perspective (Kleynhans et al., 2008). The Index of Habitat Integrity (IHI) is a model, which was devised in order to assess how much an area has deviated from the reference conditions of the area. The IHI manual can be obtained from the DWS website.

#### **2.23.1.4 Riparian Zone Assessment**

The riparian zone provides a habitat for both aquatic and land animals. The riparian zone also plays a role in maintaining the form and structure of a river channel. It also acts as a filter for sediments, nutrients and light. The riparian zone may be altered or changed by factors including the removal of vegetation, cultivation, construction, erosion, sedimentation and invasion of alien plants in close proximity to the riparian zone (WRC, 2002).

The riparian health audit (RHA) is a manual, currently being finalised by the WRC, and can be used by citizen scientists, communities, non-governmental organizations (NGOs), local environmental authorities and landowners to assess the ecological health of an area (WRC, 2016).

The RHA is a simple yet effective tool, which can be used to identify, rate, report and monitor the impacts to streams and rivers on a basic level (WRC, 2016). The RHA, similar to the IHI, works on a scoring system. Impacts, along river systems are identified and rated based on the extent and severity. The ratings range from 0 – 5 and are representative of the percentage change of the area. The core difference between the rating system of the IHI and the RHA is that the rating of impacts in the IHI is weighted. The benefit of the RHA is that it can be used by anyone with basic knowledge of riparian ecosystems as opposed to the IHI, which requires individuals with experience in riparian ecosystems.

#### **2.23.1.5 Fish Assemblage Integrity Index**

Fish, in comparison, to most aquatic invertebrate have a relatively longer life span. Fish, therefore, are good indicators of the long-term conditions of a river system. A number of factors in this index can be used to categorise river health. These factors include the number of fish that occur in a certain area, the sensitivity of fishes to various forms of disturbances as well as factors, which account for the different size classes of fish. This index incorporates these characteristics of a fish to determine the degree to which these characteristics deviates from what would have been expected naturally, without influence from humans (WRC, 2002).

#### **2.23.1.6 Land Remote-Sensing Satellite Data**

Land Remote-Sensing Data (Landsat), whilst not used as part of the RHP monitoring techniques, provides valuable information as to land cover uses and changes over time. Numerous satellites provide remotely sensed images of the Earth at a variety of resolutions. Landsat represents Earth's longest, continuously acquired collection of space-based, moderate-resolution land remote sensing data (USGS, 2015). The data dates back to 1972, however, historic imagery such as this is available at resolutions of 60m. The Landsat imagery is particularly useful to individuals who work in agriculture, forestry, regional planning, education, mapping and global change research (USGS, 2015). Landsat imagery can be used to identify changes, which occur in riparian ecosystems over time. The red-green-blue (R-B-B) band combinations, which form the Landsat image, can be changed to highlight various factors such as water, vegetation and urban areas. Landsat imagery can be obtained from the United States Geological Survey (USGS) website and can be processed using different software, such as ArcMap, QGIS, Erdas Imagine and Panorama to name a few.

## 2.24 Summary

In order for humans to continue enjoying the environment and the resources it has to offer, humans need to live by the principles of sustainability. Over-exploitation of the natural resources will only result in these resources running out or being degraded. Thus, the balance between the social, economic and environmental components is critical. It is important to remember that humans cannot survive without the natural resources the environment provides, however, the environment can adapt and change as it did for millions of years. South Africa is a very bio-diverse country, however, much of its diversity is being lost to pollution and over exploitation, and this includes freshwater resources.

Freshwater is a resource, which is essential for the majority of life on Earth. It is one of the most important resources for humans as it is used in a variety of activities namely hydration, sanitation, industry and agriculture. Due to the lower levels of rainfall experienced in South Africa, when compared to the world's average, South Africa is classified as a water scarce country. The increased pollution and ageing infrastructure only serves to increase future pressures on the water resources, in particular rivers.

If the uMngeni River, being the most important river within the uMngeni Catchment, were continually prone to degradation, the foundation of the catchments water supply would be under great strain. In addition to the financial implications, the surrounding eco-systems will also be negatively affected. To ensure that the principles of sustainability are adhered to, future developments need to consider ecological infrastructure. The subsequent chapters will focus on how urbanisation has affected the ecological infrastructure within the Palmiet Catchment.

*“To waste, to destroy our natural resources, to skin and exhaust the land instead of using it so as to increase its usefulness, will result in undermining in the days of our children the very prosperity which we ought by right to hand down to them amplified and developed.” – Theodore Roosevelt*

## CHAPTER 3 : CASE STUDY

### 3.1 Introduction

This chapter serves to place the study into context by providing background information, relating to the Palmiet Catchment. A description of the Palmiet Catchment will be provided. In addition, the various sampling points along the Palmiet River will be stated placing the analysis, in **Chapter 5**, in context. A few of the prior pollution incidents, which have occurred along the Palmiet River, will also be discussed.

### 3.2 Focus of this Study

The demand for water in the uMngeni catchment has exceeded the available supply of water (SANBI, 2016b). However, not all the water present in rivers is available for use due to the high levels of pollution. The uMngeni River, which is the most important river in the uMngeni catchment, is also one of the most polluted rivers in the country (Carnie, 2013). The high levels of pollution in the uMngeni River is an accumulation of the pollutants present within its tributaries. Therefore, no matter how small the river, pollutants within it may travel downstream and affect larger rivers.

For the purpose of this study, focus will be on the Palmiet River, a tributary of the uMngeni River. The Palmiet River flows alongside residential and industrial areas as well as informal settlements and these have major impacts on the river. In addition to this, the roads, stormwater and sewer networks, present within the Palmiet Catchment, is hypothesized to have an effect on the river.

### 3.3 Study Area

The Palmiet River is situated in the eThekweni 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. The remainder of the river is bordered by factories, built-up areas as well as 10 informal settlement.

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 encompasses both the high and middle-income categories. Low-income areas consist of the informal settlements. 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, Ecca 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. Each stream plays a role in the pollution present within the Palmiet River. In assessing the condition of the Palmiet River, it is also vital to investigate its major tributaries. **Figure 3-1** illustrates the extent of the Palmiet River as well as its numerous tributaries. The red lines represent 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.

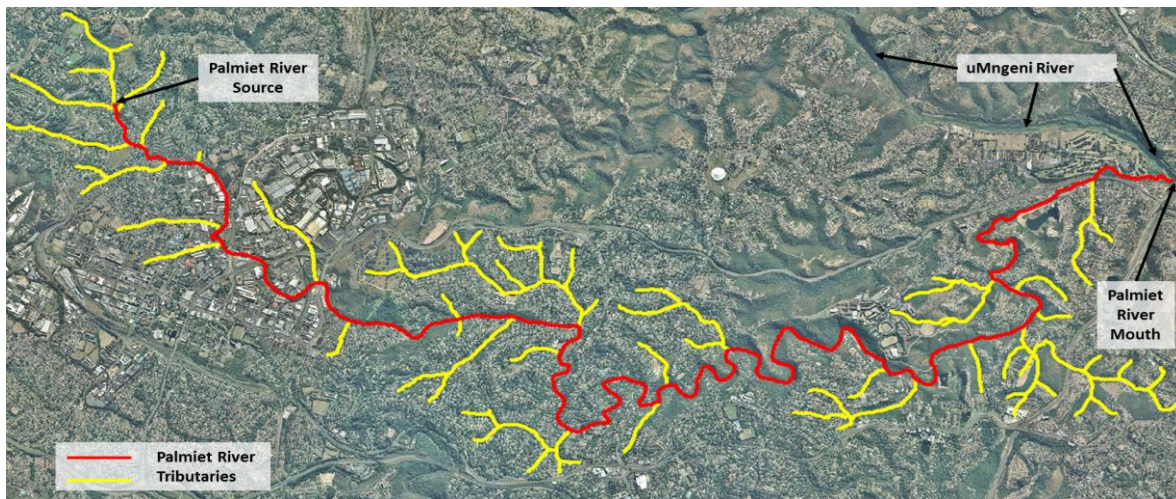


Figure 3-1: Tributaries of the Palmiet River.

### 3.4 Areas of Impact along the Palmiet River

The Palmiet River is used by a variety of people. Its uses range from recreational activities to satisfying the basic needs of people. Rivers are usually impacted by their surroundings and the Palmiet River being no exception. Along its course, the Palmiet River flows through residential and industrial areas, informal settlements, recreational facilities as well as conservation areas. **Figure 3-2** illustrates the course of the Palmiet River from its source down to the Westville North residential area. **Figure 3-3** 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.

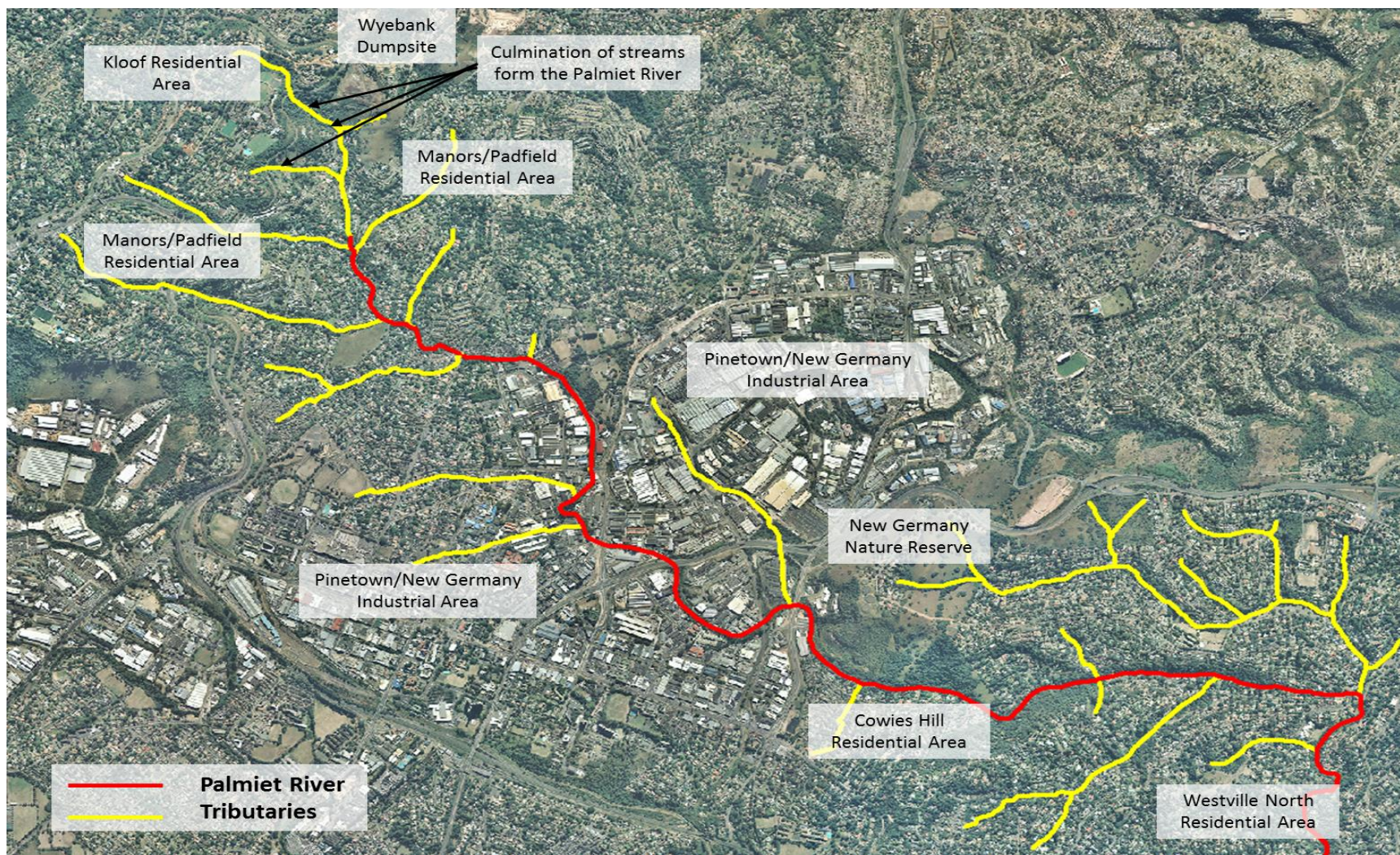


Figure 3-2: Palmiet River course from its source to the Westville North residential area.

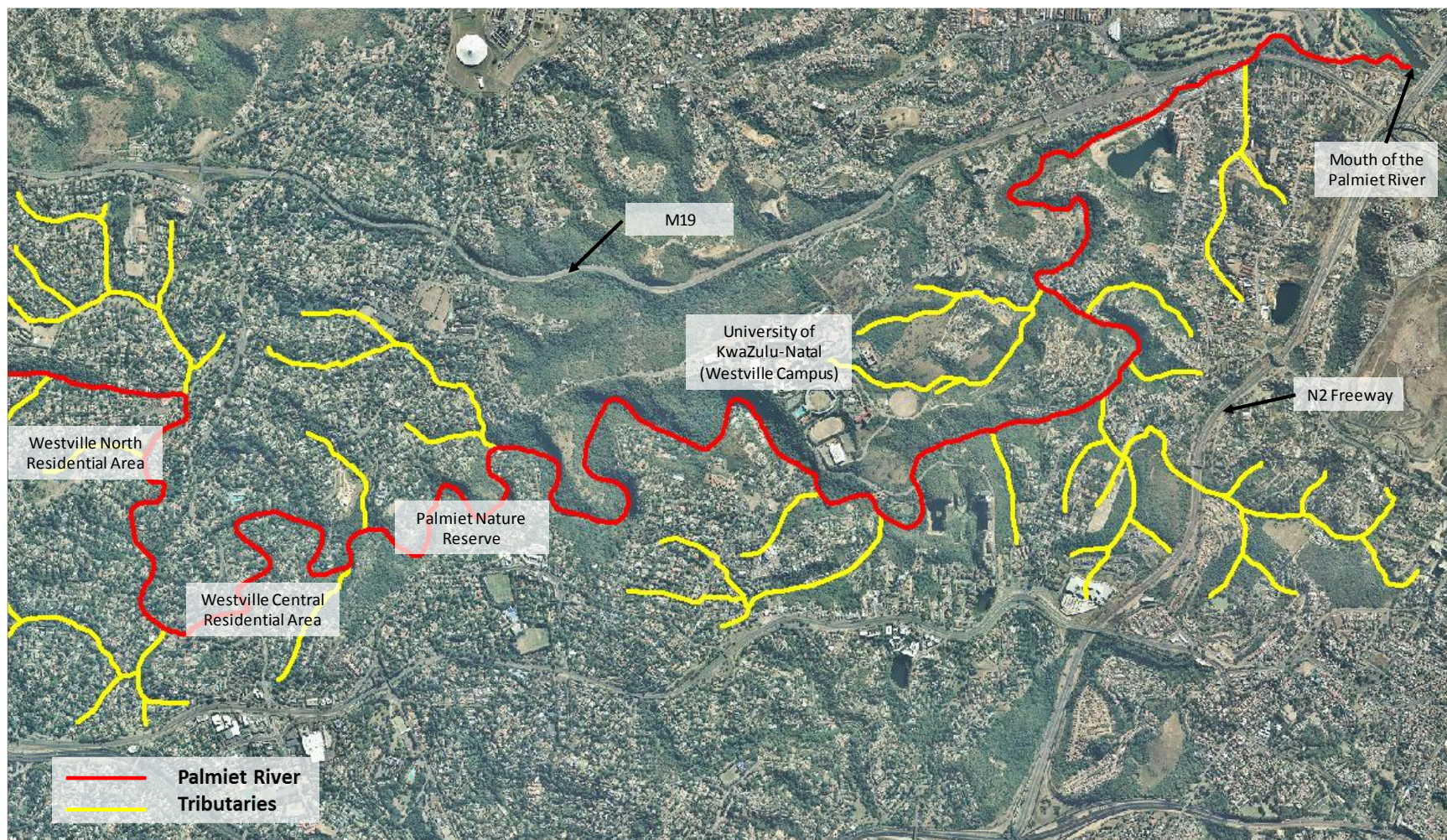


Figure 3-3: Palmiet River course from the Westville North residential area to its source at uMngeni River.

### 3.5 Rainfall in the Palmiet Catchment

Rainfall data obtained from the eThekweni Municipality was recorded at the stations present on Dunkeld Road and Kennedy Road. **Figure 3-4** illustrates the location of these 2 stations, within the Palmiet Catchment, in relation to the Palmiet River.



Figure 3-4: Location of the Dunkeld Road and Kennedy Road rainfall stations in relation to the Palmiet River (Source: Google Earth, 2016).

Dunkeld Road station is located about 2,2 km away from the Palmiet River and Kennedy Road station is located about 1,3 km away from the Palmiet River. Both these stations lie within the Palmiet Catchment, however, they are located closer to tributaries of the Palmiet River. Further details concerning the rainfall within the Palmiet Catchment will be discussed in **Chapter 5**.

### 3.6 Prior Pollution Incidents Recorded in the Palmiet River

According to the Palmiet River Watch (PRW), headed by Lee D'Eathe, the 8 significant causes of environmental degradation within the Palmiet catchment area are:

- Industrial Pollution – This is concentrated around the Pinetown industrial area.
- Sewage Pollution – This is due to illegal discharge of sewage as well as burst and overflowing sewage pipes and drains. Another contributing factor is the ageing infrastructure, which is improperly maintained.
- Waste Disposal – This is of particular concern in the informal settlements on Palmiet and Quarry Road as well as the Wyebank Municipal Disposal site.
- Freshwater pipe bursts – Excessive water in the soil can lead to the erosion of the riverbanks and increases the pollutants transported into a river system by runoff.

- Alien invasive plants and animals – This is a concern along the length of the river as these alien species out-compete the existing species for the natural resources.
- Land fragmentation – The increase in urbanization has resulted in the natural land being divided into separate fragments, each fragment cut off from the other, resulting in a significant loss in biodiversity.
- Riverbed and bank scouring – Scouring action reduces the loss of downstream habitats, destroys the riparian zone and decreases the water quality in rivers.
- Poor application of legislation – There are many laws and regulations in place, however, when it comes to the implementation of them, South Africa is falling short (D'Eathe, 2016).

**Figure 3-5** illustrates some of the previous pollution incidents, which have affected the Palmiet River. The arrowheads indicating the location along the river of the pollution events in **Figure 3-5**, do not indicate that the pollution is confined to that area, but illustrate the areas where the photos were taken. The pollution would have a more widespread effect, both upstream and downstream of the points indicated in **Figure 3-5**. Descriptions of these pollution events, presented in **Appendix B**, were obtained from articles published in the Highway Mail as well as notifications from the PRW. These describe some of the numerous impacts on the Palmiet River, caused by the increase in urbanisation and human ignorance. **Table 3-1** presents the number of pollution incidents reported in the year 2016 by members of the PRW from January to November.

*Table 3-1: Pollution incidents recorded by members of the PRW during the year 2016 (Source: D'Eathe, 2016)*

Month	Count
January	10
February	8
March	10
April	20
May	8
June	9
July	11
August	13
September	8
October	8
November	10
<b>Average</b>	<b>10.45</b>

The Highway Mail is a weekly community newspaper distributed to the Westville, New Germany, Pinetown and Cowies Hill area. The PRW consists of a group of individuals who live/work alongside the Palmiet River, and its associated tributaries, and are constantly on the lookout for pollution within the river.



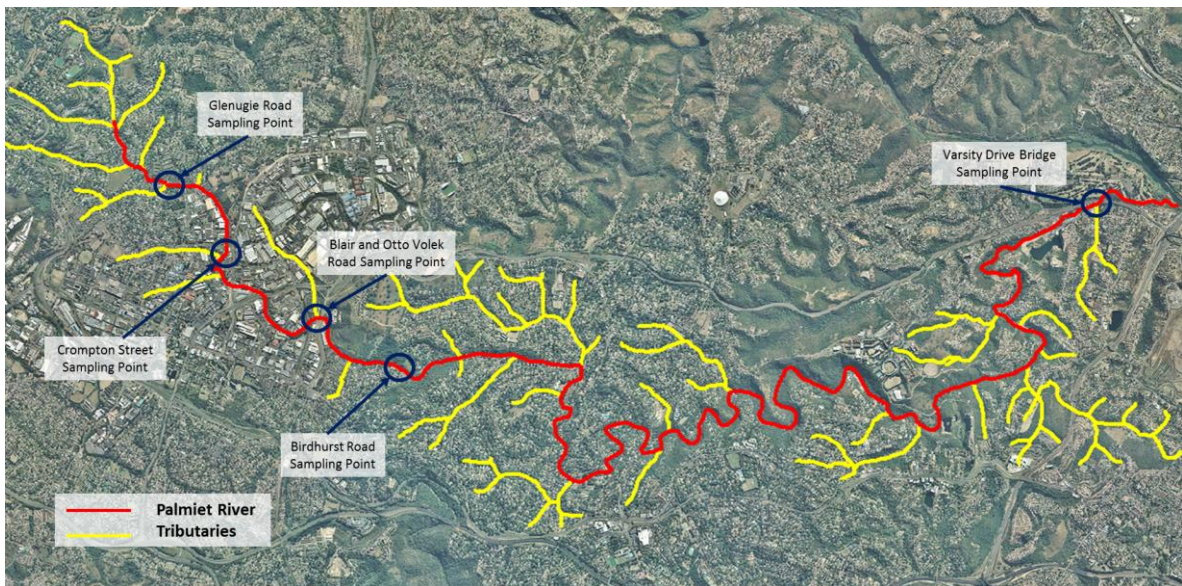
Figure 3-5: Previous pollution incidents in the Palmiet River.

### 3.7 River Monitoring

As detailed in **Chapter 2**, there are a variety of techniques, which are used to monitor river systems. With regards to the Palmiet River, the EWS samples the river at 5 points every month and miniSASS sampling is done on a yearly basis.

#### 3.7.1 Unicity River Quality Indices

The EWS, Pollution and Environment branch, samples the Palmiet River on a monthly basis. **Figure 3-6** indicates the points along the Palmiet River, which are sampled.



*Figure 3-6: Location of the sampling points undertaken by the EWS, Pollution and Environment branch.*

The sampling points are based on two factors namely points of interest and ease of accessibility. Thus, the Pollution and Environment branch has sampled the river at 5 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 (otherwise known as permanganate value after 4 hours/ PV4). The EWS, however, is primarily concerned with the efficiency of eThekwiní's sanitation system. Therefore, the Unicity River Quality Indices, published on the EWS website, incorporates only two of the variables tested i.e. organic loading and E.coli. These indices are made available to the public on the EWS website. Two randomly chosen Unicity River Quality Indices have been included in **Appendix C** to provide an idea as to what the indices are.

The points along the Palmiet River, sampled by the EWS, correspond to the points on the Unicity maps where the river water quality changes. EWS has extrapolated the results at the 5 sampling

points in order to produce an overall water quality for that section of the river course. However, this extrapolation of results does not yield an accurate estimate of the water quality for that section of the river. Pollution incidents in-between the sampling points would not be recorded on the Unicity River Quality Indices. As such, the EWS is working on a prototype for a new index, which will incorporate 7 years of historic data to provide a better indication of the water quality in the Palmiet River.

The Unicity River Quality Indices were implemented in 2010 and an analysis of all the indices yielded that the Palmiet River fluctuated between acceptable and poor standards. A full set of Unicity River Quality Indices dating back to 2010 can be obtained from the EWS website under “River Quality”. Further details regarding the chemical and biological water quality of the Palmiet River will be explored in *Chapter 5*.

### 3.7.2 miniSASS Observations

In South Africa, the miniSASS system has been devised to incorporate macro invertebrates as indicators to analyse the health of rivers. Using this system, the river is classified into 5 categories depending on its overall score, which is based on the macro invertebrate indicators. **Table 3-2** illustrates the 5 classes a river can be categorized into. The score limits present in **Table 3-2** are that of a rocky river, however, there are also limits for a sandy river, which differ slightly.

*Table 3-2: miniSASS score limits for rocky rivers (Source: miniSASS, 2016).*

Score	Description	Colour
>7.2	Natural	BLUE
6.2 – 7.2	Good	GREEN
5.7 – 6.1	Fair	YELLOW
5.3 – 5.6	Poor	RED
<5.3	Very Poor	PURPLE

**Figure 3-7** illustrates the location of the observation points along the Palmiet River. The miniSASS sampling has been done along the river at various points where there has been a change in the land use. In addition, areas, which were monitored and found to have recurring pollution incidents, were also sampled by members of the PRW.

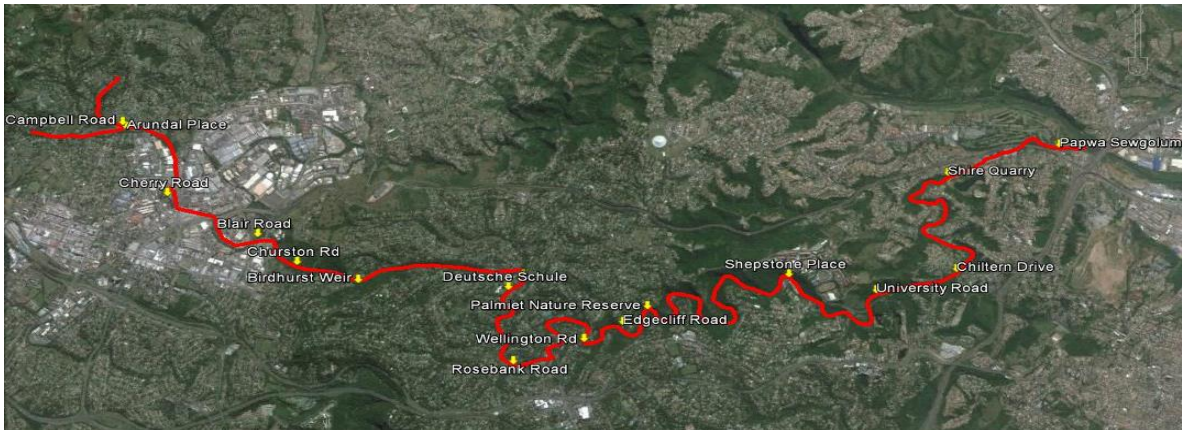


Figure 3-7: Location of the existing miniSASS sampling points.

Analysis and representation of the miniSASS observational data will be presented in **Chapter 5**.

### 3.8 The Palmiet Nature Reserve

The Palmiet Nature Reserve (PNR) is located in the centre of Westville, a suburb of the eThekweni Municipality, and is a municipal reserve which was established in 1972 (Cottrell, 1978). Both the PNR and the Palmiet River have their names derived from *Prionium Serratum*, a riverine plant. However, due to the negative impacts inflicted upon the reserve, the *Prionium Serratum* plant has disappeared. The Palmiet Rivers meanders through the PNR, which comprises of a large variety of flora and fauna (PNR, 2013).

#### 3.8.1 Flora and Fauna

The Palmiet River is a popular sightseeing spot primarily due to its diversity and scenery. There are currently in excess of 170 tree species within the reserve (PNR, 2013). In addition to the large variety of indigenous flora, there are also high numbers of invasive alien plants present within the reserve (PNR, 2013).

Mammal species are in the minority within the reserve and they are rarely seen. In the past, there have been significant damages to the habitats of the mammals and many of them were poached, which has resulted in limited number of mammal species present. In contrast to the number of mammals, there is a large variety of insects, frogs and reptiles present within the Palmiet Nature Reserve including an abundance of snakes and lizards. In addition to the land and aquatic animals, there are large varieties of bird species habiting the reserve, according to PNR (2013) there are over 150 different bird species.

### 3.8.2 Threats to the Palmiet Nature Reserve

The reserve is in an urban area, therefore, there have been many impacts, which have befallen the reserve and has reduced its biodiversity and health:

- African herbalists use the variety of plants and trees species for medicinal purposes i.e. bark and roots are removed to make traditional medicines.
- Domestic dogs have been sighted within the reserve disturbing the wildlife.
- Increasing development of the surrounding properties infringe on the boundaries of the reserve and can increase the pollution within the reserve.
- There has been vandalism of signs and noticeboards (PNR, 2013).

### 3.9 Summary

The Palmiet River represents a mere 0.63 % of the rivers within eThekweni, however, the sources of environmental degradation are affecting river systems all over the world. Along its course, the Palmiet River runs through residential areas, industrial areas and informal settlements all of which have an impact on the river and the surrounding eco-systems.

It is evident from the prior pollution incidents that the quality of the Palmiet River is at poor standards. However, the degradation within the Palmiet Catchment cannot be truly encapsulate by presenting prior pollution incidents. Therefore, this particular study explores the sources, which have contributed, to the degradation of the Palmiet River water quality, riparian zone and aquatic life by investigating the impact of the surrounding infrastructure on the Palmiet River and its riparian zone.

*“Water and air, the two essential fluids on which all life depends, have become global garbage cans.” – Jacques-Yves Cousteau*

## CHAPTER 4 : METHODOLOGY

### 4.1 Introduction

This chapter presents the methodological framework used for this study and provides the foundation on which data was collected and analysed, resulting in conclusions being drawn. This chapter will provide insight on the various research approaches, the method of obtaining results and drawing conclusions, as well as uncertainties and limitations to the study. A detailed inventory of the impacts imposed on the Palmiet River by the surrounding infrastructure was possible by the use of GIS Software, which proved to be crucial for this study.

### 4.2 Research Approaches

In order to undertake this study, and achieve the aims and objectives set, two research approaches were adopted, namely a theoretical approach and a case study approach. Both the theoretical and case study approaches were critical in answering the research question, presented in *Chapter 1*.

#### 4.2.1 Theoretical Approach

The theoretical approach examines the research topic by analysing the various information available in the existing literature. In particular, this approach is important in providing a background to this particular study. The literature review is a key component in the theoretical approach. Various information relating to the wider study area, obtained from journals, books, reports and websites, was summarized in the literature review. This is critical as it provides the reader with an understanding of the key concepts and definitions relating to the study. Concepts including the built environment, the natural environment, sustainable development and impacts on the environment, in particular freshwater resources and rivers, have been summarized and compiled into the Literature Review.

#### 4.2.2 Case Study Approach

The built environment has significant negative consequences for the natural environment, with pollution being one of the leading impacts. The case study approach places the study into context by providing the reader with an understanding of the Palmiet River, its source, course and mouth as well as the various areas, which it passes through. Along its course, the Palmiet River flows through

and around many different types of infrastructure, including roads, factories, residential properties and schools, with each impacting the river in a different way.

### **4.3 Overall Methodological Approach**

Prior to the undertaking of this research project, a research proposal was drafted and submitted for approval. The research proposal contains details relating to the motivation for undertaking this study as well as the aims and objectives required to successfully complete the study. After approval of the project proposal, research was initiated in order to accumulate relevant information for **Chapter 2**. Upon completion, **Chapter 3**, the Case Study Chapter, was undertaken. The Case Study Chapter represents a critical component in the research project as it provides an insight into the scope of the study and provides detailed information placing the study in context.

Landsat data was used to provide an indication of the increase in urbanisation of the Palmiet Catchment, thus, providing a context for the undertaking of the research. A short analysis of the rainfall, within the Palmiet Catchment has been provided to investigate whether it is the source of the increased high flows and increased scouring ability of the river. Chemical and microbiological sample results as well as miniSASS observational results were assessed and conclusions drawn on problem areas and the source of the water quality problems. Subsequently, an inventory, of the impacts imposed on the Palmiet River by the surrounding infrastructure, was produced by two methods. The first method involved observational data and numerous walks along the Palmiet River, the second method involved the representation of the impacts on maps using GIS software and Microsoft Excel. Compilation of the impacts along the course of the Palmiet River resulted in suggestions of potential recommendations, relating to the improvement of this study as well as further studies.

### **4.4 Defining the Scope of the Study**

This project forms part of the larger uMngeni Ecological Infrastructure Project (UEIP) which looks at how investing into the natural environment as opposed to the built environment can improve the conditions of the uMngeni Catchment in terms of water quality as well as the surrounding environment. The scope of this particular study is narrowed to the Palmiet River, a tributary of the greater uMngeni River.

The target audience for this study is made up of engineers, involved in the designing of infrastructure (for example, roads, pump stations, sewer lines), environmental authorities, environmental planners, municipal officials as well as members of the community who want to take pro-active steps in bettering the conditions of the Palmiet catchment.

## 4.5 Data Collection

Initially a variety of literature, relating to the built and natural environment, was collected and summarized using search engines, including Science Direct and Google Scholar. This information was then collated and compiled into a literature review.

Further data was required to produce a comprehensive case study on the Palmiet River. Rainfall stations as well as sampling points along the data were some of the information collected. 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 eThekweni Municipality, as well as rainfall data, for the Palmiet River catchment, was obtained directly from the eThekweni Municipality website.

miniSASS observational data were obtained from the miniSASS website. miniSASS results were a key component as they incorporated the health of macro invertebrates into the river health score as opposed to the chemical and microbiological testing, which only analysed the water composition.

The recording of the impacts on GIS required the use of certain existing shape-files, which were obtained from the eThekweni Municipality Photogrammetry Department as well as the Environmental Planning and Climate Protection Department (EPCPD). Historic data which was used to illustrate the land cover changes were obtained from Landsat 1-3 Multi-Spectral Scanner (MSS), Landsat 4-5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 Operational Land Manager (OLI).

A core component of the data collection process was walking along the Palmiet River. Throughout June, July, August and September 2016 different sections of the Palmiet River, and surrounding streams, were walked. During these walks, impacts imposed on the river and its riparian zone, were recorded on data record sheets. In addition to getting information relating to the current well-being

of the Palmiet Catchment, these walks were critical in analysing the areas that needed immediate attention.

#### 4.5.1 Data Record Sheets

Data record sheets were used to accurately record impacts, along the Palmiet River and its riparian zone, observed on the river walks. The data record sheets were devised after analysing the IHI as well as a final draft RHA produced by the WRC and obtained through a personal communication. However, analysis of these documents revealed that both the IHI as well as the RHA are primarily focused on rural, undeveloped areas where there are greater impacts from agricultural activities. Therefore, further research into the impacts from urbanisation, on rivers, was conducted. Thus, an impact list was devised, similar to the one found in the IHI as well as the RHA, with adjustments made to include variables causing impacts from an urban environment. The following descriptions provides a key to the data collection sheet, illustrated by **Figure 4-1**. The numbered descriptions correspond to the numbers on the data record sheet. The entire set of data record sheets have been included on the attached **DVD**. The following descriptions correspond to the numbering on **Figure 4-1**.

**[1]** – Describes the area being observed relative to the waypoints/observation points. The section of the river covered by Units 2-7 have been divided into waypoints, however, Unit 1 consists of a number of observation points due to the lack of accessibility. The distance between each waypoint is generally 200 m, however, this may vary due to accessibility problems.

**[2]** – Latitude and longitude co-ordinates at each waypoint/observation point. Listed with the upstream waypoint/observation point co-ordinate first followed by the downstream waypoint/observation point co-ordinate.

**\*[3]** – A list of potential impacts affecting the state of the Palmiet River and its riparian zone. This has been adapted from the IHI and RHA, both these documents were briefly described in **Chapter 2**. Additional impacts have been added to account for additional impacts observed within the Palmiet Catchment.

**\*[4]** – Potential causes which apply to the respective impacts. Causes may have multiple impacts and have been repeated in the appropriate areas. Causes have been identified and listed after reviewing the relevant literature as well as visual observations in the Palmiet Catchment.

Inaccessible, unexplored areas may produce additional causes, which have not been recorded, and the data collection sheet should be continuously updated if used in further studies.

**[5]** – Instream and riparian check boxes have been included to indicate whether the impacts affect the instream area, riparian area or both.

**[6]** – Rating system to identify the varying degrees of degradation, in-between each waypoint/or at an observation point, along the observed units of the Palmet River and its riparian zone.

**[7]** – Total score provides an overall ecological condition of the area observed and results have been tabulated in **Chapter 5**. The greater the overall score, the greater the deviation from natural conditions.

**[8]** – Comment boxes have been included to describe the section, between each waypoint or at an observation point, in greater detail and provides extra information where applicable.

**[9]** – States the surrounding land use.

\*Please note, the impacts stated, whilst some may be applicable to all catchments, have been included as they are particularly applicable to urbanised catchments. The causes stated also specifically apply to the Palmet Catchment and may not always be applicable to other catchments, urbanised or not. Therefore, should a data record sheet such as this be used to assess other catchments, adaptations should be made where necessary.

Waypoint: <b>1</b>	CA17-CA16	Latitude: 29°48'5.32"S - 29°48'6.07"S	<b>2</b>	Longitude: 30°51'58.01"E - 30°52'5.13"E
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3	4 RIVER/STREAM CONDITION			6
	5	5	5	
IMPACTS	CAUSES	Riparian	Instream	RATING
Indigenous Vegetation Removal	Buildings, Parks, Sports Fields, Parking Storage Areas Agriculture, Hiking Paths, Roads Walkways, Fencing/Service syst Cementation of banks, Railway Lines, Sand Mining, Dumpsite	X	X	4 / 5
Exotic Vegetation	Alien Plants, Household Gardens, Commercial Crops	X	X	5 / 5
Bank Erosion	Hiking Paths, Roads, Railway Lines, Freshwater Pipe Bursts Stormwater Outlets, Runoff, Increased Flow Hardened Surfaces, Absence of Shrubs, Excavation Alien Vegetation, Stormwater Manholes, Sewer Manholes	X	X	3 / 5
Channel Modification	Bridges, Driveways, Culverts, Piping of Rive, Gabion Baskets Channelization, Obstructions, Reduced Bank Vegetation Widening of Channel, Erosion of Soil, Impoundment, Wetland	X	X	4 / 5
Water Abstraction	Boreholes, Irrigation, Domestic Use, Dam	X	X	0 / 5
Inundation	Weir, Dam, Lake, Pond	X	X	0 / 5
Flow Modification	Wetlands, Marshes, Runoff, Gabion Mattresses, Weir Gabion Baskets, Stormwater Outlet, Sewer Overflow Pipe Scour Valve, Dam, Pond, Lake, Alien Vegetation, Obstructions Overflowing of Reservoirs, Freshwater Pipelines, Channelization	X	X	3 / 5
Bed Modification	Changes in Flow, Removal of Bed Material, Sedimentation Stabilization of Bed Material	X	X	2.5 / 5
Water Quality	Stormwater Outlet, Sewer Overflow Pipe, Sewer Pump Station Runoff from Surroundings, Excess Sediment, Colour Change Rubbish Dumping, Wetland, Sewer Manhole, Stormwater Manhole	X	X	4 / 5
Rubbish Dumping	Building Rubble, Garden Refuse, Solid Waste	X	X	4 / 5

Total 29.5 / 50  
\*Lower scores are better **7**

<b>9</b>	Land Use: Housing complexes, Factories
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<b>8</b>	<p>Comments:</p> <p>A stream which joins the Palmet River about 70m upstream from Waypoint CA16 has been polluted by sewage. The water has a black colour with a faint odour coming from it. There has been excessive dumping in this section. In the river channel there are many obstructions which reduce the width of the channel. The sewer line is still running along the river. Looking downstream, the Palmet River is bordered on the right hand side by factories and on the left hand bank by housing complexes.</p>
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\* 1. The impact ratings present in the adjacent table were used to produce Figures 5. to 5. present in Chapter 5.  
Figure 4-1: Sample data collection sheet.

In addition to the recording of 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. The IHI, is a tool designed for professional users with hands-on experience in their particular field, as such, the rating system used in the RHA was 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. The ecological category scores are:

- 0 : Natural
- 0.5-1 : Good
- 1.5-2 : Fair
- 2.5-3 : Poor
- 3.5-4 : Very Poor
- 4.5-5 : Critical

Whilst the ratings may be debatable, with different assessors having slightly differences in the scores, the underlying identification of problem areas along the Palmiet River, its tributaries and the riparian zone cannot be disputed. The scoring system is used as a means of identifying critical areas requiring immediate attention. The following is a brief overview of how each impact was rated. An illustrative guideline pertaining to the scoring of the impacts can be found in **Appendix D**.

- Indigenous Vegetation Removal – Based on how much of the natural vegetation has been removed, altered or replaced by built infrastructure. It was assumed that prior to urbanisation, the entire area consisted of vegetation.
- Exotic Vegetation – Based on the amount of exotic vegetation within each reach, i.e. the distance between each waypoint. Isolated growths of alien vegetation being on the lower end of the scoring system whilst alien vegetation, which covers a large extent in-between each waypoint, occupying the higher end of the scoring system.

- Bank Erosion – Based on the extent and severity of the erosion. Isolated small sections have been rated on the lower end of the scoring system whilst areas, which lose substantial ground after every rainfall event, have been rated on the higher end of the scale.
- Channel Modification – Primarily based on the extent to which the channel has been modified. For example, gabion baskets over a short distance on one bank as opposed to cemented walls along both banks extending from one waypoint to the other.
- Water Abstraction - There has only been one minor case where water has been abstracted to fill the Dam within the New Germany Nature Reserve.
- Inundation - There has only been one case where the riparian zone has been flooded. The terrestrial eco-system changed into an aquatic eco-system.
- Flow Modification – Based on how much the different factors, within each reach, contributes to the overall flow modification.
- Bed Modification - Bed modification has been rated based on two primary factors, i.e. the introduction of foreign bed material and the removal of the existing bed material exposing bedrock. Therefore, the rating for bed removal has been based on the extent at which the riverbed has been modified. According to the methodology employed to carry out miniSASS observations, the Palmiet River is classified as a rocky river. This indicates that it has rock outcrops as opposed to a solely sandy riverbed. However, this does not indicate that the exposure of bedrock is a natural occurrence along the riverbed (D'Eathe, 2016).
- Water Quality – Based on how significantly each factor within the reach contributes to the overall pollution of that reach.
- Rubbish Dumping – Based on the severity, extent and occurrence of the rubbish dumping.

After each river walk, any new factors, influencing the natural condition of the Palmiet River and its riparian zone, were included on 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.

## 4.6 Data Analysis

A variety of data was analysed and discussed in *Chapter 5*. The data was analysed with regards to time and position. *Chapter 5* initially begins with an analysis of Landsat imagery for the entire catchment, which dates back to 1975. Thereafter, the rainfall within the Palmiet Catchment was investigated, from the year 2010 to 2015. Chemical and microbiological test results, dating back to 2007, were then analysed. Following this, an analysis was conducted on the miniSASS observational data, dating back to 2013, at the variety of sampling points along the course of the Palmiet River. The results culminated in a current impact assessment along the accessible areas of the Palmiet River.

### 4.6.1 Land Cover Analysis

Individual bands from the Landsat data, for the years 1975, 1985, 1995, 2006, 2015 and 2016, acquired through the USGS website was stacked using Erdas Imagine 2016 in order to compile a composite image for each of the years mentioned above. Erdas Imagine software was chosen over Arcmap for its image processing capabilities. Care was taken to select images from the same month at 10 year intervals, however, due to certain factors like cloud factor, this was not always possible.

The various land classes within each year were then identified. For the purpose of this study, to illustrate the increase in urbanisation, two classes were identified. The first being “Urban” and the second class being “Natural”. The “Urban” class comprises of all buildings, roads, infrastructure and hardened surfaces throughout the Palmiet Catchment. In addition, sports fields have also been included in the “Urban” class due to their hardened surface. The “Natural” class comprises of the vegetation, water and bare soil. The Signature Editor Tool in Erdas Imagine was used to create each class.

A supervised classification method was used to classify the Palmiet Catchment. This requires the user to draw polygons encompassing areas from both the above-mentioned classes. The area encompassed consists of differently coloured pixels, by changing RGB band combinations, different areas can be highlighted. Numerous polygons were drawn for each class in order to increase the accuracy of the results. Imagery from Landsat 8 OLI and Landsat 4-5 TM had a resolution of 30 m, however, imagery from Landsat 1- 3 MSS had a resolution of 60 m. Therefore, care needed to be taken when drawing the polygons to ensure that they did not encompass pixels from another class.

On completion of the polygons, the Maximum Likelihood Algorithm was run in order to classify the Palmiet for the years previously stated. The classified images are presented in **Chapter 5**. The “Urban” class is represented in red and the “Natural” class is represented in green in the images presented in **Chapter 5**. In order to check the accuracy of each of the classified images, an accuracy check was performed on Erdas Imagine, which yielded the results presented in **Table 4-1**. The images were iterated a number of times to produce results at acceptable accuracy levels.

*Table 4-1: Accuracy assessment of the land cover maps.*

Year	1975	1985	1995	2006	2016
Overall Accuracy [%]	87.50	81.25	94.44	94.45	85.00
K	0.7778	0.6471	0.8889	0.9091	0.7000

An accuracy assessment compares two variables:

- Pixels or polygons from a classified map obtained from remote sensing data
- Groundtruth test information (Jensen, 2005).

In order to compute an accuracy assessment report, control points needed to be defined. For the 2016 image, groundtruthing was conducted on the numerous river walks and these points were used as control points. However, for the previous years, groundtruthing was not possible. Therefore, control points were defined from aerial photographs and other imagery of the area, which was obtained from the Surveyor Generals Office. These control points were randomly chosen and are used to verify that each pixel in the image has been correctly classified. The K statistic is a measure of how well each classified image compares with the input reference data. A strong agreement occurs when K is greater than 0.80, a moderate agreement occurs when K ranges from 0.4 to 0.8 and a poor agreement occurs when K is less than 0.4 (Jensen, 2005).

#### **4.6.1.1 Limitations**

- The vegetation present on Landsat images are affected by the seasons, care was taken to obtain images from the same month each year, however, this was not always possible due to factors like excessive cloud cover.

- The resolution of the images ranges from 30 m to 60 m, which plays a part in the accuracy of the results. Pan-sharpening bands were not available on the Landsat 4-5 TM and Landsat 1-3 MSS images. It is recommended that should further investigation be conducted on the land cover within the Palmiet Catchment, World View Imagery should be obtained due to its improved resolution, however, these images come at a cost.

#### 4.6.2 Rainfall Data

Rainfall data, obtained from the eThekweni Municipality website, was summarized and the monthly rainfall depth, in mm, was presented on excel graphs in **Chapter 5**. Rainfall data were obtained from the two stations within the Palmiet catchment namely, the Dunkeld Road station and the Kennedy Road Station. In addition to monthly rainfall data, annual rainfall data from 2010 to 2015 was also computed and mean values found. The impact of the rainfall trends, within the Palmiet Catchment, have also been investigated.

#### 4.6.3 Analysis of Microbiological and Chemical Testing

EWS is primarily concerned with the effectiveness of South Africa’s sanitation system, therefore, organic loading and E.coli were the key variables assessed as they could provide an indication 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. Increased soil particles in the water because of erosion may contribute to increased turbidity results. Turbidity results can be traced to bank erosion, which can be attributed to the increased scouring force of the Palmiet River. **Table 4-2** presents the thresholds for E.coli and organic loading which is used by the EWS on the Unicity River Quality Indices.

Table 4-2: EWS thresholds for E.coli and organic loading (Source: EWS, 2016).

Category	E.coli [cfu/100ml]	Organic loading (PV4) [mg/l]
Ideal	0 – 400	0 – 2
Acceptable	400 – 2 000	2 – 5
Poor	2000 – 10 000	5 – 8
Critical	>10 000	>8

#### 4.6.3.1 Limitations to the Chemical and Microbiological Results

- The composition of the Palmet River continually changes, therefore, chemical and microbiological testing can only be used as a short-term indication of water quality.
- There have only been 5 sampling points along the river, ideally more points will allow for the improved identification of problem areas.
- Often pollution incidents, which occur after the EWS sampling, would often not be reflected in the following months sampling results.

#### 4.6.4 miniSASS

In order to measure the well-being of a river, the health of the organisms also needs to be taken into account, the importance of which has been detailed in **Chapter 2**. miniSASS is a tool, which measures the health of a river by focusing specifically on the macro invertebrates residing in it. In addition to providing information, miniSASS is a tool that promotes education regarding rivers and allows everyone, irrespective of their age, to get involved and help in some way to rectify the current water situation (miniSASS, 2016). Further information relating to miniSASS has been provided in **Appendix A**.

miniSASS results obtained from 2014, 2015 and 2016 were plotted on graphs using Microsoft Excel. The mean values were then computed and categorized according to the miniSASS score limits. The different macro invertebrates present during the miniSASS samplings were analysed and the meaning behind the presence of the different macro invertebrates were analysed.

##### 4.6.4.1 Limitations to the miniSASS Results

- The majority of samplings done in a year were done in the same month. The sampling months were not consistent from 2013 to 2016. Therefore, seasonal variations may affect the numbers of invertebrates present in the river when comparing scores over the years.
- There may also be alien animal species present in the river, which can potentially affect the numbers of macro invertebrates present.
- miniSASS results are not an indication of drinking water quality, chemical and microbiological analyses still need to be done.

- miniSASS is a good sampling method to use in rural areas, which are not heavily populated and dominated by sanitation issues, however, it is inadvisable to use in highly urbanised areas such as the Palmiet Catchment according to a member of the EWS.
- miniSASS results are an indication of the long-term water quality, therefore, pollution events are not immediately reflective in the miniSASS results.

#### **4.6.5 River Walks**

The area directly adjacent to river and stream banks are termed riparian areas. The recording of impacts have been devised to incorporate both impacts to the river as well as the riparian zone. These areas play an important part in maintaining the functionality of the rivers and streams. A core part of recording the impacts, imposed by the surrounding infrastructure, was the river walks. The process for walking the river was adopted from the procedure followed by the Duzi-uMngeni Conservation Trust (DUCT), therefore, the following steps were taken:

1. The Palmiet River was divided into 7 different units based on the land use. The different units are as follows:
  - 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 have been added at every 200m of the river or in some cases, wherever access to the river could be gained.

3. The waypoints were loaded onto a hand held 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 has been influencing the river and riparian zone in any way.
5. Individuals alongside the river were alerted to the fact that there would be someone walking the river through the PRW messaging group (WhatsApp).
6. Safety procedures were followed such as the use of protective clothing, application of sunblock, carrying of water to prevent dehydration and alerting someone to the starting and ending times of the walk.
7. Pictures, taken whilst on the river walk, were taken with location tags on the camera switched on, therefore, the pictures taken had the co-ordinates attached to them.
8. After each days 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 and Microsoft Excel.

Legality concerning 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 was replaced, in 2015, by the “Nuisance and Behaviour in Public Places By-Law”.

*“Nuisance” as defined by the by-laws “means any conduct or behaviour by any person or the use, keeping, producing, by-producing, harbouring or conveying, as the case may be, of any item, substance, matter, material, equipment, tool, vegetation or animal or causing or creating any situation or condition in or on private property or in a public place or anywhere in the Municipality which causes damage, annoyance, inconvenience or discomfort to the public or to any person, in the exercise of rights common to all or of any person;”.*

With regards to the public areas, unless there is signage that restricts entry, one can enter public spaces as long as one behaves appropriately and responsibly. The Wyebank Municipal Dumpsite had restricted access, however, the authorities were contacted and entry was permitted.

Whilst some of the Palmiet River flows through municipal/public land, the majority of its tributaries flows through private properties. Prior approval is required from the relevant landowner before entering private properties. Quite often, the boundaries between private and public areas is poorly defined. However, as previously explained, as many landowners as possible were notified through the PRW WhatsApp group. The owners were very willing to accommodate the study as they had become concerned over the continuous pollution incidents occurring along the Palmiet River.

#### **4.6.5.1 Limitations to the River Walks**

As there have been no previous studies of this nature, the impacts observed cannot be accurately compared to a previous set of results. Therefore, the results obtained will serve as a baseline for future studies.

Accessibility issues were a problem within the Palmiet Catchment. As a result, not every part of the Palmiet River and its tributaries could be observed. The problems due to accessibility are due to a number of reasons including:

- Safety was of particular concern in the Pinetown/ New Germany Industrial area. Groups of individuals have been seen robbing the local business, selling illegal products and stealing copper wires and stripping them. These individuals have been seen hanging around under the bridges and around the Palmiet River. There are areas within the industrial area where the area alongside the river has become overgrown with alien vegetation providing an ideal hideout for these criminals. In addition, the informal settlement areas have also posed a major security threat.
- 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 River were also densely covered in vegetation allowing no way through. In addition, areas where the river has been piped has also been deemed inaccessible.

The observations of this particular study represent the current conditions of the Palmiet Catchment after years of being degraded. Unforeseen circumstances may arise in the future, which may potentially add to the degradation of the Palmiet Catchment or aid in the rehabilitation of the Palmiet Catchment. Therefore, the observations and ecological condition of the Palmiet River, its

tributaries and riparian zone presented in the subsequent chapter needs to be read with the understanding that the conditions within the catchment is susceptible to change.

#### 4.6.6 Analysis of Observational Data

ArcMap 10.2 was the GIS software used to produce the maps presented in **Chapter 5** included on the **DVD**. Prior to the use of the software, certain settings needed to be set such as the format for the co-ordinates, in degrees, minutes and seconds, and the measurement of distance, in metres. Another setting of critical importance was the co-ordinate system. Often shape-files come in different geographic and projected co-ordinate systems, each system different from the other. Therefore, prior to the addition of layers onto the map, a standard co-ordinate system needed to be set. Shape-files obtained from the eThekweni Municipality departments followed the WG31 co-ordinate system, therefore, this co-ordinate system was set for all shape-files created.

Certain shape-files such as rivers, drainage catchments, roads, stormwater and sewer systems were required to provide a context on which the river impact shape-files could be added. Factors influencing each impact has also been included in the maps, for example a sewer pump station plays a major role in affecting the water quality and the location of the sewer pump station, if present, has been shown in the map illustrating the water quality.

In order to represent the large amount of accumulated data onto a single page to provide an overview of the entire Palmiet River, Microsoft Excel was used. The conditional formatting tool was used to colour code the impact scores. The area between each waypoint was assessed with regards to the number of stormwater and sewer manholes, river crossings and the percent urbanised and natural. This data was obtained by dividing the area in-between each waypoint into strips. These strips were bounded by the sub-catchment, which encompassed the Palmiet River. **Appendix E** illustrates how the area between the waypoints were divided for the Kingfisher Catchment.

The overall ecological conditions, presented in **Chapter 5**, consists of an average of all the impacts imposed throughout the Palmiet Catchment. However, please note both inundation and water abstraction were not a problem throughout the majority of the catchment, besides Unit 4. It has been excluded from the calculations in Unit 1 to Unit 5 and Unit 7. Rubbish dumping was absent from Unit 6, however, it was a common occurrence throughout the Palmiet Catchment and has been included in the calculations for Unit 6. The absence of rubbish dumping is a contributor to the improved conditions within Unit 6.

As many of the tributaries to the Palmiet River were either inaccessible or non-perennial, they were not analysed. The infrastructure contributing to the same impacts were then classified into groups. In addition, a chart was formed detailing how the impacts relate to each other.

#### 4.6.7 Understanding the Results

The following key points are critical in providing a better understanding of the results presented and discussed in **Chapter 5**.

- Viable historic data, free of interference from clouds and obtained from Landsat imagery, was only available from the year 1975 onwards. Therefore, the analysis presented in **Chapter 5** includes the changes from 1975 to the present year, 2016. However, it can be noted that areas such as the Pinetown/New Germany industrial area were already quite far in terms of infrastructure development in 1975.
- The following colour scheme was used to represent the ecological section of the Palmiet River between each waypoint: [0] – Blue, [0.5-1] – Green, [1.5-2] – Light Orange, [2.5-3] – Yellow, [3.5-4] – Dark Orange, [4.5-5] – Red.
- The impacts observed and rated are a culmination of the numerous factors, which have affected the Palmiet River and riparian zone of the years. Any observations conducted under special occasions, such as during heavy rainfall events, have been noted in **Chapter 5**.
- There have not been any previously conducted studies, investigating the ecological condition of the Palmiet River and riparian zone, therefore the results obtained serve as a baseline for the current conditions of the Palmiet Catchment. Therefore, future studies of this nature conducted on the Palmiet Catchment can be compared to the results presented in **Chapter 5**. In addition, 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.
- All remedial interventions suggested are stated in **Chapter 5**. The financial feasibility and method of implementation will need to be assessed by the appropriate municipal departments.

## 4.7 Summary

The main objective of this study was to investigate the relationship between infrastructure and the condition of the Palmiet River, its tributaries and riparian zone. In addition, a brief analysis on the changes in the land use over time has been done using Landsat imagery. The land cover maps, presented in **Chapter 5** can be improved using imagery with better resolutions. In addition, results that are more accurate can be obtained by using Landsat imagery from the same month each year. However, certain factors may prevent this. The use of the Landsat data was sufficient for the purpose of this study as it validated the fact that there has been a significant increase in urbanisation over the years.

In order to record the impacts imposed on the Palmiet Catchment, visual observations of the Palmiet River, by means of numerous river walks, were undertaken. It was not possible to walk every part of the Palmiet River. However, assumptions can be drawn from the observed areas as to the state of the unobserved areas. Areas where the land use is similar, i.e. residential areas, have similar impacts as can be seen by the observations detailed in **Chapter 5** and in the additional material provided on the attached **DVD**. The observations were translated onto ArcMap 10.2 using a rating system from the RHA. This allows for the easy identification of areas requiring immediate attention. The ratings of each impact all had the same range, i.e. 0-5. However, there were certain impacts that had far greater significant impacts than others did and, a rating system that weighted the different impacts, as is done in the IHI, would produce better results. However, the focus of this study was to investigate whether there is in fact a relationship between infrastructure, within the Palmiet Catchment, and the condition of the Palmiet River. The rating system employed in this study was used as a means to identify areas, which require immediate attention. Therefore, the rating system has been effective in identifying areas that require immediate attention. The colour-coded maps and summarised Excel sheets produced in **Chapter 5** and on the attached **DVD** allows for the easy identification of these areas. As a result, the methodology detailed in this chapter proved to be effective in achieving the aims and objectives detailed in **Chapter 1**.

*"Plans to protect air and water, wilderness and wildlife, are in fact plans to protect man." - Stewart L. Udall*

## CHAPTER 5 : RESULTS AND DISCUSSIONS

### 5.1 Introduction

This chapter presents the results of the thesis obtained using the methodology presented in **Chapter 4**. Landsat imagery, covering the past 41 years, will be used to investigate and validate the increase in urbanisation within the Palmiet Catchment. Rainfall data has been analysed and its impact on the Palmiet Catchment investigated. E.coli, organic loading and turbidity results will be analysed with regards to the surrounding infrastructure. In addition, miniSASS observations data will be analysed providing a long-term indication of the current water quality within the Palmiet Catchment. Thereafter, the current ecological condition with regards to the Palmiet River and its riparian zone will be explored. The impacts of the infrastructure will be analysed and causes of degradation stated. Potential remedial interventions, which will benefit and improve the ecological condition of the Palmiet Catchment, will be suggested.

### 5.2 Land Cover Analysis

Each classified image, illustrated by **Figure 5-1** to **Figure 5-5**, indicates the amount of the natural land area, within the Palmiet Catchment, which has been urbanised. The earliest image of the Palmiet Catchment is 1975. **Figure 5-1** clearly indicates that the Pinetown/New Germany industrial area was already substantially developed.

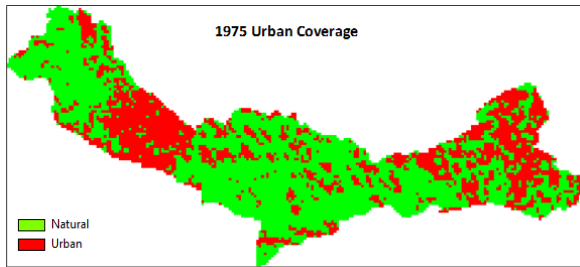


Figure 5-1: 1975 estimated urban coverage.

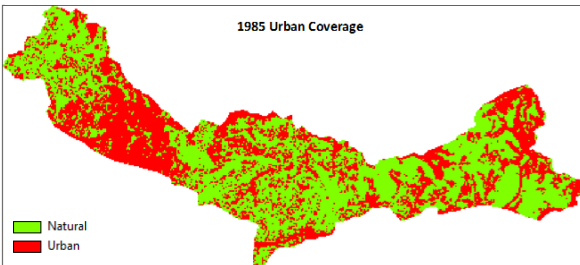


Figure 5-2: 1985 estimated urban coverage.

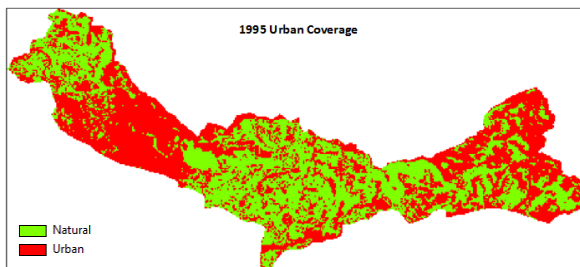


Figure 5-3: 1995 estimated urban coverage.

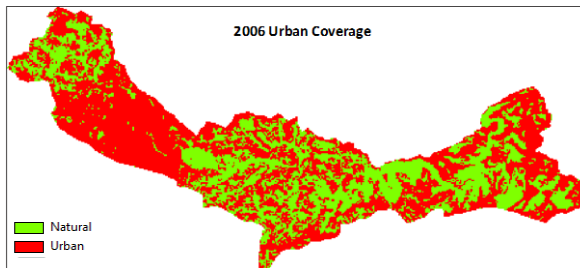


Figure 5-4: 2006 estimated urban coverage.

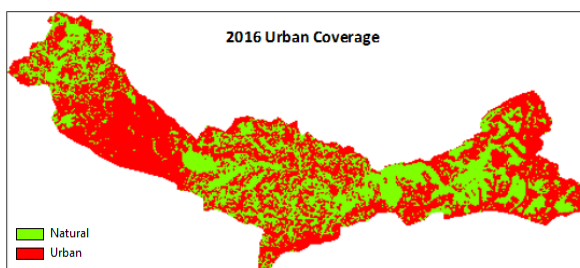


Figure 5-5: 2016 estimated urban coverage.

From the year 1975 to 1985, the majority of the changes occur within the residential areas of the Palmiet Catchment. The residential areas, were prime areas for development.

**Figure 5-3** illustrates similar changes in the residential areas with an overall 8 % increase in urban coverage throughout the Palmiet Catchment.

The overall urban coverage has increased by a substantial 24.1 % from the year 1975 to 2006. The primary changes include the construction and extension of residential buildings, roads (in the residential areas), schools, shopping centres and recreational areas. It is evident that the majority of the infrastructure development, over the past 41 years, has occurred within the residential areas of the Palmiet Catchment.

There has not been a significant increase in urban coverage from the year 2006 to 2016. The majority of the natural land area had already been developed in 2006.

The remnants of the natural vegetation is concentrated around the New Germany and Palmiet Nature Reserves. In addition, household gardens also contribute to the remaining natural areas, however, the natural vegetation has been affected by the alien vegetation and the water resources by pollution.

The number of pixels in the “Urban” and “Natural” class was used to produce an estimate percentage coverage between the two classes. **Table 5-1** presents the percentage coverage of each class.

Table 5-1: Percentage coverage of "Urban" and "Natural" class.

Year	1975	1985	1995	2006	2016
Urban Coverage [%]	36.1	44.1	52.7	60.2	60.6
Natural Coverage [%]	63.9	55.9	47.3	39.8	39.4

An increasing trend in urbanisation, of an average 8%, was observed from the years 1975 to 1985, 1985 to 1995 and 1995 to 2006. This has resulted in a decrease in the area covered by natural areas i.e. vegetation and water. **Figure 5-6** places these results in context by illustrating the increase/decrease in the residential, industrial and natural areas from 1975 to 2016.

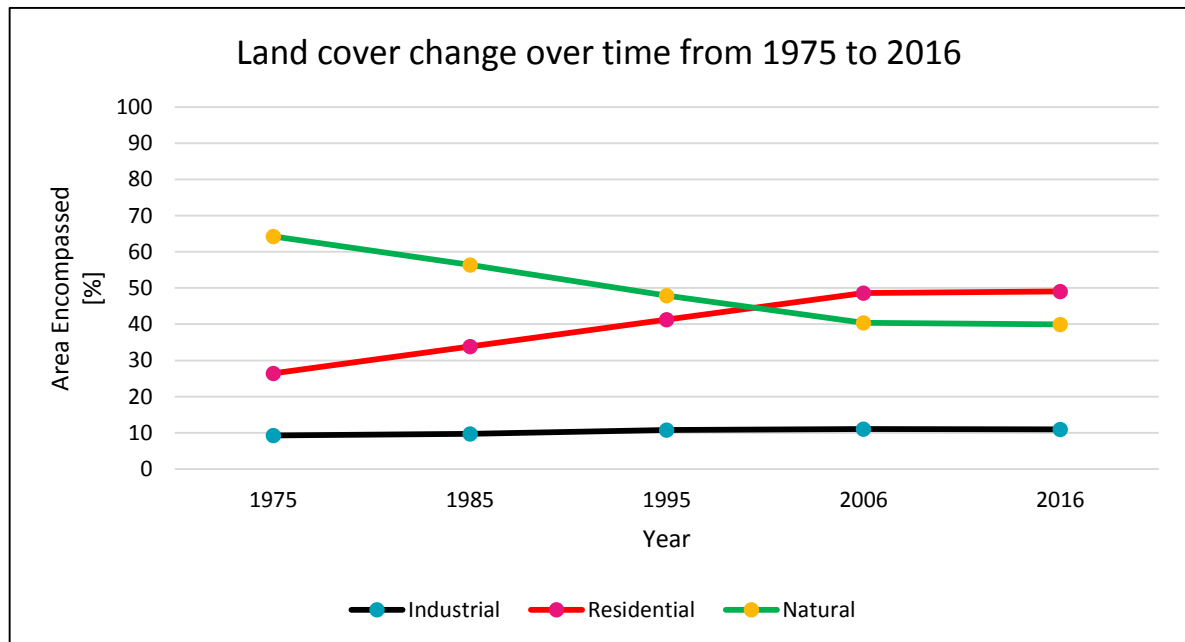


Figure 5-6: Land area of the Palmiet Catchment encompassed by industrial, residential and natural areas from 1975 to 2016.

In 1975, about 36 % of the Palmiet Catchment was urbanised. Currently there is an estimated 60 % of the Palmiet Catchment, which has been urbanised, indicating that over the past 41 years, there has been a substantial increase in built infrastructure structure development, of around 24.5 %.

Upon scrutiny of the Landsat imagery from 1975 to 2016, it can be noticed that some areas, which are red, revert to green, i.e. the catchment changes from an “urban” class back to a “natural” class. This is a direct result of imagery obtained from different months in the year and the growth of the vegetation has affected the results. This has had an effect of the overall percentage coverage of the classes as miscalculations can occur when choosing pixels. The accuracy assessment, presented in **Chapter 4**, produced indicates that the results are at acceptable standards. There is no doubt that there has been a significant increase in urbanisation over the past 41 years and this has had direct effect on the ecological condition of the Palmiet River and its riparian zone.

The classified Landsat imagery are an effective way of analysing the increase in urbanisation and associated infrastructure. The impacts of the increase in infrastructure forms the basis for conducting this study and, therefore, the above results places the sub - sequent sections in context. Urbanised areas are characterized by their hard, impermeable surfaces, be it the roofs of factories or houses or the pavements on roads and parking areas. The hardened surfaces have a direct result on the increased runoff entering the Palmiet River system over a shorter period. In addition, stormwater, which would be naturally filtered by the soils before seeping into the river, is conveyed directly into the Palmiet River without any treatment measures. This stormwater may be contaminated with a variety of pollutants including oil, diesel and washing detergents. Therefore, the hardened surfaces contribute to modifying the flow of the Palmiet River as well as the water quality.

### **5.3 Analysis of the Rainfall within the Palmiet Catchment**

**Figure 5-7** and **Figure 5-8** illustrates the monthly variations in the rainfall within the Palmiet Catchment.

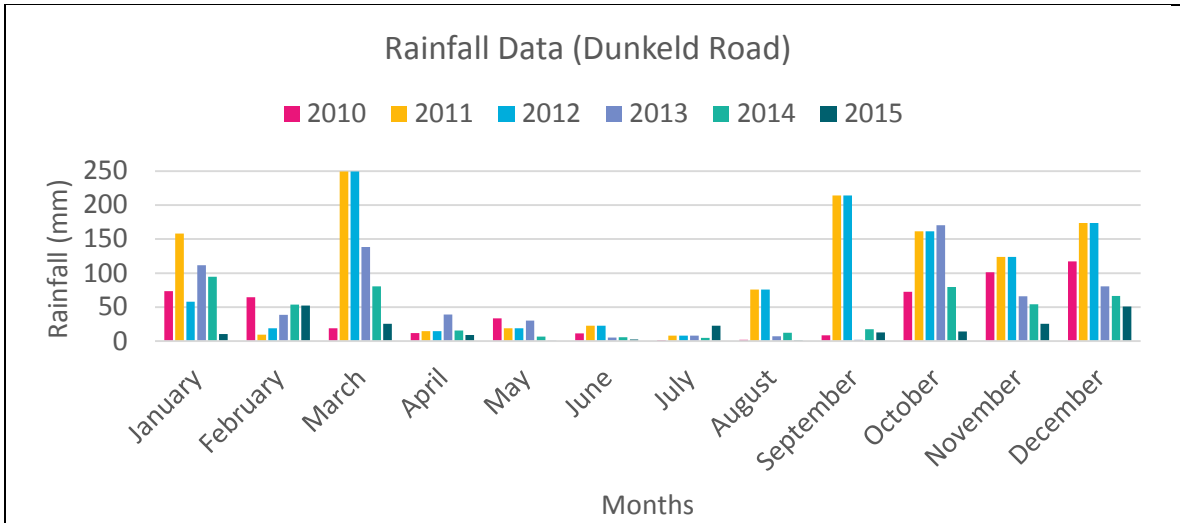


Figure 5-7: Dunkeld Road station rainfall data.

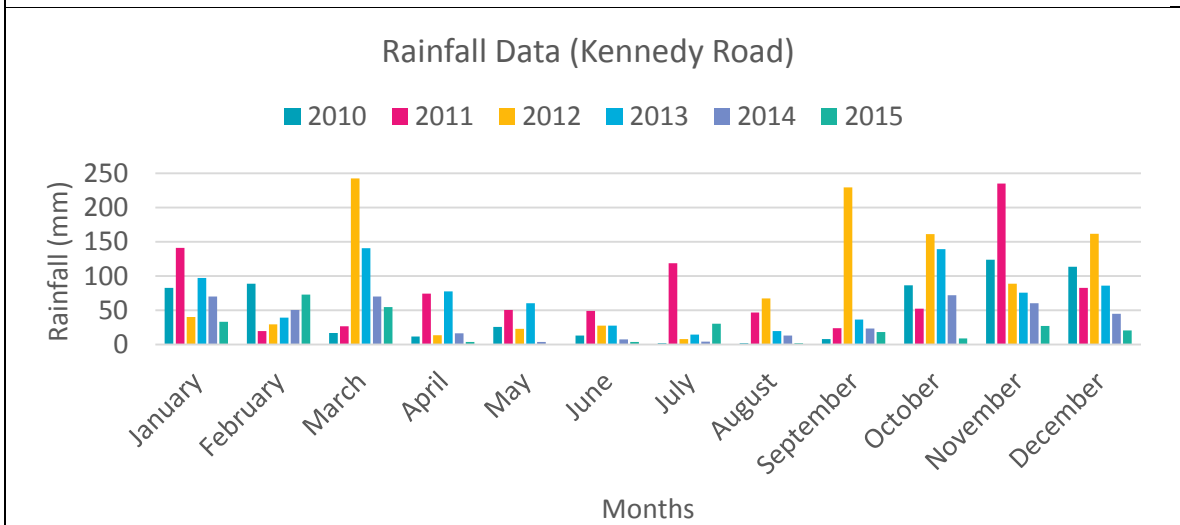


Figure 5-8: Kennedy Road station rainfall data.

Mid-October through to mid-February are generally considered the wet months in most parts of South Africa, according to the South African Weather Service, this is a trend which is also present in the Palmiet Catchment. **Table 5-2** presents the annual rainfall recorded by the two rainfall stations within The Palmiet catchment.

Table 5-2: Mean annual rainfall data for the Palmiet catchment.

<b>Year</b>	<b>Dunkeld Road Annual Rainfall [mm]</b>	<b>Kennedy Road Annual Rainfall [mm]</b>	<b>Mean Annual Rainfall [mm]</b>
2010	515.6	575.4	<b>545.5</b>
2011	1 231.2	922.6	<b>1 076.9</b>
2012	1 140.4	1 093.6	<b>1 117.0</b>
2013	696.0	815.4	<b>755.7</b>
2014	491.2	437.2	<b>464.2</b>
2015	227.0	276.6	<b>251.8</b>

The annual rainfall within the Palmiet catchment shows a decrease from the 2011/2012 years to the year 2015. Historical research conducted by du Preez and de Villiers (1987) explained that the annual rainfall within the Palmiet catchment averaged at around 1 000 mm during the 1980's. The decrease in rainfall can also be attributed to the effects of global warming.

Whilst rainfall can be attributed to the increasing the flow rate and bank erosion along the Palmiet River, it is no the major contributor as the rainfall from 2011 to 2015 shows a significant decrease. In addition, if the rainfall in the 1980's is compared to the previous years (2015) rainfall, there has been a substantial decrease in rainfall. The lack of historic studies along the Palmiet River makes it difficult to accurately assess how the impacts have changed over time. However, communication with residents in the Cowies Hill and Westville North residential areas as well as the Quarry Road informal settlement indicated that the flow rate of the Palmiet River has significantly increased over the years and the riverbanks have become more prone to erosion.

Whilst the comparison of the historic study rainfall data and the rainfall from the year 2010 to 2016 indicates that there has not been an increase in the annual rainfall over the Palmiet Catchment, there has been a substantial increase in the urbanised areas, i.e. the hardened, impermeable surfaces, over the years. This has played a significant role in modifying the Palmiet Rivers natural flow rate by allowing stormwater to enter the river system over a shorter duration. The average gradient of the Palmiet River is about 3.5 %, calculated using the elevation path profile on Google Earth.

Both the increase in impermeable surfaces as well as the steep gradient are major contributors, which have exacerbated naturally occurring conditions, such as erosion and scouring. This is an important point as this study emphasising the fact that the natural processes such as erosion and scouring are the rivers way of maintaining an equilibrium, however, these processes have been exacerbated, by the development of infrastructure, to such a degree that it is degrading the Palmiet River and its riparian zone. Therefore, heavy rainfall events ultimately results in the flooding of the river. The most recent of which occurred in the May 2016 rainfall and resulted in the collapse of the riverbanks along the Quarry Road informal settlement resulting in houses being washed away. The excessive levels of erosion has also had an impact of the water quality within the Palmiet River. This hints at the fact that the impacts within the Palmiet Catchment are linked, a fact, which will be emphasised as more results are presented.

## 5.4 Analysis of the Palmiet River Water Quality

### 5.4.1 Chemical and Microbiological Analysis

There are two variables, namely E.coli and organic loading, which are used by the EWS to assess the effectiveness of the sanitation system within the Palmiet Catchment. A major component in an effective sanitation system is the network of sewer pipes and sewer pump stations that convey sewage to the treatment plants. The spikes in E.coli and organic loading results can be attributed to failures in the sewerage infrastructure. **Table 5-3** presents the overall mean values at the various sampling points.

*Table 5-3: Mean E.coli and organic loading results from 2007 to 2015 at the various sampling locations.*

<b>Location</b>	<b>E.coli [cfu/100 ml]</b>	<b>Organic Loading (PV4) [mg/l]</b>
<i>Varsity Drive Bridge</i>	3 408	3.9
<i>Birdhurst Road</i>	9 188	4.7
<i>Blair &amp; Otto Volek Roads</i>	8 670	5.3
<i>Crompton Street</i>	8 160	5.5
<i>Glenugie Road</i>	6 838	6.3

The highlighted colours of the different values in **Table 5-3** indicate which category the values fall into i.e. green being acceptable and yellow categorized as poor by the EWS thresholds. The mean

results obtained from **Table 5-3** have been plotted against their average distances from the source of the river. **Figure 5-9** provides a good indication of how the E.coli and organic loading results vary over the length of the Palmiet River. Both the Varsity Drive Bridge (SP1) and Birdhurst Road (SP2) sampling points are located in a residential area. The Blair and Otto Volek Road (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 a combination of a residential area, shopping centres and fast food outlets. The Wyebank dumpsite is also located upstream from SP5. The dumpsite, now only open to residents in the area, previously used to receive a variety of waste ranging from household waste, garden refuse and sometimes illegal liquid substances from industries in the area. Communication with Durban Solid Waste (DSW) officials revealed that the dumpsite has not been lined with plastic, a normal intervention implemented to prevent substances from seeping out the dumpsite. Therefore, the overall high organic loading results at SP5 is to be expected. In addition, SP2 has higher E.coli results in comparison to the other sampling points, SP2 is downstream of the sewer pump station, which has been prone to a number of failures resulting in untreated sewage being discharged into the Palmiet River.

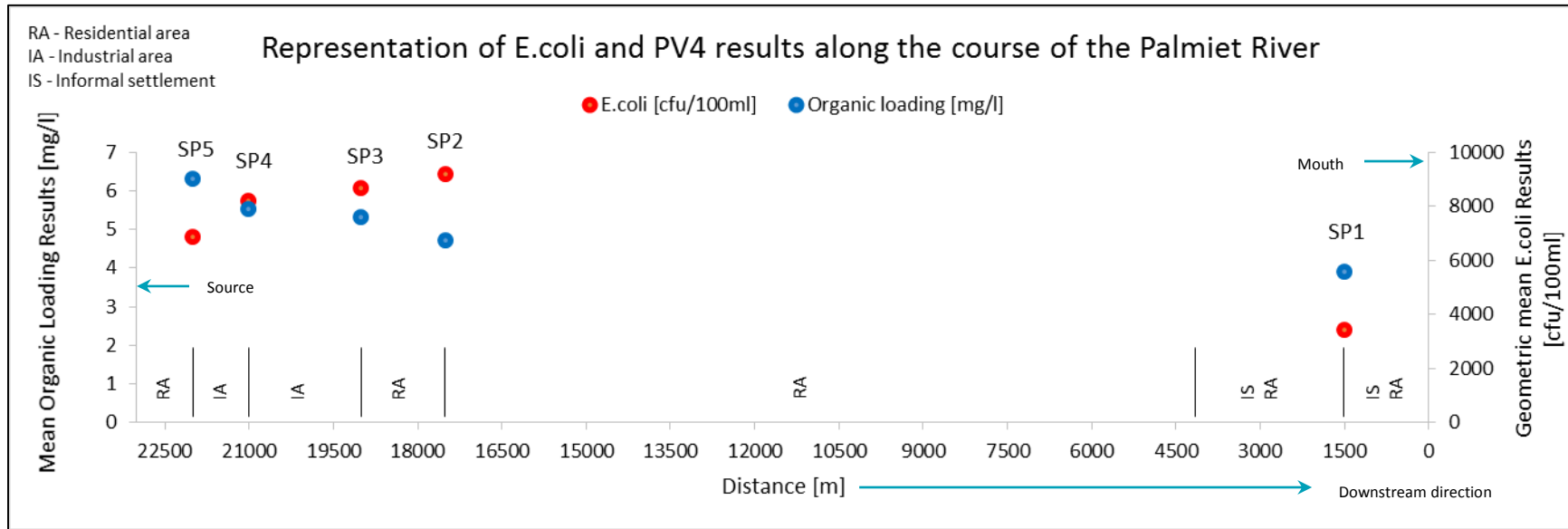


Figure 5-9: Changes in E.coli and organic loading over the length of the Palmiet River.

Ideally, with more sample points conducted along the length of the river, a better indication of the increase/decrease in E.coli and organic loading would be seen. Analysing data along the river course will allow critical areas of concern to be noted and measures implemented in order to reduce the poor results. Whilst, **Figure 5-9** is beneficial in illustrating which sample point continuously has high E.coli or organic loading levels, it does not indicate the large range in the sampling results. **Appendix F** represents the data on box and whisker plots to emphasise the range in the data.

Therefore, the majority of the sample points average in the poor region. SP3 is downstream of the Blair Road sewage pump station. As a result, when the pump station fails, there is a 2-hour storage tank capacity to contain the sewage whilst the problem at the pump station is rectified. If the volume of sewage exceeds the 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 where sanitary facilities, which cater for a number of people, such as shopping centres, and factories which are common around SP3, SP4 and SP5, can also contribute to the high E.coli counts in the sewers. Residential households, where dairy products are washed down the kitchen sink or rotten food is thrown down the sewer, are also contributors to the high E.coli counts. SP1 is downstream of numerous sewer manholes that are prone to overflowing incidents due to blockages in the sewer network. Often in residential areas, individuals have connected their stormwater to sewer. As a result, when it rains, the sewer manholes often overflow, as they are unable to accommodate the increased volumes flowing through them. 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 consists of proteins, amino acids, fats and pesticides as well as the variety of chemicals used in industrial areas. **Appendix F** contains box and whisker plots to illustrate the range in the organic loading results.

SP5 portrays constantly poor organic loading comparison to SP1, over the years 2007 to 2015. The primary reason for the poorer results is the difference in the surrounding land use at the 2 sampling points. SP5 is located upstream of the Pinetown residential area, however, in the middle of shopping centres and fast food outlets and downstream of the 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 one of the major contributors to the increase in organic loading levels. They use detergents and chemicals to keep the area clean and during the cooking of food a variety of oils and butters are used. All of this is then disposed of into the sewer system. Bear in mind, there are limits as to what you can dispose of into the sewer systems and all industries, shopping centres and fast food outlets need to comply with them. However, the cumulative effect of all the waste 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 particular, in the sewer

pipelines. The sewer pipe blockages and pump station failures which happen, on an all too frequent basis, causes this sewage to spill into the Palmet River, thereby, elevating the level of pollutants within the river. Should the sewage contaminate the Palmet River, SP5 is a prime example of the poor organic loading levels that may ensue.

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. As such, oil and diesel/petrol leaks from stationary vehicles in these areas may runoff the impermeable surfaces and find their way to the Palmet River especially during rainfall events. 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 out into the Palmet 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 organic loading level present in the Palmet River.

From the results obtained, it is evident that both residential and industrial areas have the ability to contribute to the organic loading levels in the sewers. 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 that increase the organic loading levels. Sewage from residential households can include cooking oils, butter, mayonnaise, soap, toothpaste, washing detergents and paint washed from paintbrushes, all of which can play a part in the higher levels of organic loading in residential effluent. An important point to note is that it is natural for the sewers to have high E.coli and organic loading results, however, it is not natural for the Palmet River to also have these high readings. Therefore, problems in the surrounding sewer network are directly responsible for the high level of pollutants entering the river system.

The wide area of impermeable surfaces particularly in the industrial area allows petrol, diesel and oil leaks to be transported into the stormwater drains and into the Palmet River, thereby, increasing the organic loading levels of the river. 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 an ideal situation, there should only be rainwater flowing over the impermeable surfaces, which enter the Palmiet River. However, this is not the case as there are numerous pipe blockages, pipe bursts and pump station failures, which discharges sewage, high in E.coli and organic matter, straight into the Palmiet River.

Turbidity is a water characteristic that can easily be seen, and provides an indication pollution in the river. Soil particles found in the Palmiet River, due to soil erosion and scour, contributes largely to the suspended matter present in the water. In addition to the discharge of sewage and other wastes that decrease the water quality and increases turbidity levels in the Palmiet River, an increase in turbidity levels is also an indication of increased soil particles in the river. The increase in hardened surfaces, explained by the classified Landsat imagery, allows a larger volume of runoff to enter the river system over a shorter time span, which has resulted in a heightened scouring ability of the Palmiet River. As a result, the riverbanks have been scoured and have significantly eroded away resulting in an increase in suspended matter and turbidity levels. **Figure 5-10** presents the mean of turbidity results, across all 5 sampling points, for the years 2007 to 2015. Box and whisker plots illustrating the range in turbidity values have been included in **Appendix F**.

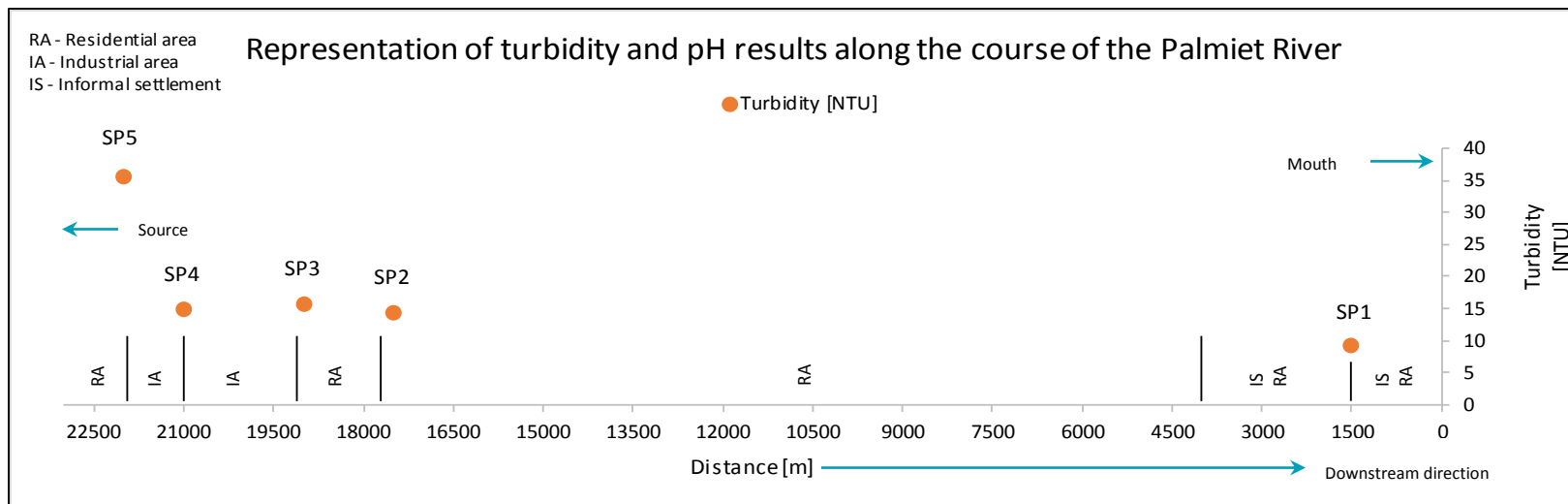


Figure 5-10: Mean turbidity results at the 5 sampling points along the Palmiet River.

Suspended matter can arise from a variety of other sources besides sewage. For example, the scouring of the riverbank displaces soil sediments into the river. There are a number of potable water leaks, within the Palmiet Catchment, which releases 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 to get into the river and causes turbulence in the river.

SP5 contains the highest turbidity results. SP5 is downstream from a vast sewer network carrying effluent from the housing complexes and residential properties. Problems in the sewer network may be a contributor to the elevated turbidity values, in comparison to the other sampling points. The upstream residential properties have encroached on the rivers riparian zone. As a result, the riverbanks may have decreased integrity due to the surrounding developments. Excessive erosion results in excess sediment being transported into the river, increasing the turbidity value.

The poor E.coli and organic loading results indicate failures in the sanitation system. In addition, the increase in turbidity indicates both a failure in the sanitation system as well as increased runoff levels and an increased flow rate within the Palmiet River. As a result, the increased runoff also plays a role in influencing the water quality of the Palmiet River. Chemical and microbiological composition of the river vary greatly. Therefore, the sampling conducted by the EWS provides an indication of the short-term water quality of the Palmiet River. miniSASS, on the other hand, provides an indication of the long-term water quality of the Palmiet River. The ensuing section will explore whether the miniSASS observations agree with the poor results from the EWS sampling.

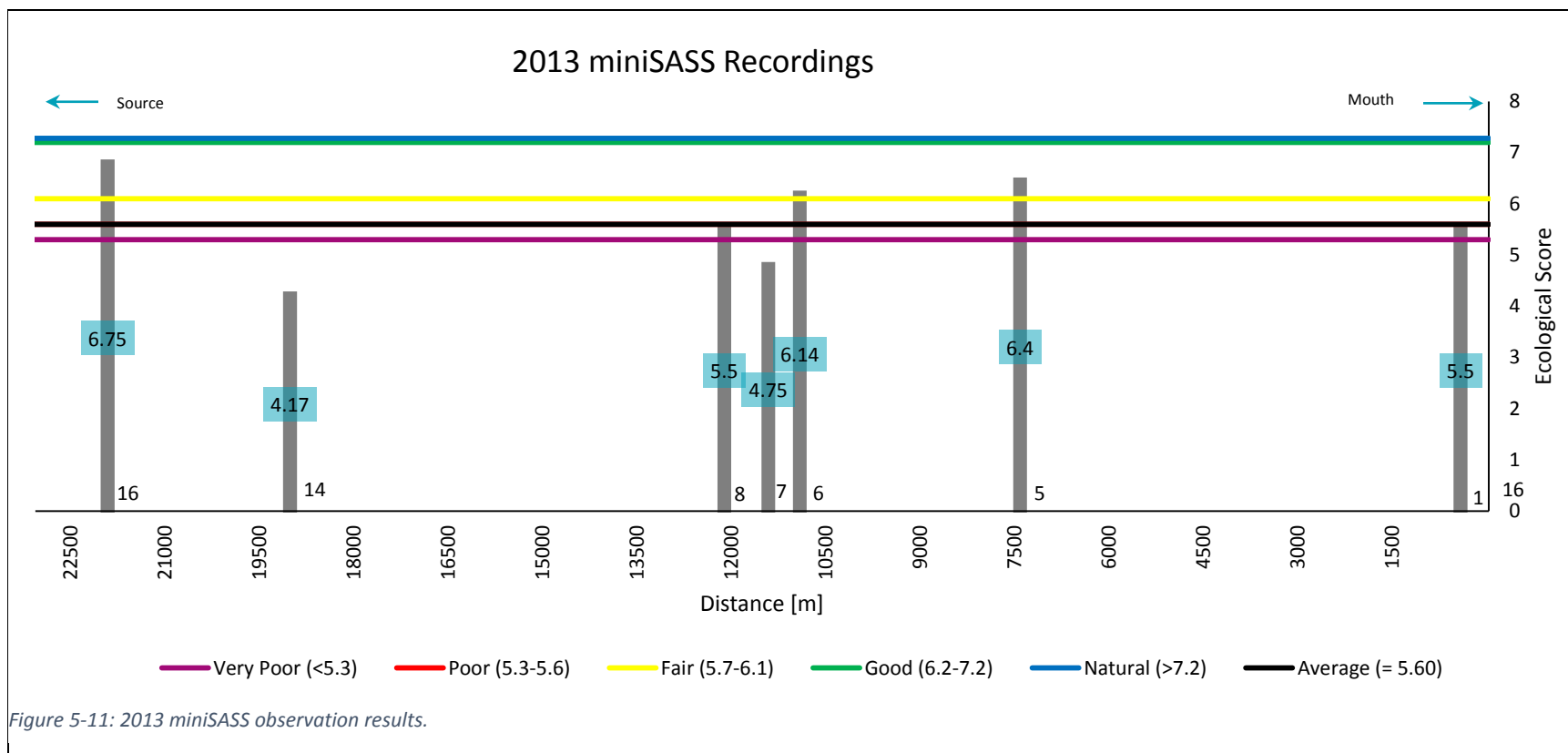
#### **5.4.2 minSASS Analysis**

The land use between the different miniSASS observations vary. The surrounding environment is an important factor when analysing the macro invertebrate indicators, as different activities along the river may affect the scores resulting in the poor water quality shown. **Table 5-4** presents a brief description of the land use at each observation point.

Table 5-4: Brief description of the land use at the various sample points along the river.

Observation Point	Land Use
[17] - Campbell Road	Residential area with a municipal dump in the area
[16] - Arundall Road	Residential area
[15] - Cherry Road	Industrial area
[14] - Blair Road	Industrial area
[13] - Churston Road	Residential area
[12] - Birdhurst Weir	Weir (pump station)
[11] - Pineside Road	Residential area
[10] - Deutche Schule	School
[9] - Rosebank Road	Residential area
[8] - Wellington Road	Residential area
[7] - Edgecliff Road	Residential area
[6] - Palmiet Nature Reserve	Nature reserve
[5] - Shepstone Place	Residential area with University in close proximity
[4] - University Road	Residential area with University in close proximity
[3] - Chiltern Road	Residential area
[2] - Shire Quarry	Residential area
[1] - Papwa Sewgolum	Golf Course

There are significantly more observation points along the river in comparison to the EWS sampling points. Points were chosen based on the surrounding significance as well as accessibility. **Figure 5-11** to **Figure 5-14** illustrates the ecological condition, with regards to the macro invertebrates, relative to the observations points along the Palmiet River. The numbers highlighted in blue indicate the ecological condition at that point and the numbers not highlighted refer to the sampling point where the observation was conducted.



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 Palmett 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 Palmett River, untreated sewage, which overflows, contaminates the Palmett 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 an impact on the water quality.

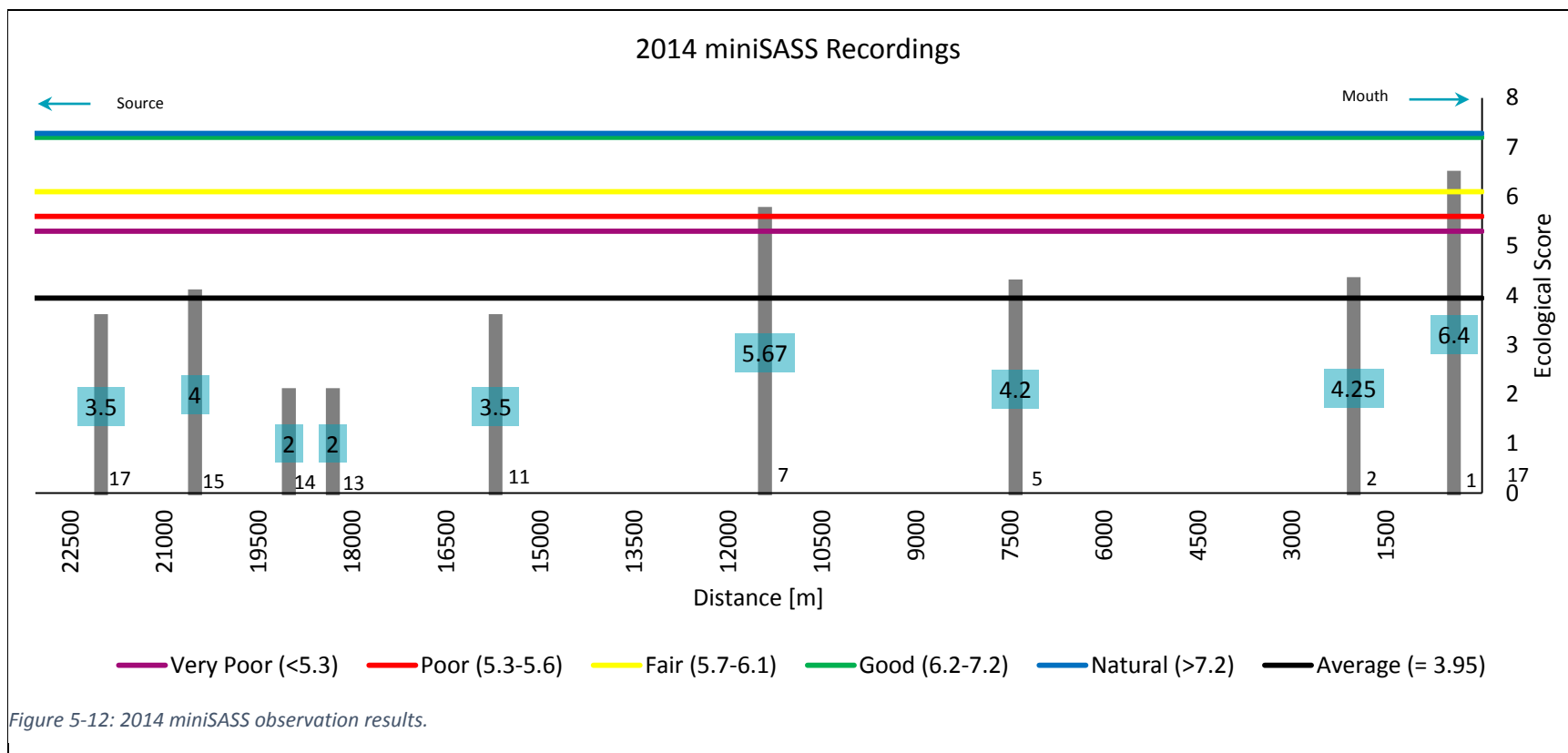


Figure 5-12: 2014 miniSASS observation results.

**Figure 5-12**, illustrating the ecological condition of the Palmiet River in the year 2014, measured at a variety of sample points, clearly indicates that the overall river health lies in the very poor region. The mean score is 3.95. The condition of the Palmiet River, with regards to the ecological condition of macro invertebrates, at point 17 has significantly decreased from the year 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 trees bearing fruits.

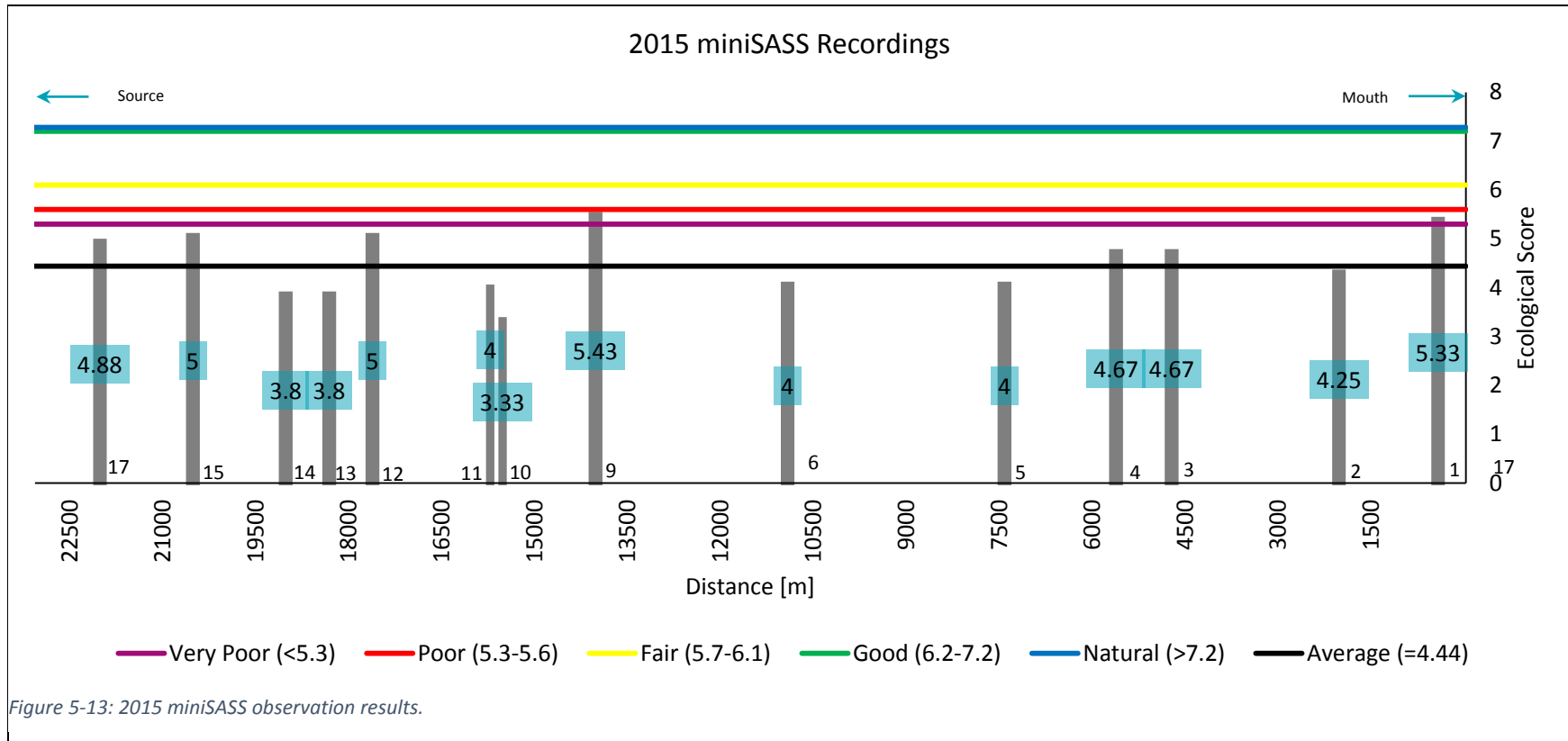


Figure 5-13: 2015 miniSASS observation results.

**Figure 5-13** summarizes the results obtained from the year 2015, illustrates that the overall water quality, based on the macro invertebrate indicators, remains in the very poor region. 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.

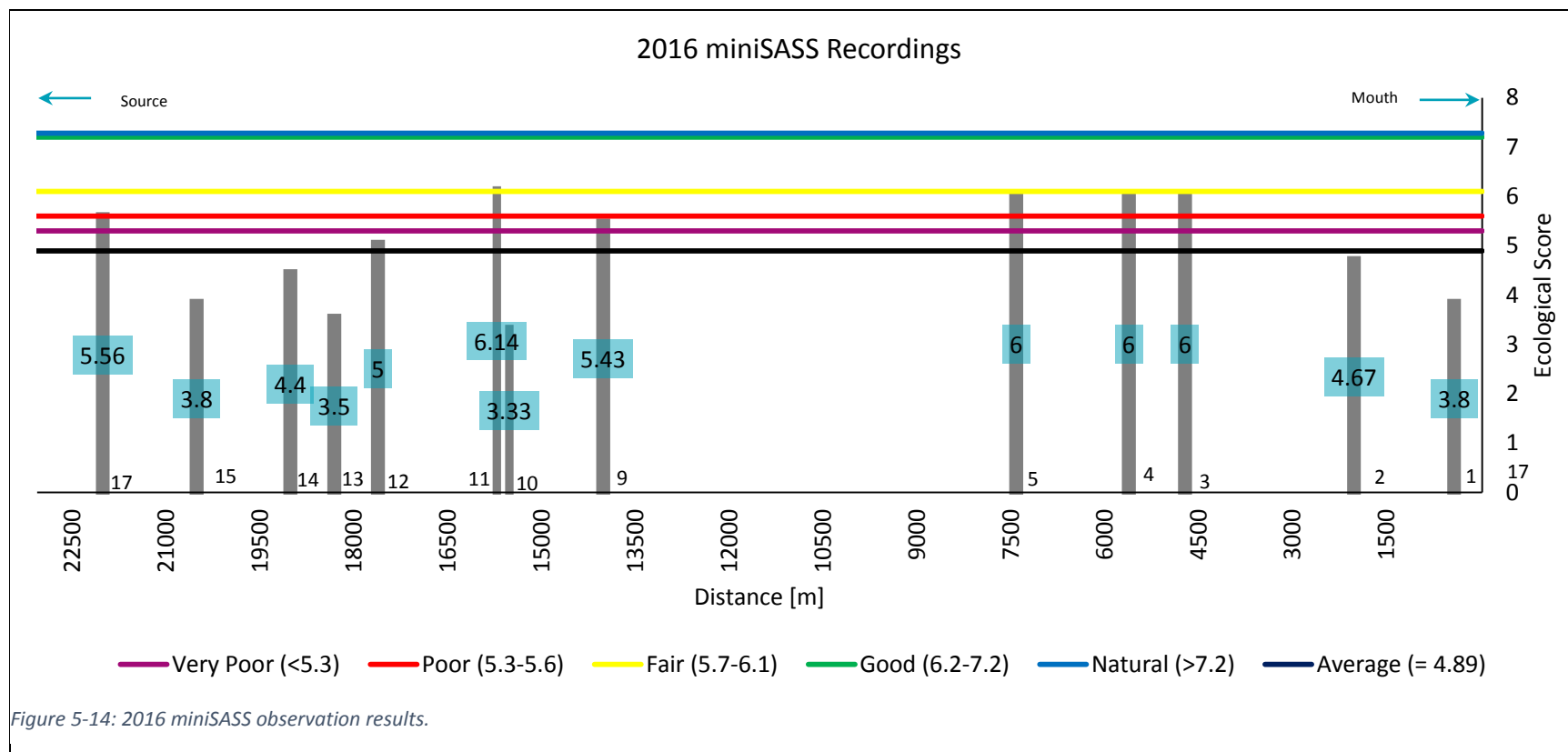


Figure 5-14: 2016 miniSASS observation results.

**Figure 5-14** provides a summary of the 2016 miniSASS observations. The mean score of 4.89, whilst an improvement from the year 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 Papwa Sewgolum golf course has had a significant decrease in its ecological condition, with regards to the macro invertebrates present, from the years 2014 to 2016. The golf course is downstream of the Quarry Road informal settlement, hence inadequate sanitation facilities as well as the lack of service delivery, i.e. the collection of waste, has significantly affected the macro invertebrates present.

### 5.4.3 Overview of the Chemical, Microbiological and miniSASS Sampling

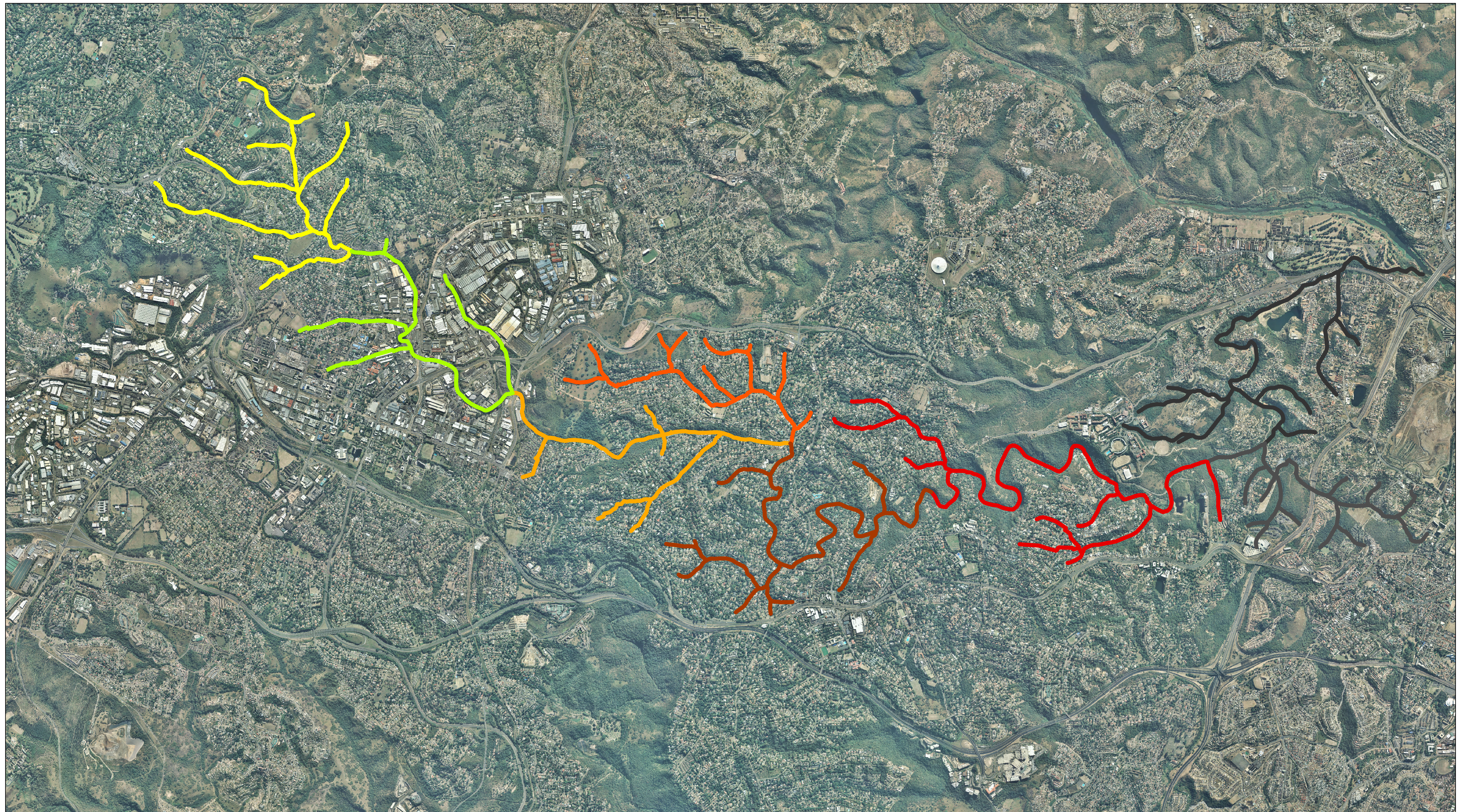
When analysing the well-being of the Palmiet Catchment, a variety of indicators need to be used in order to get an accurate estimation of the conditions present. It is not always practical to incorporate a number of different variables to analyse the water quality as the well-being of the river continually changes and pollution events cannot be foreseen. However, when considering the Palmiet Catchment as a whole, incorporating a wide variety of indicators to produce an accurate representation of the well-being of the Palmiet Catchment is of utmost importance.

Under scrutiny, 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. Therefore, the need for further, detailed investigation into the sources of degradation of the Palmiet Catchment has led to the undertaking of this particular study. The ensuing sections will explore the current status of the Palmiet River and its riparian zone and the impact of the surrounding infrastructure.

## 5.5 Areas of the Palmiet River Observed

The Palmiet River was divided into 7 units, detailed in **Chapter 4**, and observations were recorded for each unit. The 7 units encompass a variety of land uses ranging from industrial areas to residential areas as well as informal settlements. Thus, by observing the environmental impacts imposed on each unit, the manner in which the different uses of the land and built infrastructure present, can be emphasised and focused on. **Figure 5-15** illustrates the division of the Palmiet River into the 7 units.

**Figure 5-16** to **Figure 5-22** illustrates the detailed extent covered by each unit as well as some of the major infrastructure. Due to the large amount of information, summarized sheets and an overview of the impacts have been presented in this chapter. Detailed explanations of each impact within each unit can be found on the attached **DVD**.



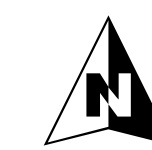
Please refer to individual descriptive maps of each area which details the accessible areas of each unit.

**The Palmet River**

**Units of the Palmet River**

Legend	
Palmiet River	Unit 4
Unit	Unit 5
Unit 1	Unit 6
Unit 2	Unit 7
Unit 3	Inaccessible

1 cm = 200 meters



**Figure 5-15**

Drawn By: Semeshan Naidoo

Checked by: Semeshan Naidoo

Page 5-20

Date: 05/10/2016



[1] - 29°47'22.8"S, 30°51'30.5"E  
Lollipop climbers spotted on the below the dumpsite.



[2] - 29°47'13.9"S, 30°51'30.9"E  
Wyebank Municipal Dumpsite above tributaries of the Palmiet River.



[3] - 29°47'28.7"S, 30°51'18.0"E  
A tributary of the Palmiet River flows down a small waterfall.



[4] - 29°47'28.7"S, 30°51'13.2"E  
A stone bridge has been constructed over a tributary of the Palmiet River.



[5] - 29°48'3.9"S, 30°51'49.9"E  
Individuals have easy access to dump their waste from bridges constructed over the Palmiet River

1 cm = 56 meters

# UNIT 1

## Wyebank/Kloof Residential Area Description of the Area

### Legend

- Unit 1 Palmiet River
- Unit 1 Tributaries
- Unit 1 Roads
- Unit 1 Stormwater pipes
- Unit 1 Stormwater Manholes
- Unit 1 Sewer pipes
- Unit 1 Sewer Manholes



Figure 5-16

Drawn By: Semeshan Naidoo

Checked by: Semeshan Naidoo

Date: 09/09/2016



[1] - 29°48'3.73"S, 30°51'49.4"E  
Glenugie Road Bridge obstructing the flow of the Palmiet River



[2] - 29°48'4.6"S, 30°51'51.4"E  
Wall of gabion baskets implemented along the banks of the Palmiet River



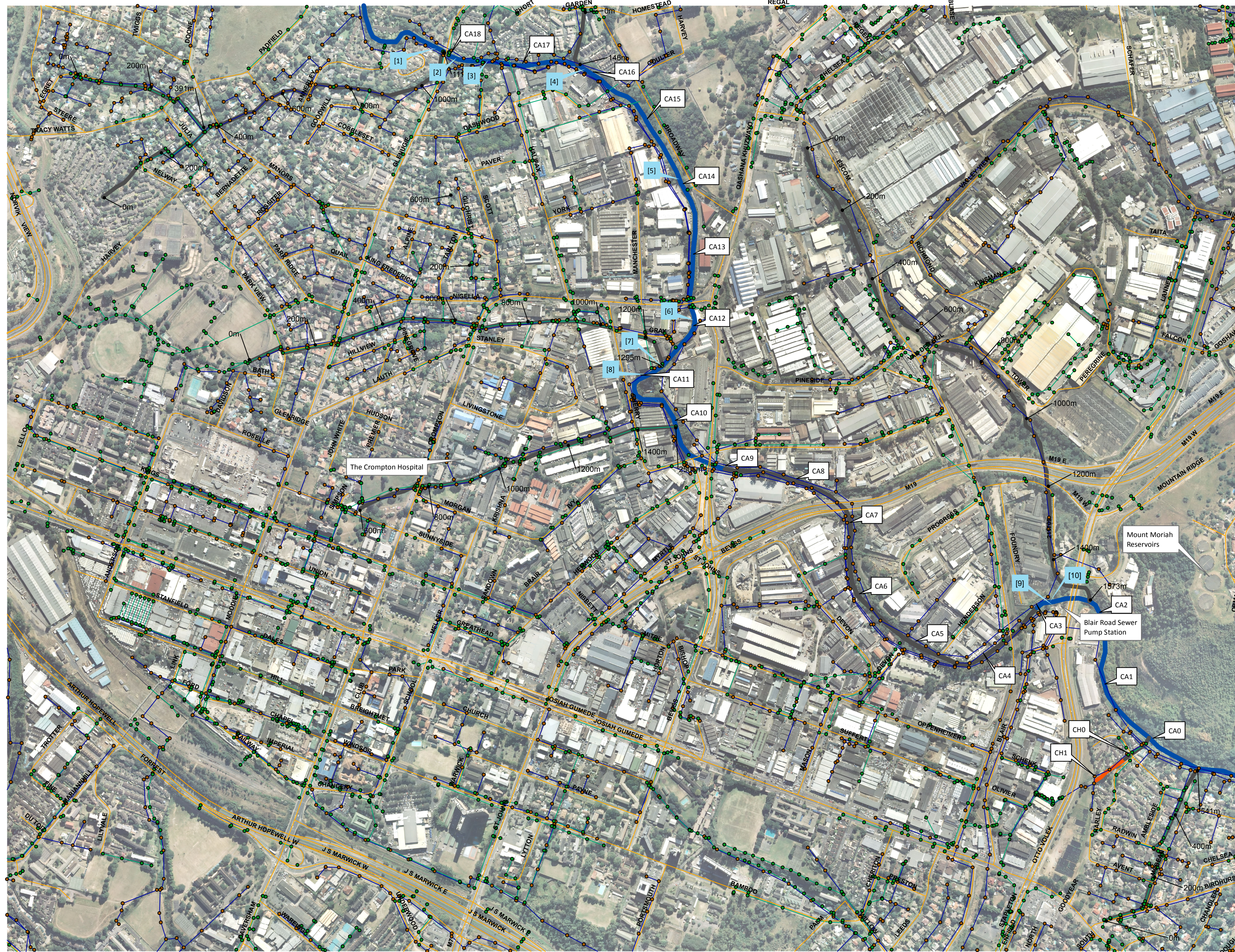
[3] - 29°48'4.8"S, 30°51'54.6"E  
Sewer line running along the Palmiet River



[4] - 29°48'5.6"S, 30°52'4.4"E  
Sewer cover missing causing potential pollution in the Palmiet River



[5] - 29°48'15.3"S, 30°52'13.9"E  
Palmiet River bank has been cemented



[6] - 29°48'27.7"S, 30°52'15.3"E  
Flow of the Palmiet River has undermined the gabion baskets



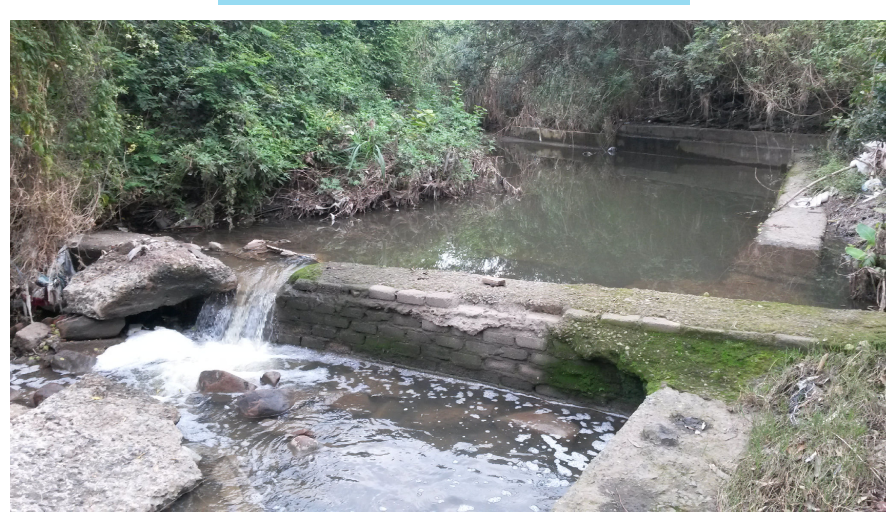
[7] - 29°48'31.9"S, 30°52'12.3"E  
Severe bank erosion



[8] - 29°48'32.5"S, 30°52'10.7"E  
Indigenous vegetation has had to make way for parking and factories



[9] - 29°48'52.9"S, 30°52'51.6"E  
Numerous sewer manholes in the riparian zone of the Palmiet River



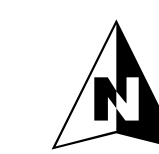
[10] - 29°48'52.6"S, 30°52'51.2"E  
Weir about 5m upstream from the Blair Road pump station

## Unit 2 Industrial Area Description of the Area

### Legend

<b>Unit 2 Palmiet River</b>	<b>Unit 2 Tributaries</b>	<b>Unit 2 Roads</b>	<b>Unit 2 Sewer Manholes</b>
<b>Accessible</b>	<b>Accessible</b>	<b>Unit 2 Stormwater Pipes</b>	<b>Unit 2 Stormwater Manholes</b>
Yes	Yes	Unit 2 Stormwater Pipes	Unit 2 Stormwater Manholes
No	No	Unit 2 Sewer Pipes	Unit 2 Sewer Manholes

1 cm = 60 meters



Page 5-22

### Figure 5-17

Drawn By: Semeshan Naidoo

Checked by: Semeshan Naidoo

Date: 20/08/2016



[1] - 29°49'07.4"S, 30°53'05.9"E  
Raw sewage being discharged directly into the Palmiet River



[2] - 29°49'8.0"S, 30°53'17.1"E  
Reeds cover the riverbanks



[3] - 29°49'12.1"S, 30°53'29.4"E  
Stormwater outlet has roots growing in it



[4] - 29°49'11.9"S, 30°53'36.0"E  
Riverbed has been scoured down to bedrock



[5] - 29°49'9.2"S, 30°53'38.0"E  
The Palmiet River upstream of the Stafford Road Bridge



### UNIT 3

## Cowies Hill/ Westville North Residential Area Description of the Area

#### Legend

##### Unit 3 Palmiet River

##### Accessible

- Yes
- No

##### Unit 3 Tributaries

##### Accessible

- Yes
- No

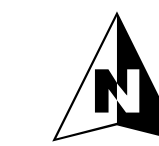
##### Unit 3 Roads

##### Unit 3 Stormwater Pipes

- Unit 3 Sewer Manholes
- Unit 3 Stormwater Manholes
- Unit 3 Sewer Pipes

##### Unit 3 Sewer Manholes

1 cm = 40 meters



### Figure 5-18

Drawn By: Semeshan Naidoo

Checked by: Semeshan Naidoo

Date: 20/08/2016



[1] - 29°48'36.0"S, 30°53'22.5"E  
Source of the Kingfisher Stream



[2] - 29°48'46.0"S, 30°53'27.3"E  
Hammerkop Dam wall compromised



[3] - 29°48'47.4"S, 30°53'27.1"E  
Water Lilly Dam



[4] - 29°48'52.5"S, 30°54'05.2"E  
Mass of built infrastructure within the Riparian Zone



[5] - 29°48'56.1"S, 30°54'16.3"E  
River piped at Jupiter Road



[6] - 29°48'54.7"S, 30°54'18.7"E  
Alien plants growing in the stream channel



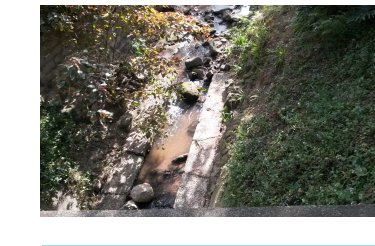
[7] - 29°48'54.0"S, 30°54'20.5"E  
Sunnybrae Drive Road crossing



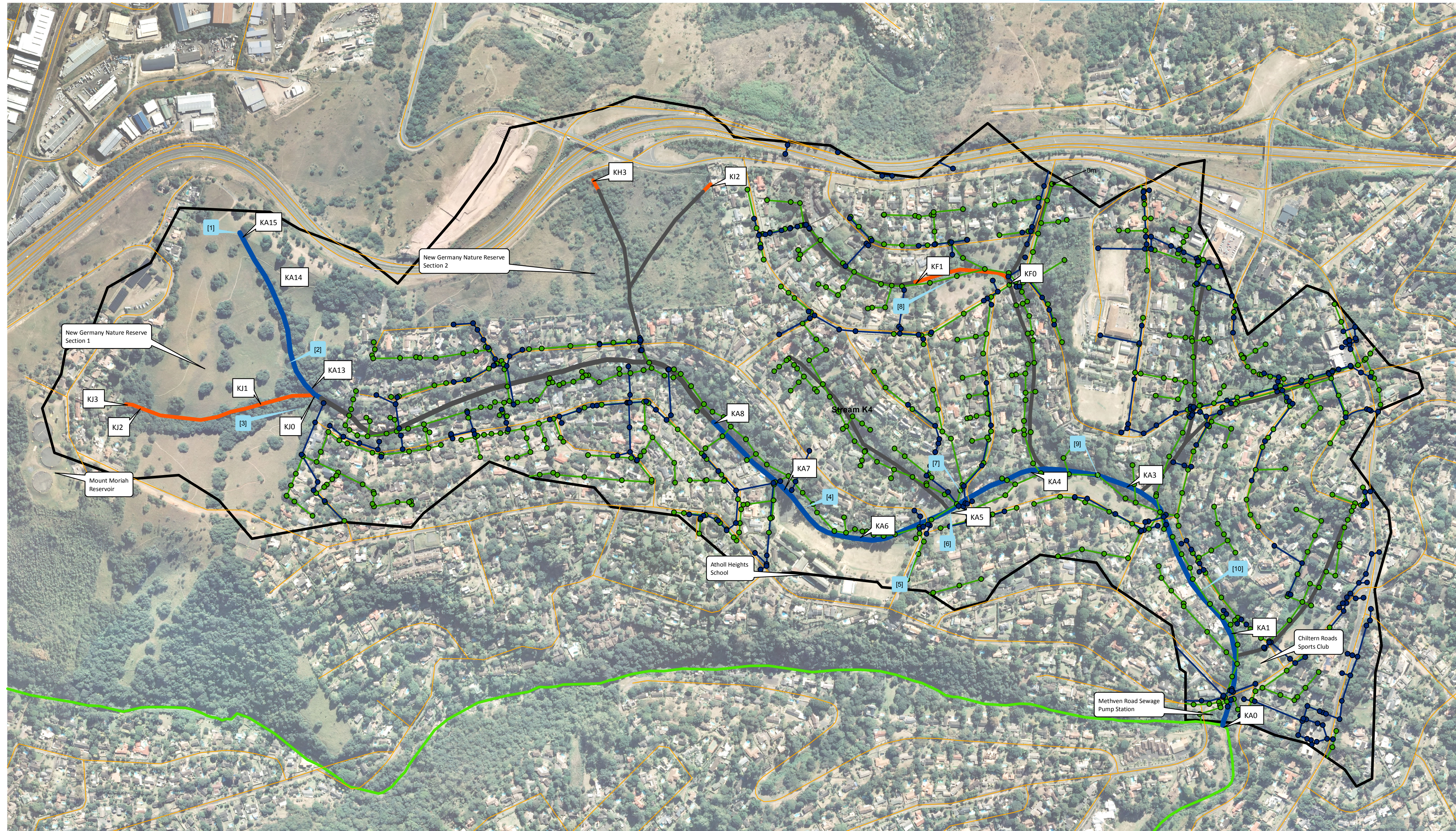
[8] - 29°48'38.7"S, 30°54'17.3"E  
Natural Wetland on Duncan Drive



[9] - 29°48'51.8"S, 30°54'27.6"E  
Severe Bank Erosion along Sunnybrae Park



[10] - 29°48'57.6"S, 30°54'37.3"E  
Channelization of the Kingfisher Stream along Fyfe Avenue



**UNIT 4**  
**Kingfisher Catchment**  
**Description of the Area**

**Legend**

**Kingfisher Stream**   **Kingfisher Stream Tributaries**

**Accessible**

- Yes
- No

**Accessible**

- No
- Yes

— Unit 4 Roads

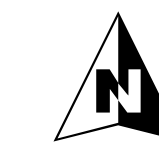
— Unit 4 Stormwater Pipes

• Unit 4 Stormwater Manholes

— Unit 4 Sewer Pipes

• Unit 4 Sewer Manholes

1 cm = 50 meters



**Figure 5-19**

Drawn By: Semeshan Naidoo

Checked by: Semeshan Naidoo

Date: 06/08/2016



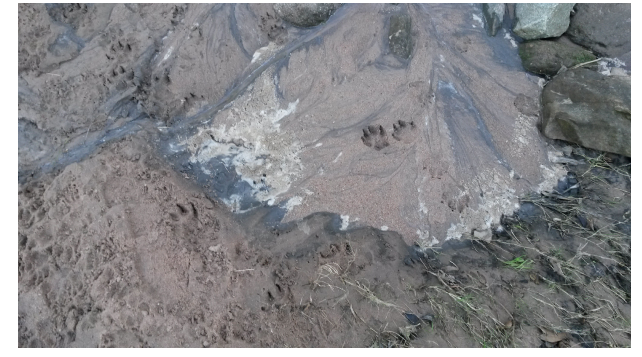
[1] - 29°49'9.2"S, 30°54'38.2"E  
Severe bank erosion



[2] - 29°49'1.921"S, 30°54'20.4"E  
Dumping of garden refuse



[3] - 29°49'23.0"S, 30°54'32.8"E  
Gabion baskets undermined



[4] - 29°49'25.7"S, 30°54'36.7"E  
Sedimentation caused by the erosion of soil and increased flow of the Palmet River



[5] - 29°49'30.6"S, 30°54'30.2"E  
River bank infrastructure in poor condition



[6] - 29°49'33.5"S, 30°55'20.1"E  
Balloon vine covering indigenous vegetation

### UNIT 5

## Westville Residential Area Description of the Area

### Legend

Unit 5 Palmet River		Unit 5 Tributaries		Unit 5 Roads		Unit 5 Sewer Manholes	
Accessible	Yes	Accessible	Yes	Unit 5 Stormwater Pipes	Unit 5 Stormwater Manholes	Unit 5 Sewer Pipes	Unit 5 Sewer Manholes
	No		No				

1 cm = 45 meters

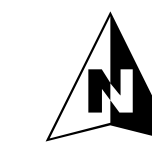


Figure 5-20

Drawn By: Semeshan Naidoo

Checked by: Semeshan Naidoo

Date: 21/08/2016



[1] - 29°49'30.4"S, 30°56'59.3"E  
Sewage contaminated water flowing out from a tributary.



[2] - 29°49'29.4"S, 30°56'58.5"E  
Sewer line running across the Palmiet River.



[3] - 29°49'30.4"S, 30°55'59.6"E  
Weir constructed across the river channel.



## UNIT 6

### Palmiet Nature Reserve to University Road Description of the Area

#### Legend

#### Unit 6 Palmiet River Accessible

- Yes
- No

- #### Unit 6 Tributaries Accessible
- Yes
  - No

- Unit 6 Roads
- Unit 6 Stormwater Pipes
- Unit 6 Stormwater Manholes
- Unit 6 Sewer Pipes
- Unit 6 Sewer Manholes

1 cm = 40 meters

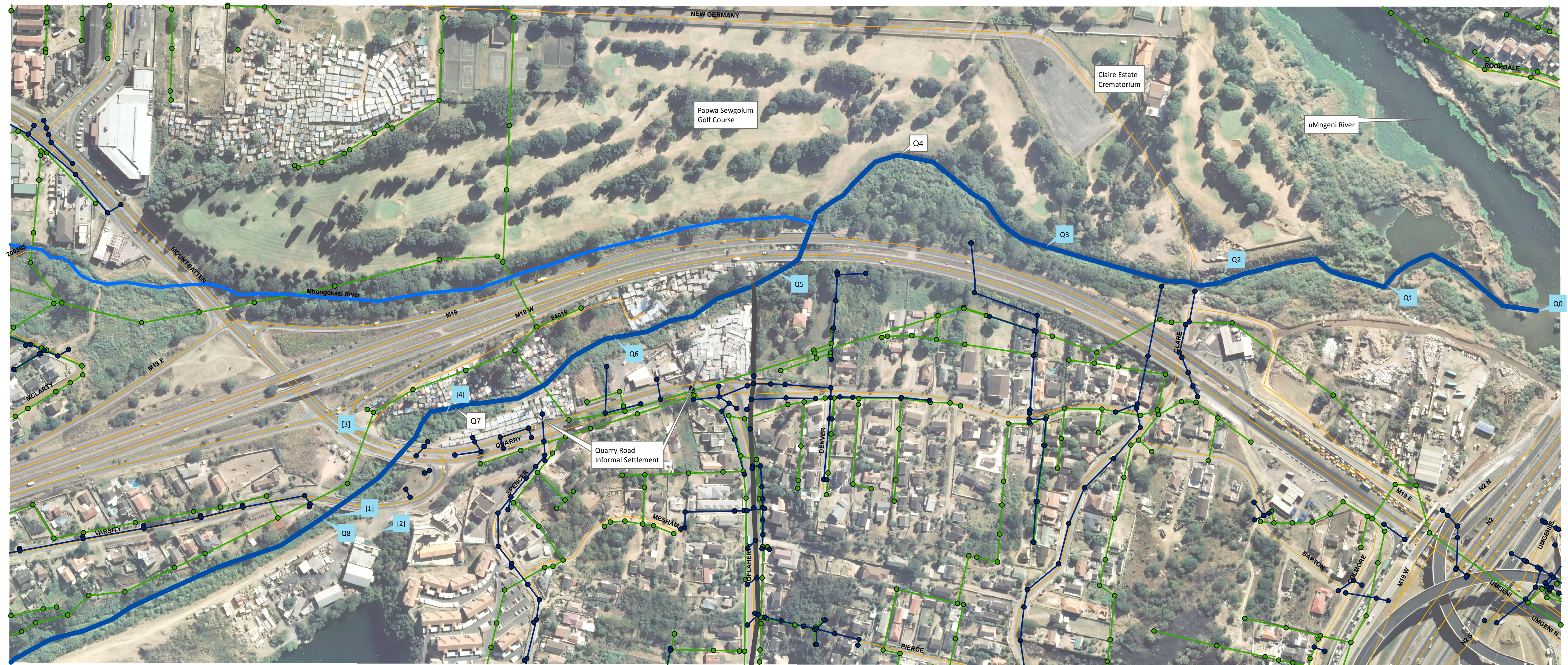


#### Figure 5-21

Drawn By: Semeshan Naidoo

Checked by: Semeshan Naidoo

Date: 27/08/2016



[1] - 29°48'20.0"S, 30°57'54.37"E  
Varsity Drive Bridge has become an accumulation point for waste.



[2] - 29°48'20.5"S, 30°57'56.4"E  
Retention pond constructed to retain the water falling down the steep cliff.



[3] - 29°48'16.8"S, 30°57'56.0"E  
Contractors dump building rubble at the Quarry Road Informal Settlement.



[4] - 29°48'16.5"S, 30°57'59.0"E  
Severe bank erosion along the river bordered by the Quarry Road Informal Settlement.

## UNIT 7

### Quarry Road Informal Settlement Description of the Area

#### Legend

Unit 7 Palmet 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 5-22

Drawn By: Semeshan Naidoo

Checked by: Semeshan Naidoo

Date: 26/09/2016

## 5.6 Impact of Infrastructure within the Palmiet Catchment

The data recorded, during visual observations along the Palmiet River, is summarized and illustrated by **Figure 5-23**. The following are a few points to consider, with regards to **Figure 5-23**:

- The deterioration of the Palmiet River is recorded right from its source in the Kloof/Wyebank residential area.
- The condition along the Palmiet River show signs of improvement as the river flows downstream, however, its condition deteriorates again at Unit 7. The majority of the worst impacts are concentrated in Unit 2, the industrial area, and Unit 7, the Quarry Road informal settlement.
- The removal of indigenous vegetation is a problem throughout the Palmiet River, the only areas that show some signs of preservation is within the boundaries of the PNR, part of Unit 5 and Unit 6. Both the bank erosion and bed modification show signs of improvement in Unit 6. This indicates that the section of the river, encompassed by Unit 6, is able to attenuate the flow to an extent. This can be attributed to the riparian zone, in these areas, which is dense with vegetation. However, the majority of the vegetation is alien vegetation.
- Moving downstream from the Unit 2, there are significantly less points along the river that contribute to the decreased water quality. Solid waste, which ends up in the river, is concentrated in Unit 2, where littering and illegal dumping is a problem, and Unit 7, where the lack of service delivery has resulted in an accumulation of waste along the riverbanks.
- Under scrutiny, it is evident that the ecological condition of certain impacts increase and decrease together. Identifying the reason for this trend led to the hypothesis of source problems, which cause a number of visible symptoms throughout the Palmiet Catchment. This concept is explored in greater detail in sub-sequent sections.
- The infrastructure statistics presented provides an overview of some of the infrastructure present in-between each waypoint. However, not all infrastructure present in-between each waypoint has an impact in that region.

Following **Figure 5-23**, an overview is provided on each unit detailing areas, which require immediate attention. Thereafter, the impact-causing infrastructure will be grouped according to the source problems within the Palmiet Catchment.

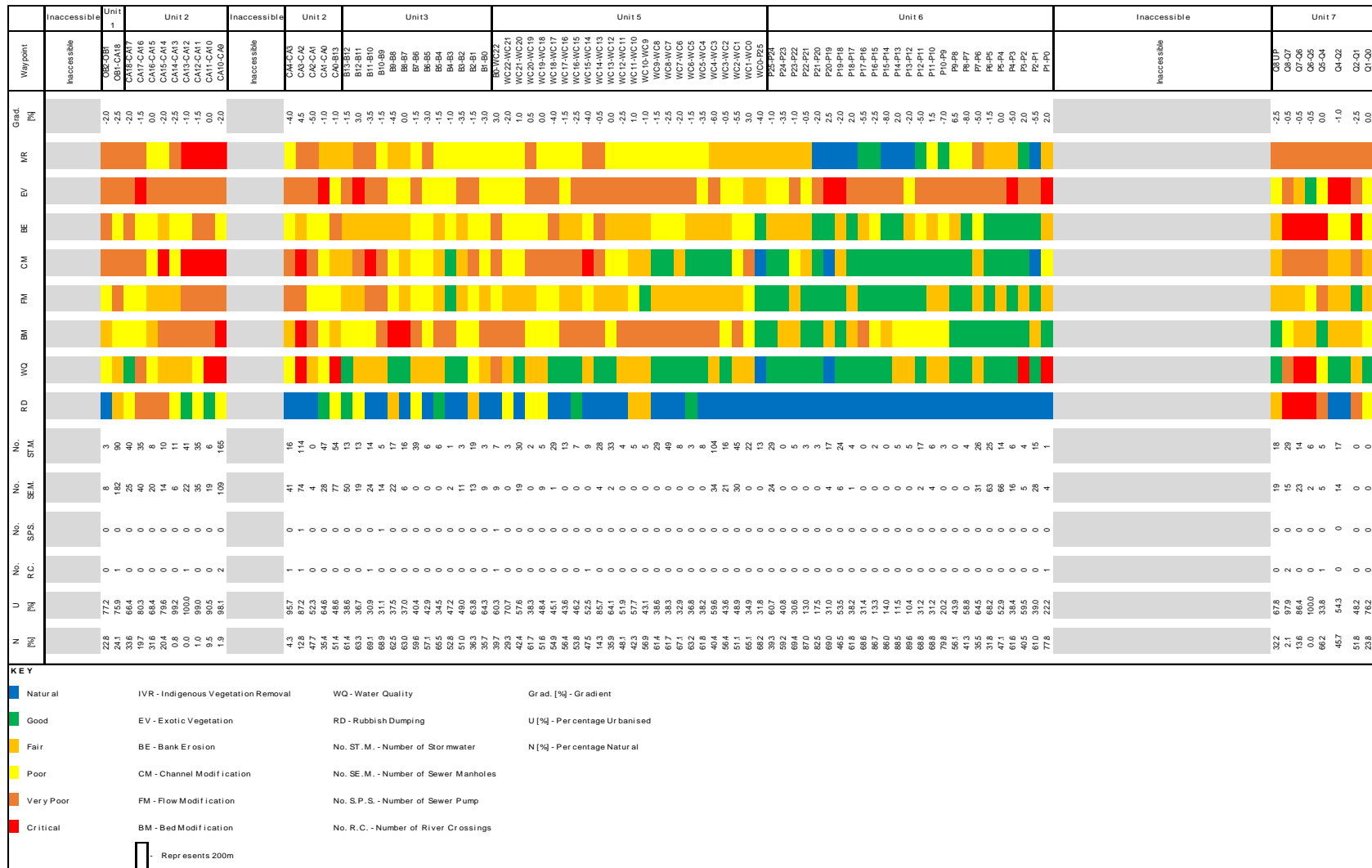


Figure 5-23: Ecological condition along the length of the Palmiet River.

## 5.7 Unit 1 – Wyebank and Kloof Residential Area

Unit 1 is a very important area as it is the highest point in the Palmiet catchment where the water quality is affected. The streams that form the source of the Palmiet Catchment have been significantly affected by the pollutants seeping out of the Wyebank Dumpsite, which has not been lined with any impervious material.

Table 5-5: Details regarding some of the infrastructure within Unit 1.

Riparian corridors have been severely impacted in this area due to the fragmentation of the natural land. **Table 5-5** presents details regarding some of the infrastructure that has aided in the fragmentation of the land.

	Details
Land use	Residential area
Area [km <sup>2</sup> ]	4.8
Hardened surfaces [%]	60.5
Length of roads [km]	96.9
Length of stormwater network [km]	11.1
Length of sewer network [km]	25.4

### 5.7.1 Overall State of Unit 1

**Table 5-6** presents the overall ecological condition of the observable areas of Unit 1. Unit 1 is an area that average in the fair ecological condition. Being a residential area, the majority of the Palmiet River, and its tributaries, flows through residential properties and has been fenced up. Ideally, more points along the river

Table 5-6: Overall ecological condition at each observation point in Unit 1.

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

\*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.

should be investigated to provide a better indication of the overall ecological condition. However, upon observation of the data record sheets, included on the attached **DVD**, it is evident that the impacts at the majority of the observation points are similar. Therefore, whilst more observation

points would be ideal, the areas that have been observed do provide a good estimate of the ecological condition.

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 recurring problems. Therefore, **Figure 5-24** was used to identify impacts that are common throughout Unit 1.

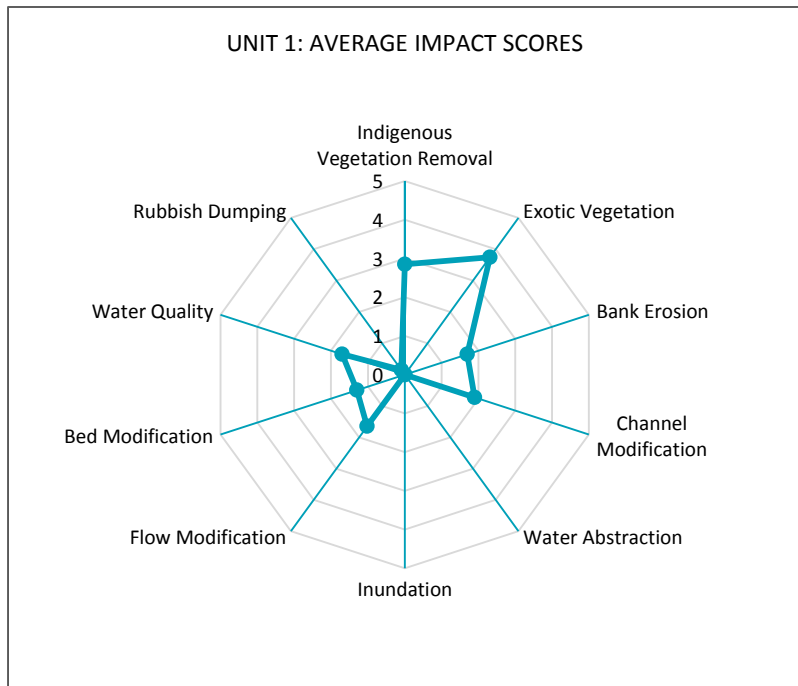


Figure 5-24: Average Ecological Impact Scores for Unit 1.

Exotic vegetation, in particular alien plants, are a problem present at each observation point, therefore, producing the high average score, as indicated by **Figure 5-24**. 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 the resources and their 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 OB2, are the 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 that 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 raw, untreated sewage. Increased flow rates do not appear to be a major problem contributing to the bank erosion. However, the sewer line has been constructed along the riverbank, which has aided in destabilizing the riverbank. Therefore, increased runoff flowing over the riverbanks is sufficient to cause the erosion of the riverbank.

- 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 in the air, 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. This is a direct result of the lack of lining around the dumpsite.

## 5.8 Unit 2 – Industrial Area

There are numerous businesses and factories in the area as well as a sewer pump station, located on Blair Road. The pump station has had numerous problems resulting in untreated sewage being discharged directly into the Palmiet River. The last major discharge occurred on the 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, certain industries have illegally discharged trade effluent into the Palmiet River. It can be noted that it is only a few industries, which cause the problem. This unit covers the Palmiet River from Glenugie Road, a pre-dominantly residential area with many housing complexes, down through the Pinetown/New Germany Residential area and up to Ambleside lane, a residential area.

**Table 5-7** presents details regarding some of the infrastructure that 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.

Immediately noticeable is the increase in infrastructure present within Unit 2 as opposed to Unit 1. The impacts of this infrastructure have been elaborated in the additional material provided on the DVD. Access to certain parts of the Palmiet River was not possible due to certain safety reasons discussed in Chapter 4.

Table 5-7: Details regarding some of the infrastructure within Unit 2.

	Details
<b>Land use</b>	Industrial area
<b>Area [km<sup>2</sup>]</b>	5.5
<b>Hardened surfaces [%]</b>	85.1
<b>Length of roads [km]</b>	137.8
<b>Length of stormwater network [km]</b>	30.4
<b>Length of sewer network [km]</b>	49.6

### 5.8.1 Overall State of Unit 2

Table 5-8 presents the overall ecological condition of the Palmiet River analysed in Unit 2, in-between each waypoint. Based on the ecological condition of the Palmiet River as well as visual observations, areas requiring immediate attention were highlighted.

Unit 1 presented conditions ranging between good to fair, however, Unit 2 presents conditions ranging from poor to very poor. Unit 2 is a vastly more urbanised area containing larger stormwater 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

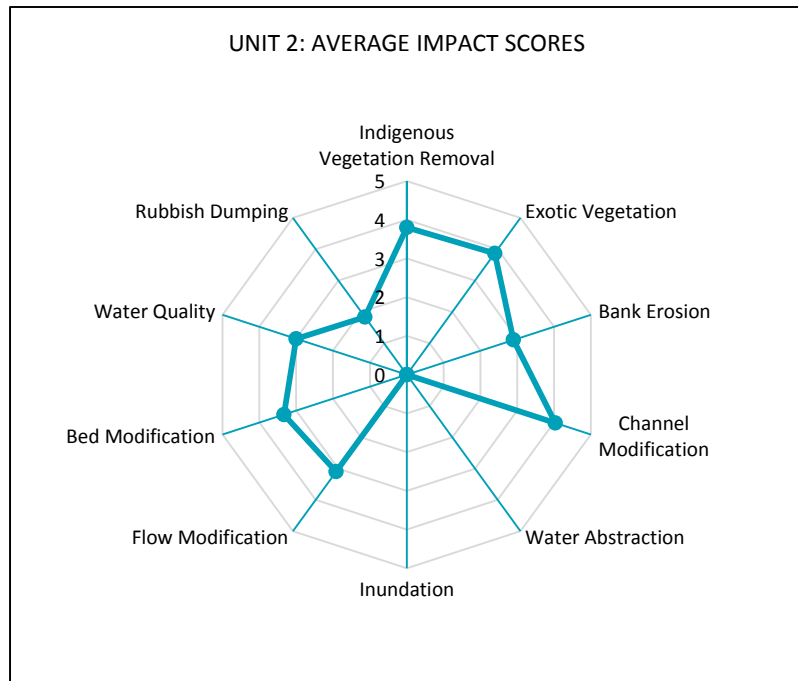
Table 5-8: Overall ecological condition at each waypoint in Unit 2.

Waypoints	*Overall Rating [ /40]	*Percentage Change [%]	*Overall Ecological Condition
OB1 - CA18	24.5	61.25	Poor
CA18-CA17	24.5	61.25	Poor
CA17-CA16	29.5	73.75	Very Poor
CA16-CA15	23	57.5	Poor
CA15-CA14	25.5	63.75	Poor
CA14-CA13	22.5	56.25	Poor
CA13-CA12	27.5	68.75	Poor
CA12-CA11	30.5	76.25	Very Poor
CA11-CA10	29.5	73.75	Very Poor
CA10-CA9	33	82.5	Very Poor
CA4-CA3	22	55	Poor
CA3-CA2	27.5	68.75	Poor
CA2-CA1	23.5	58.75	Poor
CA1-CA0	22.5	56.25	Poor
CH1-CH0	22.5	56.25	Poor

\*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.

Figure 5-25.

Comparison of **Figure 5-25** and **Figure 5-24** 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 *Figure 5-25: Average Ecological Impact Scores for Unit 2.*



In addition, Unit 2 has substantially more areas that require immediate attention in comparison to Unit 1. The areas that 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 are slowly being eroded away. After a few more heavy rainfall events, the fences may fall down due to the significant bank erosion. This erosion can be attributed to the increased levels of runoff as well as the implementation of infrastructure, which has infringed on the rivers riparian zone, thereby, destabilising the riverbanks.
- Waypoints CA12 to CA10 (Bank Erosion) - Gabion baskets have been implemented at intervals, however, 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 that have been incorrectly placed serve little function against the force of the river.
- Waypoints CA11 to CA9 (Bed Modification) - The Palmiet River, in-between the above mentioned 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 in-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, however, the above-mentioned waypoints are of particular concern. The riparian zone, in-between the above mentioned 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 channelling the river downstream.
- Waypoints CA13 to CA9 (Flow Modification) - The cementation of the riverbanks and the implementation of gabion baskets along the riverbank 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 in-between waypoints CA13 and CA9 have reduced the channel width, as a result the water flowing out the downstream side of these bridges are at a significantly higher velocity than the water entering the bridge culverts. However, these bridges have also served as an attenuation mechanism on the upstream side. Vegetation and litter, in some, cases have accumulated under these bridges, which may potentially result in the back flooding.
- Waypoints CA17 to CA14 (Rubbish Dumping) - There has been excessive dumping of both solid waste and garden refuse in-between waypoints CA17 and CA14. The problematic area is the area directly adjacent to Broadway Street, 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 onto the Palmiet rivers 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 and the illegal activities of industries. It is common to see water, which has undergone colour changes, or foam flowing out of the Ivy Road culvert during rainfall events as industries take advantage of the rain to get rid of their trade effluent.

- 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, as a result raw, untreated sewage is often discharged directly into the Palmiet River.

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

The majority of the infrastructure consists of houses, sewer networks (transporting predominantly household effluent), stormwater systems and roads. **Table 5-9** presents the lengths of the roads, sewer pipes as well as stormwater pipes within 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.

As is synonymous with the other units observed, there have also been significant impacts on this unit of the Palmiet River. Bed modification, i.e. the exposure of bedrock, is of particular concern along Unit 3 and it has been caused due to the numerous modifications made to the river system.

The statistics presented in **Table 5-9** indicate that Unit 3 is the least developed when compared to Units 1 and 2. However, there are still many significant impacts imposed on the Palmiet River and its riparian zone. These impacts have been emphasised on the additional material provided on the *DVD*.

*Table 5-9: Details regarding some of the infrastructure within Unit 3.*

	Details
<b>Land use</b>	Residential area
<b>Area [km<sup>2</sup>]</b>	4.1
<b>Hardened surfaces [%]</b>	46.7
<b>Length of roads [km]</b>	51.1
<b>Length of stormwater network [km]</b>	13.8
<b>Length of sewer network [km]</b>	15.1

#### 5.9.1 Overall State of Unit 3

**Table 5-10** 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 5-10** indicates that the average ecological condition of the Palmet River, observed in Unit 3, fluctuates between fair and poor. The areas that require immediate attention are as follows:

- Waypoints CA0 to B13 (Bank Erosion) - The bank along this section of the river is being severely eroded. This can be attributed to the increased scouring ability

Table 5-10: Overall ecological condition at each waypoint in Unit 3.

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

\*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.

of the river, particularly during rainfall events. 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 is more built 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 have seen foam on the river. Blockages in the sewer networks are common resulting in the discharge of sewage into the Palmet 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 5-26** illustrates the average scores of each impact, higher average impact scores indicate problems common throughout Unit 3.

Evident from **Figure 5-26** is the problem of bed modification. The riverbed, particularly downstream of the Birdhurst Road weir, has been scoured down to bedrock. This is a direct result of the increased flow rate within the Palmiet River, which has resulted in an increase in its scouring ability.

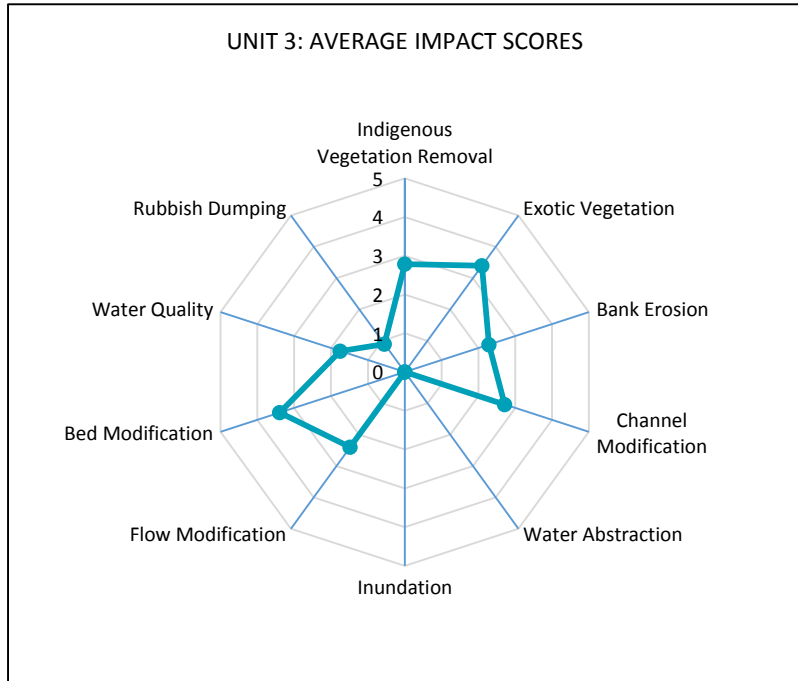


Figure 5-26: Average Ecological Impact Scores for Unit 3.

Unit 3 presents similar scores to Unit 1 in terms of the

removal of the indigenous vegetation. In addition, when considering the overall ecological, 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 will at a similar scale.

### 5.10 Unit 5 – Methven Road Pump Station to PNR

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 4.8km. This unit of the Palmiet River has a significantly wider riparian zone, averaging around 6m, in comparison to the previous units analysed. **Table 5-11** presents average statistics of some of the infrastructure present within Unit 5.

A large number of households are on septic tanks and this is indicative by the reduced sewer infrastructure present in Unit 5. This was confirmed with the EWS.

Table 5-11: Details regarding some of the infrastructure within Unit 5.

Details	
Area category	Residential area
Area [ <i>km</i> <sup>2</sup> ]	4.8
Hardened surfaces [%]	53.3
Length of roads [ <i>km</i> ]	77.7
Length of stormwater network [ <i>km</i> ]	20.5
Length of sewer network [ <i>km</i> ]	3.5

### 5.7.1 Overall State of Unit 5

Table 5-12 presents the overall ecological condition, in-between each waypoint, of the Palmet River observed in Unit 5.

As indicated by Table 5-12, the condition of the Palmet River observed in Unit 5 ranges between the fair and poor conditions. Impacts, which are problematic throughout Unit 5, are summarized in Figure 5-27.

Table 5-12: Overall ecological condition at each waypoint in Unit 5.

Waypoints	*Overall Rating [ /40]	*Percentage Change [%]	*Overall Ecological Condition
B0-WC22	23.5	58.75	Poor
WC22-WC21	22	55	Poor
WC21-WC20	18.5	46.25	Fair
WC20-WC19	24	60	Poor
WC19-WC18	23.5	58.75	Poor
WC18-WC17	20.5	51.25	Poor
WC17-WC16	18.5	46.25	Fair
WC16-WC15	20	50	Poor
WC15-WC14	25	62.5	Poor
WC14-WC13	22	55	Poor
WC13-WC12	18	45	Fair
WC12-WC11	18	45	Fair
WC11-WC10	19.5	48.75	Fair
WC10-WC9	19.5	48.75	Fair
WC9-WC8	17.5	43.75	Fair
WC8-WC7	16.5	41.25	Fair
WC7-WC6	17.5	43.75	Fair
WC6-WC5	17	42.5	Fair
WC5-WC4	15	37.5	Fair
WC4-WC3	15	37.5	Fair
WC3-WC2	12.5	31.25	Fair
WC2-WC1	17	42.5	Fair
WC1-WC0	17	42.5	Fair

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 Palmet River downstream of waypoint WC23. The sources within the Kingfisher Catchment, which increases the flow rate of the stream, have a resultant impact on the Palmet River.

\*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.

The increased volume of water flowing into the Palmet River as well as the increased volumes of water from upstream have scoured the riverbed at a larger degree 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. Descriptions on each impact

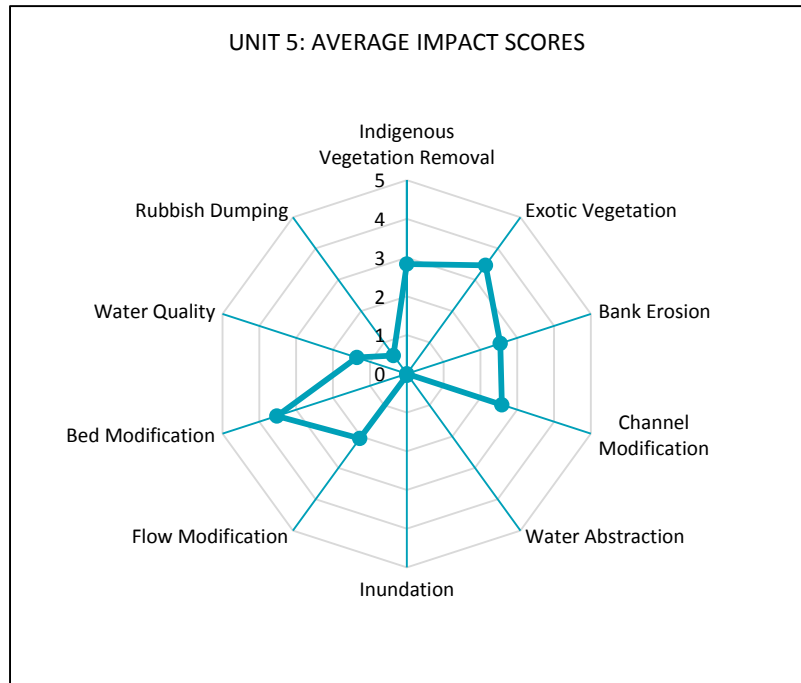


Figure 5-27: Average Ecological Impact Scores for Unit 5.

attached **DVD**. 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 Palmet 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, particularly on the downstream side of the bridges.
- Waypoints WC23 to WC22 (Water Quality) - There have been numerous reports of occurrences where the Methven Road pump station has had some sort of failure resulting in raw untreated sewage being discharged directly into the Palmet River.
- Waypoints WC22 to WC20 (Rubbish Dumping) - There has been excessive amounts of garden refuse thrown over private property fences directly on the rivers riparian zone, particularly at

waypoint WC21. The dead vegetation has smothered the natural vegetation and has attracted pests to the area.

### 5.11 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 unit, 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 impacted by the surrounding built infrastructure.

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, it is significantly less developed 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

*Table 5-13: Details regarding some of the infrastructure within Unit 6.*

	Details
<b>Area category</b>	Residential area
<b>Area [<math>km^2</math>]</b>	3.7
<b>Hardened surfaces [%]</b>	47.1
<b>Length of roads [<math>km</math>]</b>	20.1
<b>Length of stormwater network [<math>km</math>]</b>	15.3
<b>Length of sewer network [<math>km</math>]</b>	13.6

Palmiet River. **Table 5-13** presents average statistics of some of the infrastructure present within Unit 6.

5.11.1 Overall State of Unit 6

Table 5-14 presents the overall ecological condition within Unit 6. The overall scores indicates 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.

Table 5-14: Overall ecological condition at each waypoint in Unit 5.

Waypoints	*Overall Rating [ /40]	*Percentage Change [%]	*Overall Ecological Condition
WC0-P25	5.5	13.75	Good
P25-P24	10.5	26.25	Good
P24-P23	10	25	Good
P23-P22	14	35	Fair
P22-P21	11.5	28.75	Good
P21-P20	7	17.5	Good
P20-P19	8.5	21.25	Good
P19-P18	11.5	28.75	Good
P18-P17	10	25	Good
P17-P16	11.5	28.75	Good
P16-P15	12.5	31.25	Fair
P15-P14	9	22.5	Good
P14-P13	10	25	Good
P13-P12	11	27.5	Good
P12-P11	12	30	Fair
P11-P10	14.5	36.25	Fair
P10-P9	15	37.5	Fair
P9-P8	11.5	28.75	Good
P8-P7	11	27.5	Good
P7-P6	16	40	Fair
P6-P5	9	22.5	Good
P5-P4	11	27.5	Good
P4-P3	10	25	Good
P3-P2	13	32.5	Fair
P2-P1	8.5	21.25	Good
P1-P0	18	45	Fair

\*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.

Figure 5-28 provides a summary of the individual ecological conditions, which 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 few 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

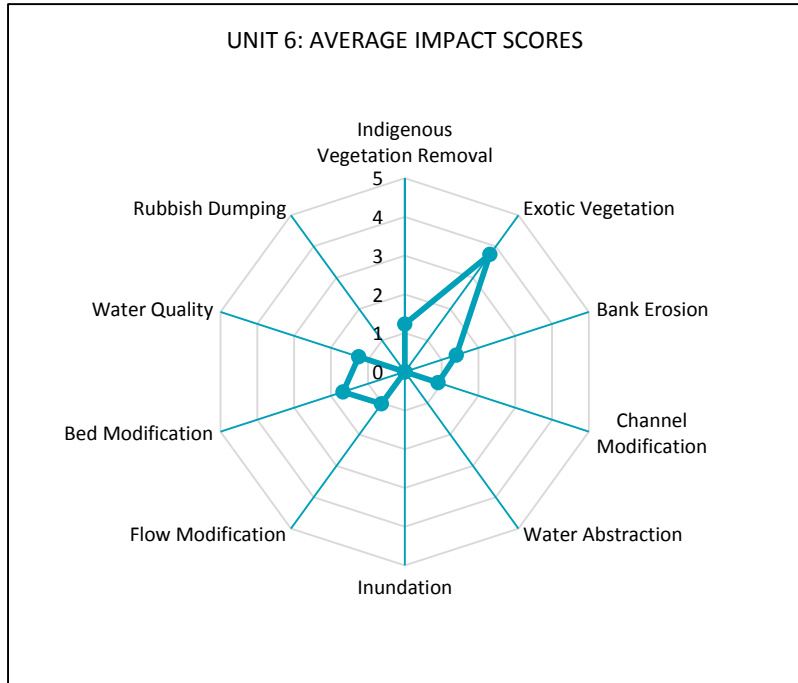


Figure 5-28: Average Ecological Impact Scores for Unit 6.

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 at the sewer manholes. Raw, untreated sewage flows into the Palmiet River affecting the water quality of all areas downstream.

### 5.12 Unit 7 – Varsity Drive Bridge to uMngeni 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 eThekweni 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. However, the Quarry Road informal settlement, due to its proximity to the Palmiet River, has not been fully recognized by the eThekweni Municipality and few services have been provided. There are numerous illegal electricity cables crossing the area and even along the riverbanks. This poses as a serious safety risk and which has 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.

**5.9.1 Overall State of Unit 7**

**Table 5-15** 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. A detailed explanation of each impact has been included on the attached **DVD**. The areas that require immediate attention are:

*Table 5-15: Overall ecological condition at each waypoint in Unit 7.*

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

\*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.

- 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 increased scouring ability of the Palmiet River as well as the destabilisation of the riverbanks by the building of houses.

- 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 where 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, the last being Black Mamba's.

The previous paragraph details individual problems that require immediate attention. **Figure 5-29**, illustrates the average ecological condition of the impacts within Unit 7.

Waypoint Q0 is the mouth of the Palmiet River and 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

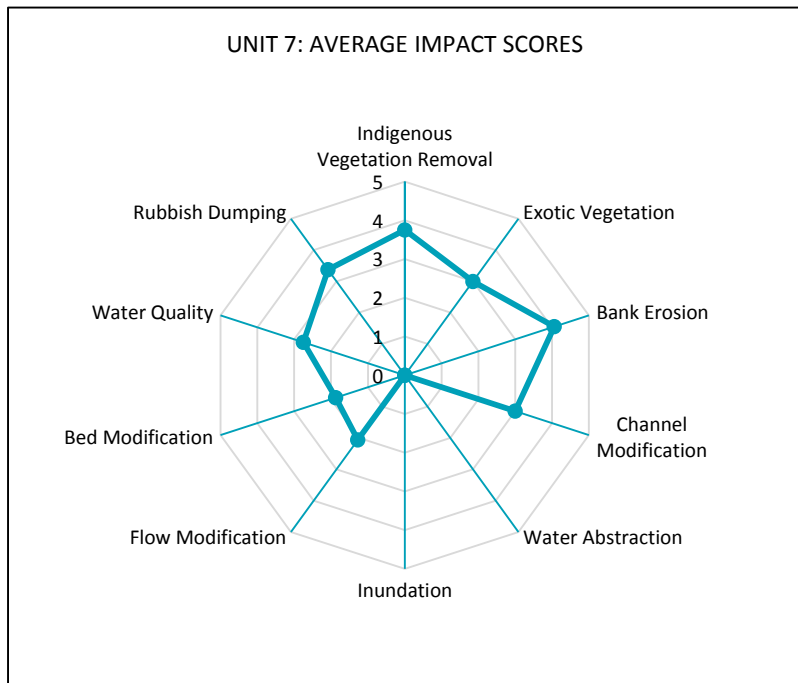


Figure 5-29: Average Ecological Impact Scores for Unit 7.

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.

### 5.13 Unit 4 - The Kingfisher Catchment

The Kingfisher Stream, a tributary of the Palmiet River encompassed by the Kingfisher Catchment, 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 that 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 1 200 m 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 that the stream flows through, the area allocated to the New

*Table 5-16: Details regarding some of the infrastructure within Unit 4.*

Germany reserve, household gardens and the small wetland located near Duncan Road. **Table 5-16** presents some details regarding the infrastructure within Unit 4. **Table 5-16** indicates that Unit 4 has similar levels of infrastructure in comparison to Unit 3. Whilst, the level of development in the area may be

	Details
<b>Area category</b>	Residential area
<b>Area [<math>km^2</math>]</b>	2.3
<b>Hardened surfaces [%]</b>	60.9
<b>Length of roads [<math>km</math>]</b>	56.9
<b>Length of stormwater network [<math>km</math>]</b>	9.4
<b>Length of sewer network [<math>km</math>]</b>	19.9

similar, in terms of the figures presented in **Table 5-16**, the Kingfisher Catchment encompasses an area of  $2.2km^2$ . The impacts of the development of the area within the Kingfisher Catchment has emphasised in the additional material provided on the **DVD**. 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.

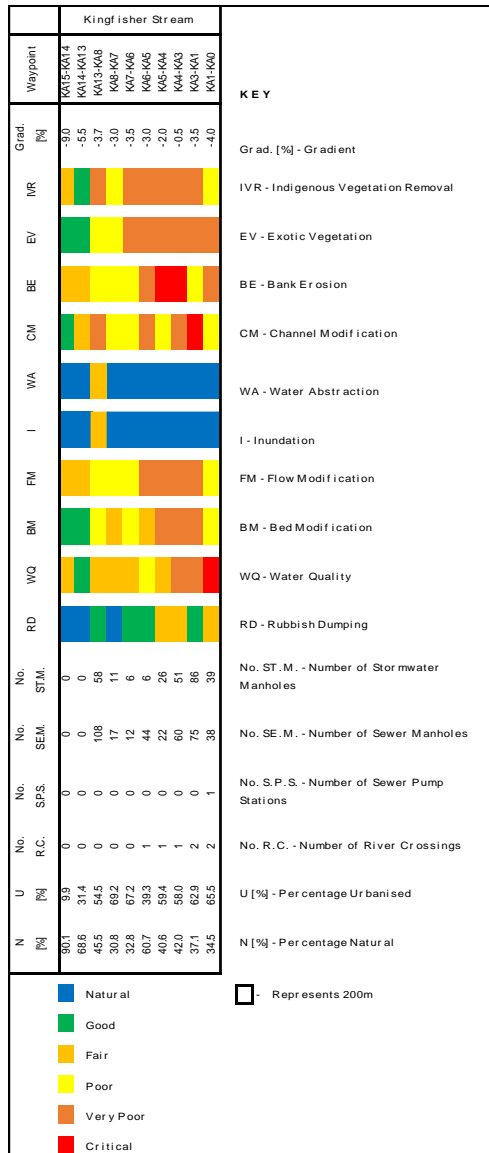


Figure 5-30: Ecological condition along the Kingfisher Stream.

**Figure 5-30** illustrates the severity of the impacts along the Kingfisher Stream. Areas that 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. This is a direct result of the concrete column supports for the sewer line, which have been implemented along the riverbanks. In addition, the increased scouring ability of the Kingfisher Stream plays a role in contributing to the bank erosion.
- 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 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 gully's 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 streambed with bedrock 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.

**5.13.1 Overall State of Unit 4**

**Table 5-17** presents the overall ecological condition at each waypoint. **Table 5-17** indicates that the average ecological condition of *Table 5-17: Overall ecological condition at each waypoint in Unit 4.*

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

Waypoints	Overall Rating [ /50]	Percentage Change [%]	Overall Ecological Condition
KA15	3.5	7	Natural
KA15-KA14	8.5	17	Good
KA14-KA13	11	22	Good
KA13-KA8	21.5	43	Fair
KA8-KA7	19	38	Fair
KA7-KA6	22.5	45	Fair
KA6-KA5	23.5	47	Fair
KA5-KA4	25.5	51	Poor
KA4-KA3	27.5	55	Poor
KA3-KA1	24	48	Fair
KA1-KA0	22	44	Fair
KF1-KF0	10.5	21	Good
KH3	19	38	Fair
KI2	9	18	Good
KJ3	14.5	29	Good
KJ3-KJ2	18.5	37	Fair
KJ2-KJ1	11.5	23	Good
KJ1-KJ0	7	14	Good

Abstraction have played a role in affecting the stream and the riparian zone and has, therefore, been included.

The most critical of the previously 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 5-31** 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

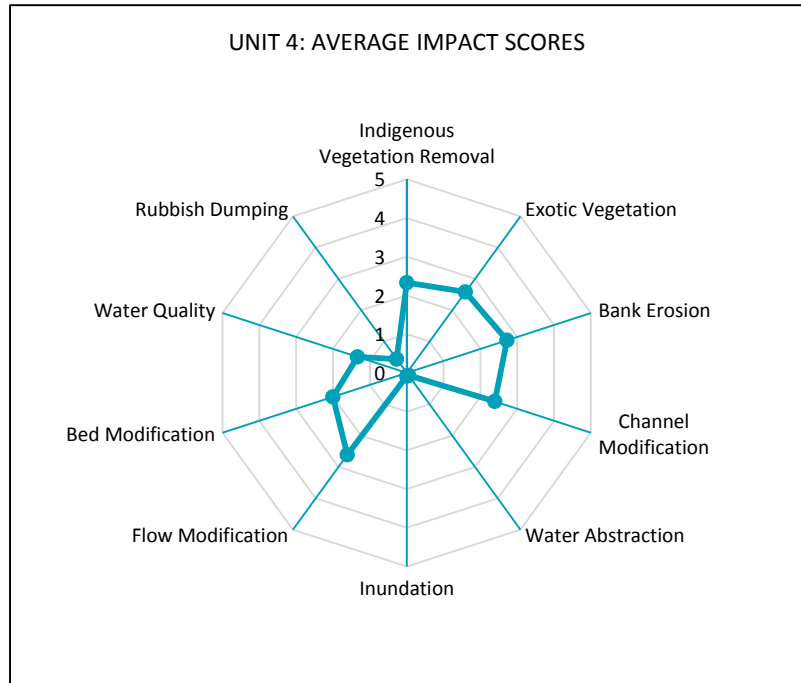


Figure 5-31: Average Ecological Impact Scores for Unit 4.

scores this assumption proved valid, however, both flow modification and bank erosion portray scores that 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 that has been significantly modified by hard infrastructure, which reduces the water's infiltration ability. This increased flow results in the scouring of the riverbanks.

## 5.14 Infrastructure at the Source

As previously explained, there are groups of impacts whose ecological conditions increase and decrease together. This substantiates the hypothesis that there are source problems, within the Palmet Catchment, which gives rise to a number of symptoms. The symptoms are easily noticeable, however, the underlying problems are ignored. The following sub-sections provides details regarding the source problems.

### 5.14.1 Flow Modification

Table 5-18 presents the infrastructure that is associated with modifications to the Palmett Rivers natural flow rate.

Table 5-18: Infrastructure associated with modifying the Palmett Rivers flow rate.

Flow Modification	
<b>Impermeable surfaces</b> -Roads -Parking areas -Walkways -Building roofs	Impermeable surfaces, for example roads, parking areas, building roofs, increase the amount of runoff being discharged into the Palmett River by preventing infiltration.
<b>River crossings</b> -Bridges -Culverts	River crossings assist in attenuating the flow rate of the river on the upstream side.
<b>Stormwater Network</b> -Stormwater manholes -Stormwater outlets	Runoff entering stormwater drains is conveyed through stormwater pipes to the river where it is discharged via the stormwater outlets.
<b>Sewer network</b> -Sewer overflow pipes -Sewer manholes	The sewer network often discharge wastewater resulting in an increased volume of substances entering the river system.
<b>Hard infrastructure modifications</b> -Gabion baskets -Cemented walls	Infrastructure implemented to stabilise the riverbanks assist in channelling the water downstream and reduces the amount of water able to infiltrate into the surrounding riverbanks.
<b>Weir</b>	Weirs serve as an attenuation mechanism.
<b>Reservoir</b>	Water, overflowing from reservoirs is conveyed through the stormwater network, and is discharged into the nearest watercourse.

Figure 5-32 illustrates the relationship between flow modification and the other applicable impacts assessed. Naturally, the removal of the indigenous vegetation, a direct result of urbanisation, is at the core of the relationship between the impacts. The indigenous vegetation has been replaced

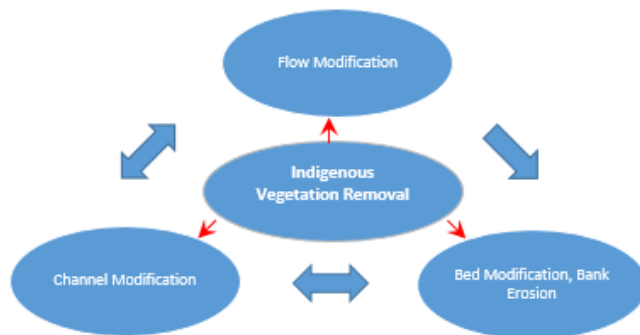


Figure 5-32: Impacts that have resulted due to flow modification.

by the infrastructure listed in **Table 5-18**. The increased flow rate of the Palmiet River, which usually lasts for a shorter duration, has resulted in the scouring of both the riverbed as well as the riverbank causing excessive erosion. In order to stabilise the riverbanks, hard infrastructure measures have been implemented along parts of the river channel. Whilst these measures have aided in stabilising the riverbanks, they have also assisted in channelling the river downstream. The implementation of supports for the sewer pipelines running along and across the Palmiet River have also aided in destabilising the riverbanks causing erosion.

The major contributor to the increased flow rate of the Palmiet River can be directly attributed to the increased levels of runoff. The Palmiet Catchment has seen a significant increase in hardened, impermeable surfaces from 1975 to 2016 as indicated by the classified Landsat imagery. The flow hydrographs, presented in **Chapter 2**, illustrate the effect the hardened surfaces have on the volume of water entering the Palmiet River over time. The increased volumes of water, prevented from infiltrating into the underlying soil can be calculated as presented by **Equation 5-1** and **Equation 5-2**.

*Equation 5-1: Volume of water prevented from infiltrating into the underlying soils in 1975.*

$$V = A * h$$

$$V = \left( \frac{36.1}{100} * 27920000 \right) * h$$

$$V = 10079120h \text{ m}^3$$

*Equation 5-2: Volume of water prevented from infiltrating into the underlying soils in 2016.*

$$V = A * h$$

$$V = \left( \frac{60.6}{100} * 27920000 \right) * h$$

$$V = 16919520h \text{ m}^3$$

Where: V = Volume [m<sup>3</sup>]

: A = Area of hardened surfaces [m<sup>2</sup>]

: h = rainfall over a certain duration [mm]

The volume has been left in terms of h as the rainfall varies between the different seasons. However, from 1975 to 2016, there is an increase of

6840400h m<sup>3</sup> of stormwater, which is unable to infiltrate into the underlying soil. However, the biggest problem is not the increased levels of runoff, it is the shorter time that it takes the increased runoff to enter the Palmiet River. The quick discharge of the stormwater into the Palmiet River has increased the rivers natural scouring ability, which has caused severe erosion. The riverbanks observed in Units 1 to 7, with the exception of Unit 6, have all been severely scoured resulting in riverbanks at varying degrees of failure.

The industrial area, encompasses 10.8 % of the Palmiet Catchment, however, it is the main contributor to the increased levels of runoff entering the Palmiet River. The numerous roads, parking facilities, walkways, storage areas and roofs have prevented the natural infiltration process resulting in the transport and discharge off runoff into the Palmiet River.

Units 1,3,4,5 and 7 also aid in the increased levels of runoff, however, not as significantly as Unit 2. The residential areas, which encompass 86.6 % of the Palmiet Catchment, are middle to high-income areas. The residential properties in Units 1,3,4,5 and 6 are big with large gardens. These gardens allows stormwater to infiltrate into the soil and seep into the Palmiet River at a slower constant rate.

The riparian zone along Unit 6 has significantly less infrastructure development in comparison to Units 1 to 5. The riparian zone is covered in dense vegetation, the majority of which is alien vegetation, however, this has aided in slowing down the flow rate of the Palmiet River and minimised the erosion of the riverbanks.

This indicates that the Palmiet River system is able to attenuate the increased volumes of runoff to an extent. However, the unrestricted growth of infrastructure development along the riparian zone of the Palmiet River has reduced the functionality of the Palmiet River system. Therefore, in order to rehabilitate and restore the Palmiet Catchment, interventions need to be implemented to aid in increasing the time taken for runoff to enter the river system.

### **5.14.2 Water Quality**

**Table 5-19** presents the infrastructure associated with contributing to the deteriorating water quality of the Palmiet River.

Table 5-19: Infrastructure associated with decreasing the water quality of the Palmiet River.

Water Quality	
<b>Impermeable surfaces</b> -Roads -Walkways -Parking areas	Impermeable surfaces prevent runoff, potentially carrying pollutants, from being naturally filtered by the soil layers before entering the river system.
<b>Stormwater Network</b> -Stormwater manholes -Stormwater outlets	The stormwater network conveys runoff contaminated with pollution into the river.
<b>Sewer network</b> -Sewer pump stations -Sewer manholes -Sewer overflow pipes	Sewer networks, often prone to failures, discharge untreated sewage into the river. Illegal stormwater to sewer connections also result in the overflowing of sewer manholes, resulting in wastewater contaminating the river.
<b>Weirs</b>	Weirs retain water in the river channel, thereby, exposing pollutants to sunlight for a longer period.
<b>Industries</b>	Illegal discharges by industries result in the deterioration of the water quality in the river.
<b>Dumpsite</b>	The absence of any sort of lining around the Wyebank Municipal Dumpsite has resulted in a number of substances, primarily organic substances, contaminating the river.
<b>Informal settlement</b>	Lack of service delivery and poor sanitation facilities has resulted in the accumulation of waste along the riverbanks and open defaecation at the edge of the riverbanks.

**Figure 5-33** illustrates the relationship between water quality and the impacts that have contributed to it. The natural vegetation was replaced by impermeable surfaces and sewer networks. The scouring of the riverbanks has caused excessive erosion that has resulted in sediment being transported into the Palmiet River. This has resulted in colour changes in the water and a decrease in turbidity levels. Rubbish dumping also plays a role in affecting the water quality with the problem areas being the Wyebank dumpsite and the informal settlements.

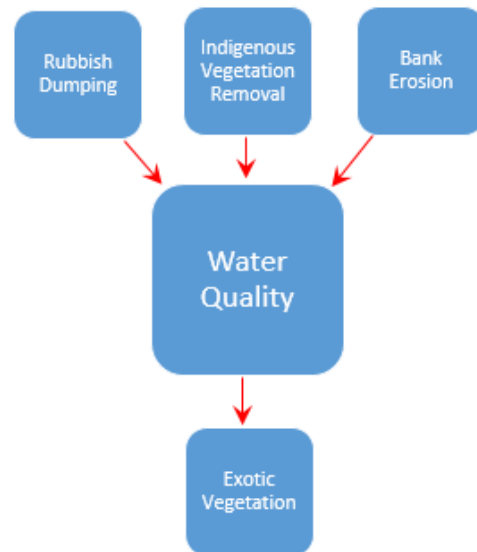


Figure 5-33: Relationship between the impacts with focus on water quality.

The sewer network was identified as a major problem, which has affected the water quality throughout the Palmiet River. The E.coli and organic loadings indicate that the sanitation system within the Palmiet Catchment is in a poor state. The majority of the Palmiet Catchment consists of middle to high-income residential areas, therefore, the majority of households are connected to the sewer network as opposed to having septic tanks on their properties. The problems at the pump stations as well as blockages in the sewer lines, have resulted in raw sewage being discharged directly into the Palmiet River. Unit 2 is the biggest problem area with regards to water quality. The majority of pollutants are introduced to the river in Unit 2, be it by illegal activities of industries, blockages in the sewer network or problems at the Blair Road pump station.

Unit 7 encompasses the Quarry Road informal settlement where there are no sewer systems in place for the residents. Observations conducted in this area yielded that the Palmiet River, and its riparian zone, is often used as a toilet due to the inadequate sanitation facilities in the area. As a result, it is both lack of adequate sanitation facilities as well as the operation of existing sewer networks that degrade the water quality of the Palmiet River.

However, the Palmiet River is polluted right from the source by leachate seeping out of the Wyebank Municipal Dumpsite. miniSASS observations near the source of the Palmiet River indicate very poor results. In addition, the Wyebank Municipal Dumpsite, upstream of the source of the Palmiet River, is polluting the source tributaries of the Palmiet River with leachate and other organic substances.

Visual changes to the Palmiet River are reported by members of the PRW. There are numerous reports of pollution incidents which originate in Unit 2 and whose affects are seen in Units 3. However, reports of visual water quality changes along Units 5 and 6 are seldom reported. This indicates that the Palmiet River system is to some extent, able to filter the pollutants. This ability, evident in Unit 5 and 6 can be attributed to a number of reasons.

The dense vegetation downstream of the upper boundary of the PNR (Unit 5) has played a role in filtering out the pollutants. The majority of the vegetation consists of alien vegetation, however, they have aided in filtering the pollutants. These pollutants have also aided in the growth and spread of the alien vegetation.

The Palmiet River, in Unit 5 and 6, has not been channelized as severely as Unit 2. The channelization of the Palmiet River, encompassed by Unit 2, has resulted in the Palmiet River flowing around factories and buildings. The narrow channel of the Palmiet River in Unit 2 is often shaded by the

surrounding buildings. However, in Units 5 and 6, a wider channel is exposed to sunlight. Studies have indicated that exposure to sunlight aids in killing bacteria in rivers, i.e. E.coli (Caslake et.al., 2004). Therefore, the exposure of sunlight along Units 5 and 6 have aided in purifying the Palmiet River to an extent.

In order to assess the impact the poor water quality of the Palmiet River has on the uMngeni River, specifically with regards to E.coli and organic loading levels, further raw sampling data was obtained from a point upstream and downstream of the Palmiet River mouth. **Table 5-20** presents the average results from 2007 to 2015 of the points upstream and downstream of the Palmiet River mouth as well as the overall result of the Palmiet River.

*Table 5-20: Impact the Palmiet River water quality has on the uMngeni River.*

Year	Sample Point			
	Upstream of the Palmiet River mouth		Downstream of the Palmiet River mouth	
	E.coli [cfu/100ml]	Organic Loading [mg/l]	E.coli [cfu/100ml]	Organic Loading [mg/l]
2007	7 444	3.2	2 500	2.8
2008	5 769	3.4	773	2.6
2009	2 583	8.8	1 727	4.1
2010	3 889	5.6	1 700	2.9
2011	7 375	4.4	64 600	3.3
2012	33 545	3.6	8 125	3.7
2013	4 625	4.5	3 273	3.0
2014	11 777	9.0	2 854	3.7
2015	33 400	5.1	5 210	3.4

It was expected that the water quality of the Palmiet River would have a negative effect on the uMngeni River, however, the results indicate the opposite when comparing E.coli and organic loading levels. According to the EWS thresholds, presented in **Chapter 4**, the E.coli levels upstream of the Palmiet River mouth has averaged in the critical region from 2009 to 2015 whilst, organic loading results average in the poor region. The E.coli levels ascend to poor levels downstream of the

Palmiet River and the organic loading levels increase to acceptable standards. There have been two years where this trend was not reciprocated and these values have been highlighted in grey in

**Table 5-20.** The Palmiet River aids in improving the water quality of the uMngeni River, to an extent. However, the dilution, which arises when the Palmiet River flows into the uMngeni River, may also be a contributor to the improved results. However, interventions implemented within the Palmiet Catchment to improve the quality of water will have a greater impact on improving the water quality of the uMngeni River.

### 5.14.3 Alien Vegetation

This problem has been introduced by homeowners. A variety of exotic plants was introduced to the gardens, of residential properties, based on their aesthetics. The alien vegetation has spread into the neighbouring areas and has become a problem throughout the catchment. Ideal conditions, i.e. sufficient water, sunlight and lack of competition, has allowed these plants to thrive.

### 5.14.4 Service Delivery and Human Ignorance

The upper areas of the Palmiet Catchment, i.e. Units 1 to 5, are middle to high-income areas. As a result, there are no service delivery problems in these areas. Being middle to high-income areas, there is a significantly higher amount of waste produced in these areas as opposed to lower income areas, i.e. the informal settlements. The rubbish dumping, which occurs in the upper areas of the Palmiet Catchment, is mainly due to the lack of consideration for the natural environment. Individuals, unable or unwilling to take responsibility for their waste items have discarded their waste items on the riverbanks in the hopes that the Palmiet River take care of it for them.

In the lower areas of the Palmiet Catchment, i.e. Unit 7 and the surrounding informal settlements, the lack of service delivery is a major problem. The amount of waste generated in the informal settlements is significantly lower than in the middle and high-income areas, however, the waste generated has been allowed to accumulate due to the absence of service delivery. In addition, lack of trust between the municipal officials and the residents of the informal settlements, have prevented anyone from the municipality from entering these areas.

Waste, originating from any source, is transported by the Palmiet River into the uMngeni River and eventually ends up on the Durban beachfront. The eThekweni Municipality spends money every year

cleaning the litter off the beachfront. However, it would be more beneficial to invest this money in mitigating the waste from being transported to the Durban Beachfront.

#### **5.14.5 Enforcement of Laws and Regulations**

Numerous effective laws and regulations have been devised to protect the natural environment. However, the acknowledgement of the various laws and regulations is inadequate. There needs to be continuous monitoring and checks to verify that everyone is upholding the law and their actions are in line with them. There are numerous cases where the Palmiet River has been polluted or contractors have illegally dumped their waste items along the riverbanks and not been prosecuted.

### **5.15 Potential Remedial Interventions**

The potential interventions proposed in the following sub-sections have been divided into short-term interventions and long-term interventions. Short-term interventions are quick and easy to implement and will address the symptoms of the underlying problems present in the Palmiet Catchment. These interventions are required to prevent further degradation whilst the long-term interventions are approved. The long-term interventions will address the source of the problems. The interventions stated below are further divided into municipal driven projects, individual/community driven projects and projects that will benefit from the co-operation of both the eThekweni Municipality as well as individual landowners. Municipal driven projects will be an initiative from the municipality and implemented in public areas. Individual/community driven projects are those that can be implemented in private properties, should the owner wish to do so.

#### **5.15.1 Short-Term Interventions – Municipal Driven Projects**

##### **5.15.1.1 Gabion Baskets and Masonry Drop Works**

Gabion baskets or masonry drop works do not have to be implemented along the entire river, however, they need to be implemented at regular intervals to successfully attenuate the flow rate of the Palmiet River. Areas that will benefit from these interventions were selected based on the impacts to the area. For example, areas where the riverbanks have been severely scoured resulting in severe erosion as well as areas where the extended exposure of bedrock was present was considered priority areas which would require upstream interventions to reduce the flow rate of the Palmiet River. Areas, which would benefit from flow attenuation measures include:

- Industrial area (Unit 2) – Downstream of Crompton Street Bridge.
- Cowies Hill Residential area (Unit 3) – Both upstream and downstream of the Birdhurst Road weir.
- Kingfisher Stream (Unit 4) – Preferably downstream of the Atholl Heights School.
- Rodger Sishi Bridge (Unit 5) – Both upstream and downstream of the bridge.
- Quarry Road Informal Settlement (Unit 7) – Both upstream and downstream of the Quarry Road Bridge.

The implementation at the above strategic points will greatly benefit the downstream areas by reducing the scouring ability of the Palmiet River, reducing riverbank erosion and will allow the riparian vegetation to grow along the riverbanks. In addition, the water will be kept in the river channel for a longer period, thereby, increasing the exposure of the water to sunlight. Studies have indicated that exposure to sunlight aids in killing bacteria within water bodies.

#### **5.15.1.2 Gabion Baskets, Geo-textile Bags, Vetiver Grass**

Whilst the implementation of the gabion baskets/masonry drops works will aid in retaining the flow and decreasing the high scouring ability of the Palmiet River, there are areas along the Palmiet River that require measures to stabilise the riverbanks. Therefore, interventions to stabilise the riverbank needs to be implemented in conjunction with flow attenuation interventions.

The use of Vetiver Grass, whilst not indigenous, is highly beneficial in providing stability to the riverbanks due to their long roots and fast growth. Vetiver grass does not spread. They have been used in many areas to stabilise the riverbanks. In addition, planting of Vetiver grass will also reduce the amount of pollutants, transport by runoff, into the Palmiet River. However, the vegetation will require time to grow and the critical areas required previously require immediate interventions.

Therefore, around these areas the use of geotextile sand bags or gabion baskets are required to reinforce the riverbanks. Whilst not ideal, the situation calls for an intervention that can be immediately implemented. Vegetation will be to catch on much faster along geotextile bags as opposed to gabion baskets.

With the use of geotextile sand bags or gabion baskets, it is critical that these are implemented along both sides of the Palmet River bank, at the areas stated below, to prevent the erosion of the opposing bank. The following areas were identified as critical as further bank erosion could compromise the surrounding infrastructure and present a safety hazard.

- Unit 1 (Between observation points OB2 to OB1)
- Unit 2 (Between waypoints CA12 to CA10)
- Unit 3 (Between waypoints CA0 to B13)
- Unit 4 (Between waypoints KA5-KA3)
- Unit 5 (Between waypoints WC23 to WC22)
- Unit 7 (Between waypoints Q8 to Q4 and Q2 to Q0)

#### **5.15.1.3 Alien Vegetation Removal**

Alien vegetation, whilst not all are considered invasive, still pose a problem throughout the Palmet Catchment. Due to the flooding events of the Palmet River and constant exposure to pollutants, the riverbanks have had a major invasion of alien vegetation. The Palmet River acts as a dispersal mechanism for the seeds and spores given off by the alien vegetation. However, as much as the alien vegetation is considered a problem to be rectified, there are certain plants, such as the Spanish Reed and Napier Grass, which have been integral in stabilising the riverbanks and reducing erosion. Therefore, by removing this vegetation, additional interventions need to be implemented to prevent the erosion of the riverbanks.

Control measures needs to involve the killing of the current alien vegetation, the killing of any potential seedlings and regular follow-up inspections to prevent any possible re-growth or re-invasion. There are three general principles, which should be adhered to in any alien control method strategy, devised:

- The light alien invasive vegetation should be dealt with first, as it is generally easier to deal with, balloon vine is a major problem throughout the Palmet Catchment and is a prime example of light alien vegetation, which could be eliminated first.

- The spread of the alien vegetation usually occurs downhill, therefore, the area around the Wyebank Municipal Dumpsite should be where the eradication of alien vegetation begins and from there, efforts should move downwards through the catchment.
- It is unlikely that control measures will be 100 % successful the first time round, therefore, follow-ups and regular monitoring of the area is of critical importance to prevent any re-growth or re-invasion. Often, within the Palmiet Catchment, efforts are made to remove the alien vegetation from certain areas, however, the lack of regular monitoring has allowed the alien vegetation to re-invade the area.

It is highly recommended that the alien vegetation removed should be re-used for other purposes where possible. Many alien plants can be used for compost, firewood, building materials and furniture. Therefore, the benefits that arise from the removed alien plants needs to be considered before they are discarded, this will promote the concept of re-use.

#### **5.15.1.4 Education**

Education and the understanding of the problems within the Palmiet Catchment are critical in rehabilitating and maintaining the Palmiet Catchment. Awareness needs to be created to all who live and work in the Palmiet Catchment about how it is being impacted by the surrounding infrastructure and illegal activities of individuals. This can be done by providing everyone within the Palmiet Catchment with brochures explaining the negative impacts. In addition, these brochures can contain information relating to how individuals can take responsibility and, in their own, way help restore the Palmiet Catchment. The majority of landowners within the Palmiet River are unaware that the implementation of measures, such as SUDS and DWWTP on their properties, can be beneficial to them and the catchment.

### **5.15.2 Short-Term Interventions – Individual/Community Driven Projects**

#### **5.15.2.1 Palmiet River Watch**

The PRW, started by Lee D’Eathe in 2013, regularly monitors the water quality of the Palmiet River. Any change to the smell or colour of the river is immediately reported. The river watchers include residents and business owners who live or work alongside the Palmiet River and its tributaries. However, there are blind spots along the river where there are no river watchers. Getting more people to join the organization, from these areas, would be a great way to increase awareness and

create a sense of responsibility towards the environment. Similar organizations can be initiated in other catchments, which will promote the restoration of said catchments.

### **5.15.3 Short-Term Interventions – Co-operation between the Municipality and Individuals/Community**

#### **5.15.3.1 Promotion of Recycling**

Higher up in the Palmiet Catchment, the lack of awareness and human ignorance are the contributors to the litter in the catchment. Greater awareness needs to be created around the effects of littering and discarding rubbish along the riverbanks. This can be done through television adverts and putting up posters. In addition, individuals need to be made aware that items such as glass can be recycled, and that there are companies willing to pay for it. The eThekweni Municipality could potentially bring DSW on-board and get them to buy glass and other items from individuals. Individuals can make money by recycling their waste items. In the current era, individuals require an incentive to “do good”, therefore, by agreeing to pay for certain waste items, individuals have an incentive to recycle their waste.

Keeping with the idea of giving individuals an incentive, competitions can be held within the different suburbs. For example, the individual, which brings in the most waste for recycling, for any given time period, will receive a pre-determined lump sum of cash. With the current rates of inflation, individuals will be willing to do almost anything to earn some extra money.

Individuals who dump their rubbish along the Palmiet Riverbanks, particularly evident in the industrial area, should be heavily fined so they think twice about doing so. In order for them to be caught, regular monitoring needs to be conducted.

#### **5.15.3.2 Solid Waste Clean-up**

Quarry Road is the major area identified where rubbish dumping is a problem. On the 23rd of September 2016, they had initiated a waste disposal project, whereby, the residents will collect different types of solid waste, i.e. plastic, paper, cardboard etc. DSW will collect the waste items collected and the residents will be paid for collecting the items. This will significantly reduce the amount of waste discarded along the riverbanks and create awareness in the area. This has been initiated on a small scale and around 10 people from the community will help in collecting the waste.

However, it is recommended that the eThekweni Municipality pay for recycling containers to be placed at Quarry Road. Every resident can then contribute to the correct disposal of his or her waste items. The waste items will, therefore, not be discarded along the riverbanks and transported downstream to the beachfront areas. Whilst the Palmiet River may not contribute to all the litter found on the beachfront, it does transport waste items to the Durban beachfront. Savings incurred from cleaning up the beachfront can be better spent on remedying the ecological infrastructure.

Residents of the Quarry Road informal settlement also indicated that they do not always receive bin bags to discard their waste items. It is highly likely that the contractors hired to give out these bags are in fact taking them and privately selling them. It is up to the eThekweni Municipality to monitor the contractors to ensure that the residents get the monthly supply of black bin bags.

There are also other informal settlements within the Palmiet Catchment. It would be a good initiative for the waste disposal project, initiated at Quarry Road, to gain momentum. It can then be implemented within the other informal settlements. Distrust between the residents of the informal settlements and the municipality have prevented any municipal official from entering these areas. Therefore, the residents of the Quarry Road informal settlement should spread the word about how the municipality is aiding them in cleaning up their area. To promote trust between the municipality and residents of the informal settlements, the municipality should employ some of the residents to clean up the waste. This will be beneficial to the residents of the informal settlements, the Palmiet Catchment, the uMngeni River and the Durban beachfront, as jobs will be created and there will be slightly less waste on the beachfront.

#### **5.15.4 Long-Term Interventions – Municipal Driven Projects**

##### **5.15.4.1 Detention Pond**

Detention ponds are temporary storage areas, which are designed to accommodate stormwater runoff for short periods. This is not to be confused with retention ponds, the core difference being that a retention pond always contains water. The stored stormwater is able to infiltrate into the underlying soil layers or it can be discharged into watercourses at a pre-determined rate. Stormwater outlets can be diverted into detention ponds. The detention pond will be able to store the stormwater and discharge it at a constant rate into the Palmiet River. In addition, filter traps inserted into the inflow stormwater outlet can potentially remove pollutants from the stormwater runoff, therefore, discharging cleaner water into the Palmiet River.

The construction and implementation of detention ponds are directly dependant on space. Therefore, when considering the Palmiet Catchment, the area, which will benefit the most from a detention pond is the New Germany Nature Reserve, above waypoint KH3. As previously explained, there are numerous stormwater outlets being channelled to a point, the resultant inflow of stormwater has eroded the surrounding areas and damaged the protection works implemented. This area is municipal land, therefore, the implementation of a detention pond will not be a problem with regards to space.

The other area, which will benefit from the implementation of a detention pond, is the area between waypoints KJ3 and KJ2, of Unit 4. When the reservoirs overflow, the water is discharged through the stormwater outlets at this point which has resulted in the heavy scouring of the surrounding area. Measures need to be implemented to prevent the reservoirs from overflowing such as sensors if there are not any currently, however, should those measures fail, the detention pond should act as a secondary measure. However, a detention pond in this area should be designed to accommodate a greater inflow than can be expected from rainfall. The volume of water, which overflows, needs to be incorporated into the calculations when sizing the detention pond. The detention pond will need to be fairly large, possibly with more than one chamber i.e. each chamber flows into the one below it, thereby, reducing the force at which the water is flowing.

The initial costs, as with all other SUDS interventions, will be relatively high. In addition, the cost associated with extending the stormwater outlets, so they flow directly into the detention ponds, needs to be incorporated in the final costs.

#### **5.15.4.2 Pervious Pavement**

Pervious pavement option 2, as described in **Chapter 2**, is the design, which allows the runoff to recharge groundwater as well as to be collected for other purposes. This will allow both humans and the environment to benefit equally from the management of stormwater, in line with the concept of sustainable development, which was discussed in **Chapter 2**.

In order to incorporate the pervious pavement design, the existing pavement layers would need to be removed. The costs incurred would dissuade all private landowners from incorporating it. Therefore, it is recommended that the eThekweni Municipality implement pervious pavements at new developments in public areas. The Pinetown/New Germany industrial area is currently being upgraded with Bus Rapid Transport (BRT) lanes. It would be beneficial if pervious pavements were

used along the sidewalks as well as for the proposed bus terminals and passenger queuing areas. The BRT lane runs throughout the industrial area, the largest land area from all 7 units covered by hard, impermeable surfaces, therefore, the implementation of pervious pavements in this area would have the biggest effect.

#### **5.15.4.3 Stormwater Drains**

Stormwater drains are found throughout the Palmiet Catchment, on roads and parking areas. The conventional stormwater drain design consists of an impermeable base. However, this design could be adapted to incorporate a permeable base. This will allow runoff, which collects in the drain, to filter into the underlying soil. This will reduce the amount of runoff entering the Palmiet River as well as the time that it takes for the runoff to enter the Palmiet River. Existing stormwater infrastructure can be adapted to incorporate the porous or permeable base, therefore, reducing the costs of implementing a new stormwater drainage system.

Unit 2, the industrial area, should be the first area where the permeable base stormwater drains are incorporated due to the large surface area covered by hard, impermeable surfaces. The resultant effect will potentially reduce the rivers scouring ability, thereby, reducing the erosion and exposure of bedrock observed in Unit 3.

#### **5.15.4.4 Sewer Network Monitoring Systems**

Quite often both manholes and sewer pipes overflow without anyone noticing. It is only once the contamination has reached critical levels that people downstream notice changes in colour and odour. However, by this stage, there would have already been substantial impacts to the water quality, aquatic wildlife and surrounding environment.

Therefore, there should be a system in place, which is able to detect when sewer manholes reach a certain level or if sewer overflow pipes are discharging sewage into the Palmiet River. Systems have already been implemented to detect leaks in water pipelines. Similar technologies can be implemented to detect overflowing instances in the sewer network. Internal leak detection systems used in water pipelines which measure the flow or pressure across two points can be retrofitted to the sewer pipelines. In addition, if individuals had connected their stormwater to the sewer network, this can be identified by the increased flow rate between the two points, during rainfall events.

Sensors can also be implemented at each manhole relaying information when the wastewater in the systems exceeds a certain amount. During heavy rainfall events, this can be attributed to illegal stormwater connections. The DWS can then employ their tactic of putting smoke down the sewer manhole and then wait and see which property it escapes from. Should there be overflowing of the sewer manholes on a day with no rainfall, the overflowing can be attributed to blockages in the network.

The systems would require constant monitoring which will aid in job creation. Rather than waiting for a sewage overflow to be reported, by which the time the damage has already been done, implementing monitoring systems will allow potential overflowing instances to be mitigated. However, the cost factor of implementing these systems plays a major role. It is recommended that further research be done on these systems, taking into consideration the continuous costs associated with purifying water resources.

#### **5.15.4.5 Decentralized Wastewater Treatment Plants**

The Palmiet River is continuously being polluted by raw sewage, be it by the pump station failures or the overflowing of the sewer networks. DWWTP, as discussed in **Chapter 2**, has the potential to reduce the load on the sewer network as it allows sewage to be treated on site and re-used for non-potable uses.

The DWWTP can be implemented at the 3 pump stations to act as a safety measure to accommodate the sewage once the 2-hour storage capacity has been exceeded. The DWWTP has a large capacity and can be installed in a parallel configuration, which further increases the capacity. The treated wastewater can then be used for non-potable uses at the pump station or discharged into the Palmiet River, at an improved quality than the discharge of untreated sewage, as is the current norm.

DWWTP can also be implemented at common overflow points along the sewer network. Should blockages arise in the sewer network, the wastewater can be diverted to a DWWTP instead of being discharged into the Palmiet River.

#### **5.15.4.6 Wetland**

Before considering the option of investing in a constructed wetland (CW), the wetland, currently existing in Unit 4 along Duncan Road, needs to be rehabilitated. The wetland area has become

overgrown with alien vegetation. The restoration of the existing wetland should be prioritised over the construction of a new one. Continued degradation to the existing wetland will result in further negative impacts to the downstream areas, an aspect that has become evident by the removal of the wetland at Sunnybrae Park, also from Unit 4.

Whilst the implementation of CW's will provide significant benefits to the entire Palmiet Catchment, in terms of flood attenuation, improving water quality and promoting biodiversity, CW's need to be implemented in conjunction with other measures. The Palmiet River is quite often susceptible to severe pollution events, therefore, whilst wetlands are able to purify water, the water quality entering the wetland will cause the degradation of the wetland (Randwater, 2016). Therefore, should CW's be considered a viable, cost effective solution to the current problems facing within the Palmiet Catchment, they would need to be implemented with upstream pre-treatment measures.

The ensuing discussion will focus on areas that could benefit from the implementation of a CW. Further studies, regarding wetland delineation, needs to be conducted to gather information relating to the water table, types of soils, preferably hydromorphic, and types of plants, preferably hydrophytic (DWS, 2008). The areas presented below are strategic points, on municipal land, which were identified based on the benefits to the downstream areas.

- **Area 1 (Wyebank Municipal Dumpsite)** - The implementation of a CW, upstream of observation point OB7 and running across the base of the dumpsite, will positively affect the water quality of the streams, which forms the source of the Palmiet River. The leachate seeping out the dumpsite will have high organic loading levels, due to the disposal of large volumes of household waste. Therefore, as previously explained, to implement a wetland and maintain its ecological condition, it is highly recommended that some form of leachate pre-treatment occur. Thus, the wetland can provide a “polishing effect” on the water quality.
- **Area 2 (Municipal Land Opposite Ambleside Lane)** - As detailed in previous sections, Unit 3 has the worst cases of riverbed scouring which has resulted in the exposure of bedrock. The rivers scouring action has also extended to the riverbanks causing significant erosion. This is a direct result of the increased high flows present in the Palmiet River, particularly during heavy rainfall events. The industrial area, upstream of the proposed location for the CW, has the most area covered by impermeable surfaces throughout the catchment. As a result, the amount of runoff

entering the river in this area, particular during heavy rainfall events, will be significantly more than in any other area.

In addition, there have been numerous pollution incidents, originating from the industrial area, being reported downstream as individuals along the river have noticed the colour changes in the river. These are reported to EWS officials who then follow-up. However, by this time the water quality has already been severely compromised. The CW could potentially act as a barrier, filtering out the pollutants and therefore, the water quality will not be as significantly compromised as opposed to without any median in-between. However, as previously stated, the CW will need to be implemented in conjunction with upstream pre-treatment measures so as to not compromise the integrity and functioning of the wetland.

There are numerous benefits associated with investing in large ecological infrastructure projects such as a wetland. However, in the case of the Palmiet River where there are areas which require immediate attention, it would be more beneficial to invest in a number of smaller interventions at the critical areas to prevent further degradation of the catchment while the source of the problems are being addressed. Thereafter, the options of wetlands can be re-investigated to further enhance the ecological condition of the Palmiet Catchment.

The high levels of continuous pollutants introduced to the Palmiet River, as indicated by the analysis of the Palmiet River water quality, validates the implementation of pre-treatment measures. The processes and requirements needed for the proposal, construction and implementation of a wetland requires time, however, there are areas along the Palmiet River, which are in critical condition requiring immediate attention.

### **5.15.5 Long-Term Interventions – Co-operation between the Municipality and Individuals/Community**

#### **5.15.5.1 Pervious Pavements**

All new developments, private or public, need to incorporate SUDS in their designs. Whilst this is beneficial, the problem lies with the existing area covered by hard, impervious surfaces. Any new development will only add to the current problems. Therefore, should private land owners wish to incorporate pervious pavements on the land, the eThekweni Municipality could agree to cover part of the costs or re-reimburse private landowners in some way. Individual landowners will benefit the

most from pervious pavement option 3, detailed in **Chapter 2**, as all the runoff can be collected and used directly for non-potable activities. Parking areas, driveways and walkways would be ideal locations, on private land, where pervious pavements can be incorporated.

#### **5.15.5.2 Gravity Fed Rainwater Harvesting System**

Gravity fed rainwater-harvesting systems will be more cost effective to implement than rainwater harvesting systems that require pumps to transport the runoff. The voluntary implementation of a rainwater harvesting system on private property should be encouraged within the Palmiet Catchment. The eThekweni Municipality could subsidy property owners who are willing to implement a rainwater harvesting system on private properties. A rebate is given to individuals who have implemented solar geysers and the idea is slowly gaining momentum, therefore, a similar approach should be considered with rainwater harvesting systems.

The primary benefits of incorporating rainwater-harvesting systems in the Palmiet Catchment are:

- Reduce the monthly water bill of households and businesses.
- Reduce the high flows and scouring ability of the Palmiet River during rainfall events.
- Reduce the overall stress on water resources.
- Increase awareness and education on the benefits of re-using water.

Rainwater harvesting systems, due to the variability of rainfall in South Africa, are designed to be a supplement to the water demands. The variability in rainfall prevents individuals from being directly dependant on such a system.

#### **5.15.5.3 Decentralized Wastewater Treatment Plants**

DWWTP can also be implemented on a voluntary basis on private properties. This allows individuals to take some level of ownership for their wastewater. The treated wastewater can be used for non-potable activities. However, the costs of implementing a DWWTP will be high for private landowners to shoulder. As a result, they will not be interested in implementing an expensive system irrespective of the long-term benefits. In order to increase interest in this technology, the municipality could agree to cover part of the costs, reimburse the landowners in some way or provide some sort of incentive.

The Quarry Road informal settlement has inadequate sanitation facilities to cater for the residents. Containerised ablution facilities have been set-up at the Quarry Road informal settlement, however, these facilities are often blocked with the wastewater overflowing into the settlement and into the Palmiet River. The wastewater could be diverted to a DWWTP. The wastewater, once treated, can be used for non-potable uses within the settlement. The Quarry Road informal settlement was investigated, however, DWWTP can be implemented within all the informal settlements within the Palmiet Catchment. It is highly recommended that the municipality cover the costs of implementing DWWTP in the informal settlements as the residents will be unable to cover the expenses of a DWWTP.

This will increase trust in the relationship between the eThekweni Municipality and the residents of the informal settlement. In addition, the residents will be able to learn how to use and maintain the DWWTP and the benefit it has for them and the surrounding environment.

#### **5.15.5.4 Buffer Zones**

Recommended, minimum buffer widths have been presented in **Chapter 2**. The buffer zones, within the Palmiet Catchment, are in a poor condition due to the infestation of alien vegetation, encroachment of the surrounding developments and the impacts of urbanisation. Whilst it is not possible to increase the width of the buffer zones without demolishing existing infrastructure, the remnants of the buffer zones can be rehabilitated and maintained. Private property owners can assist by simply removing alien vegetation and planting indigenous vegetation. However, for this to be effective, it needs to be done in conjunction with the alien control measures. Private property owners should also restrict and where possible abstain from developing the buffer zone areas. Preserving and maintaining these buffer zones will play a role in reducing the negative impacts imposed on the river system.

#### **5.15.5.5 Employment**

The implementation of the interventions suggested will give rise to numerous job opportunities. It is recommended that the eThekweni Municipality should employ people from within the Palmiet Catchment, i.e. the residents of the informal settlements. Awareness will be created and the residents will earn an income every month.

## CHAPTER 6 : CONCLUSIONS AND RECOMMENDATIONS

### 6.1 Introduction

This chapter presents the conclusions of the study. As such, it summarizes the results of this research by highlighting the key findings. In addition, recommendations relating to the implementation of potential remedial interventions are included. Improvements, relating to this study, and areas, which would benefit from further studies, have also been incorporated in this chapter.

### 6.2 Summary of Results

The focus of this study involved evaluating the relationship between the infrastructure within the Palmiet Catchment and the state of the Palmiet River. The results indicated that as the infrastructure in the catchment has increased, the ecological condition of the river has decreased in direct correlation. However, the impacts of the infrastructure are not limited to the water quality, the entire river system and wider natural environment of the Palmiet Catchment has been affected. It is important to note that impacts such as scouring and erosion are natural processes within any river system, however, the visual observations have indicated that these natural processes have been exacerbated to such an extent that the Palmiet River system is being degraded. The summarized results (see *Figure 5-23*), illustrating the varying ecological condition along the length of the Palmiet River, validate the hypothesis that the surrounding infrastructure has had a direct impact on the Palmiet River system.

Classified Landsat imagery indicated an estimated 24.5 % increase in urban areas from the year 1975 to 2016. Urban areas are characterized by their hardened, impermeable surfaces, which substantially reduce the amount of water able to infiltrate into the underlying soil layers. As a result, during rainfall events, there is a significantly larger volume of water, which is discharged into the Palmiet River over a short period. Analysis of the rainfall data from 2010 to 2015 showed an overall decrease in rainfall levels. The 2015 annual rainfall data was compared with a study conducted in 1987, which further validated that rainfall levels have decreased. Therefore, it is the increase in hardened surfaces and infrastructure implemented along the riverbanks, which have modified the flow rate of the Palmiet River resulting in increased erosion and an increase in the scouring ability of the Palmiet River. The scouring ability of the river and increased erosion of the riverbanks

increases the amount of sediment, which is transported into the river system, causing increased turbidity levels as indicated by the sampling data obtained from 2007.

The river has been investigated in detail along 7 units and the results show that all of the units have been affected by pollution. In particular, negative correlations between the water quality of the river and the sanitation system, dumpsite and industries have been established. It is important to note that the tributaries, which form the source of the Palmiet River, are polluted by leachate and other organic substances leaking out of the Wyebank Municipal Dumpsite. miniSASS samplings conducted along the entire length of the river provides evidence that the water quality is at a poor standard along the entire length of the river. Analysis of the EWS raw sampling data further validates that the water quality of the Palmiet River is affected. Two primary variables were analysed, namely E.coli and organic loading, as they are used to assess the effectiveness of the sanitation system within the eThekweni Municipality. The poor water quality can be attributed to failures in the sewer infrastructure, i.e. blockages in the sewer infrastructure, overflowing of the sewer network and problems at the sewer pump station. In addition, the Pinetown and New Germany industrial area has the added impact from illegal activities of industries.

The industrial area is also one of two areas where litter and rubbish dumping is a major problem. After rainfall events, the riverbanks of the Palmiet River are covered in waste items. Rubbish has been dumped at a variety of locations, concentrated mainly in the close vicinity of roads in the industrial area. After rainfall events, the rubbish is washed downstream. The biggest problem, with regards to rubbish dumping, is the large amounts of rubbish, which are dumped in Unit 7, primarily at the Quarry Road informal settlement. There are also large amounts of building rubble that are discarded along the riverbanks in Unit 7.

Upon analysis of the 7 units of the Palmiet River, it is evident that the majority of interventions, which have been implemented thus far, address the symptoms of the problems only, whilst the source of the problem remains unaddressed. It is highly recommended that in devising a rehabilitation strategy, greater emphasis should be given to addressing the source of the problems as opposed to the symptoms.

Another important result from this investigation is that the river has the capacity to attenuate and restore its ecological condition as shown by the assessment of Unit 6. This unit has an adequate buffer zone, free of “hard” infrastructure, which aids in the restoration and natural functioning of

the river system. The Palmiet River and wider catchment are still at redeemable standards. A number of interventions have been suggested, whilst all may be suitable, further investigation needs to be conducted on whether they will be cost-effective to implement. Remedial interventions, such as the investment into permeable pavements and rainwater harvesting tanks to address the issues of increased runoff and DWWTP and sensors at sewer manholes to address the issues of decreased water quality, have been suggested to address the source problems within the catchment. The increased levels of runoff and poor water quality of the Palmiet River are problems, which require immediate attention. These source problems have caused a number of symptoms throughout the Palmiet Catchment.

### **6.3 Improvements**

Recommendations to improve the current study includes the improvement of Landsat data as the changes in land cover and land use can be investigated in much greater detail. As a result maps can be produced presenting numerous other classes, thereby, providing an improved indication of how the natural land has changed over the years.

Studies should also be conducted in other catchments in order to validate the fact that the problems experienced within the Palmiet Catchment are a common occurrence. Individuals from other catchments may already have implemented interventions to address the issues and communication with the officials may produce ideas, which can be implemented in the Palmiet Catchment.

This study provides evidence to validate the hypothesis that the infrastructure within the Palmiet Catchment has a negative impact of the Palmiet River system. Further studies can investigate the correlations between the current level of infrastructure and the degree of degradation within the Palmiet Catchment. With the critical infrastructure identified, correlations can then be applied to other urbanised river catchments. Therefore, instead of undertaking numerous river walks to identify the problems within other catchments, a standardized assessment tool can be developed based on the assessment methodology used for the current study. The key infrastructure can be identified and used to determine the impacts to the catchment. This is a similar approach to the miniSASS sampling where the ecological condition is determined based on the observation of certain, pre-determined macro invertebrate. In addition, the EWS uses two pre-determined variables to assess the effectiveness of the sanitation system in eThekweni. Therefore, a tool can be

devised based on a set of pre-determined infrastructure and be used to assess the impacts to other catchments.

*“The only way forward, if we are going to improve the environment, is to get everybody involved.” – Richard Rogers*

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## APPENDIX A : MINISASS ADDITIONAL INFORMATION

Macro invertebrates are becoming increasingly common indicators to use to assess water quality in rivers and streams. A river cannot be deemed healthy based solely on its chemical water quality, the surrounding biological community is also a very important factor. Benthic macro invertebrates, such as aquatic insects, crayfish, snails and worms, are widely used to assess the health of a river. Macro invertebrates are used as indicators for a number of reasons:

- Usually have high numbers present in rivers.
- They often remain in the same area for the duration of their life span.
- Their tolerances to pollution are known
- They are dependent on the surrounding land and river for survival (Oleson, 2013).

In addition, chemical samples obtained from rivers indicate the river quality at that moment. However, the quality of water in the rivers can rapidly change (Oleson, 2013). Macro invertebrates, on the other hand, live in the rivers and their composition can be altered by periodic episodes of pollution or continuous streams of pollution, thus, macro invertebrates are good indicators of the long-term indicators of water quality.

Different types of macro invertebrates require different conditions to survive and are classified into 3 categories based on these requirements (miniSASS, 2016). These categories are:

- Category 1 (Pollution sensitive macro invertebrates) - Macro invertebrates which fall into this category include mayflies, stoneflies and caddisflies. These macro invertebrates require higher dissolved oxygen levels, neutral pHs and cold water to survive (Chadde, 2016). When these macro invertebrates occur in abundance, it indicates that the river is in good condition. If these macro invertebrates, which were once in abundance, decrease in numbers after subsequent sampling, it indicates that a pollution incident has occurred.
- Category 2 (Semi-tolerant pollution macro invertebrates) - This category includes scuds, dragonflies and damselflies. These macro invertebrates are able to tolerate slight degradation in the water quality of rivers. Their abundance and diversity are good indications that the river health is in the fair to good region (Chadde, 2016).

- Category 3 (Pollution tolerant macro invertebrates) - These macro invertebrates can survive under low dissolved oxygen levels, in both high and low pH ranges and in warm water. Macro invertebrates forming this category include aquatic worms, snails and leeches. When these macro invertebrates are present, it indicates that the water is of poor quality as these macro invertebrates thrive on poor water quality (Chadde, 2016).

**Table A-1** presents the scores for the different macro invertebrates, which can be collected during the miniSASS samplings.

*Table A-1: Macro invertebrate scores (Source: miniSASS, 2016).*

<b>Macro invertebrates</b>	<b>Score</b>
Flatworms	3
Worms	2
Leeches	2
Crabs/Shrimps	6
Stoneflies	17
Minnow Mayflies	5
Other Mayflies	11
Damselflies	4
Bugs/beetles	5
Caddisflies	9
True flies	2
Snails	4
Dragonflies	6

Macro invertebrates with higher scores, for example stoneflies and other mayflies, require good quality water to survive. If they are in abundance in the rivers, this is a good indication that the water quality is of good/natural condition. On the other hand, macro invertebrates with lower scores, for example leeches and worms, can survive in polluted waters. Therefore, the higher your final score, the better the river water quality is.

Mayflies, stoneflies and caddisflies, the macro invertebrates belonging to the pollution sensitive category, normally require dissolved oxygen levels of greater than 5 ppm to survive. In terms of pH, aquatic macro invertebrates can survive in waters with a pH ranging from 6.5 to 7.5. Snails require a pH of 7.5 to 9 and plants can survive in pH's ranging from 6.5 to 12 (Chadde, 2016).

Aquatic worms are commonly found in soft sediments, which are rich in organic matter. Some of these aquatic worms can survive under "zero oxygen" conditions, thus, these worms are found in abundance in areas receiving excessive organic matter (EcoSpark, 2013). Therefore, large numbers of worms can indicate that there are elevated levels of organic matter and low dissolved oxygen levels as a result of sewage discharge.

Snails generally feed by scraping algae and organic nutrients from the debris found in and around a river system. Snails are able to tolerate low dissolved oxygen levels as some of them have lungs and come to the water surface to breathe (EcoSpark, 2013). Some snails are, therefore, able to inhabit polluted areas.

A site, which contains a large variety of taxa, suggests that the habitat and water quality is at acceptable standards to support macro invertebrate life. A greater range of habitats is directly linked to the diversity of species, which it can support. Therefore, a river, which has been contaminated by pollutants, loses its habitat variability, thus, the area will have far lower species diversity (EcoSpark, 2013).

High numbers of a particular species indicates that the habitat available and water quality conditions favours that particular species (EcoSpark, 2013). In terms of water quality, this can be both good and bad. For example, high numbers of worms indicates polluted water conditions, however, high numbers of caddisflies is an indication that the water quality is of a good condition.

## **APPENDIX B : DESCRIPTION OF PRIOR RECORDED POLLUTION INCIDENTS IN THE PALMIET RIVER**

### **B.1 Incident 1**

- Date Observed - 25 March 2014
- Location Observed - Palmet River near Cherry Road
- Description - The Palmet River was polluted by substances believed to be industrial dyes. This resulted in the red discolouration of the river water. The water quality was significantly compromised which directly affects the surrounding flora and fauna. Any substance discharged in the upper areas of the Palmet River will naturally flow downstream affecting everything as it passes by.

### **B.2 Incident 2**

- Date observed - 29 June 2015
- Location Observed - Vicinity of Blair Road Pump Station
- Description - The Palmet River had a significant deterioration in its water quality because of the Blair Road Pump Station. Sewage was discharged into the river from this pump station. Thus, the organic matter content of the river drastically increased. In addition to the aquatic organisms, which were negatively affected, the suspended particles emitted into the river, increased turbidity and prevented the sunlight from penetrating the surface of the water hindering natural processes.

### **B.3 Incident 3**

- Date Observed - 18 November 2014
- Location Observed - Palmet River in the vicinity of Churston Road

- Description - Residents living along Churston Road and other neighbouring roads noticed the discolouration of the Palmiet River. The Palmiet River appeared to be turquoise in colour. This is a result of some sort of industrial effluent being discharged into the Palmiet River, either illegally or through a burst pipe or pipe blockages.

#### **B.4 Incident 4**

- Date observed - 5 August 2014
- Location Observed - In the vicinity of Essex Place down to the Palmiet Nature Reserve
- Description - Dead fishes were observed, by environmentalists and community members, floating down the river. Numerous pollution incidents spanning over about 2 weeks has increased the mortality rates of fishes habiting the Palmiet River. These pollution events include pipe bursts, the industrial discharge of sewage, either illegally or by problematic infrastructure, and blockages. In addition to the increased mortality rates of fishes, the river water was discoloured and water quality was compromised.

#### **B.5 Incident 5**

- Date Observed - 31 May 2016
- Location Observed - Bed and Breakfast located on Palmiet Drive
- Description - The Blair Road pump station overflowed with sewage, this sewage was then discharged directly into the Palmiet River. This was a result of an unexpected pipe blockage during a repair session. Blair Road pump station is located about 5.85 km upstream from where the photo of incident 5 was actually taken. This is a prime example of a pollution incident, which occurred upstream having serious negative effects on the downstream areas. This was a major spill event leading to the municipality issuing a warning message.

#### **B.6 Incident 6**

- Date Observed - 27 May 2016

- Location Observed - Palmet River in the vicinity of Shepstone Road
- Description - There was a pipe burst in Shepstone Road, the pipe burst was caused by a construction vehicle, which unintentionally hit a pipe valve. Water was cut off in most parts on New Germany, however, the water already lost, due to the pipe burst, entered the stormwater drains and was discharged directly into the Palmet River. In addition to the effects on the actual Palmet River, the excess water caused the soils to displace resulting in excess sediments entering the Palmet River. The Palmet River, thus, discoloured to a murky brown. The increased suspended solids present in the water also hindered natural processes by preventing sunlight from penetrating the water surface.

### **B.7 Incident 7**

- Date Observed - 8 May 2016
- Location observed - Birdhurst Road
- Description - The heavy rainfall in May resulted in the flooding of the Palmet River. However, the rain is not the sole contributor, infrastructure has been built in close proximity to the Palmet River encroaching on the channel width. In this instance, there is a bridge in the vicinity, which has narrowed the river channel resulting in the higher peak flow levels. The water overflowed into this resident's house and soaked into his garden.

### **B.8 Incident 8**

- Date Observed - 16 December 2014
- Location Observed - Bed and Breakfast located on Palmet Drive
- Description - Numerous sewer blockages, pump station failures and pipe bursts resulted in untreated, industrial sewage being discharged, through stormwater and sewer networks directly, into the Palmet River. This industrial sewage consisted of cleaning agents and solvent fumes. As a result, the river underwent numerous colour changes from a dirty blue to green, grey, black and brown. A profane smell accompanied this discolouration. This resulted in the increased mortality rates for crabs, fish, frogs and other organisms habiting the river. In

addition, tourism was negatively affected. Tourists from Canada, who chose to stay in the Palmiet Drive Bed and Breakfast, left with a bad impression after they saw the pollution in the river.

## **B.9 Incident 9**

- Date Observed - 27 November 2011
- Location Observed - Quarry Road Informal Settlement
- Description - Heavy rain resulted in the flooding of the Palmiet River. However, the heavy rainfall alone was not the only contributor. The Palmiet River runs through a highly urbanised area, which contains many hard, impermeable surfaces. This significantly reduces the amount of water able to infiltrate into the soil, thus, the water entering the stormwater drains is increased. This water is then discharged directly into the Palmiet River. Combine the increase in stormwater discharge with the fact that there is infrastructure encroaching along the river channel, and you get a river, which is ready to burst its banks. The Quarry Road inhabitants felt the effects of this as they had some of their houses washed away during the November 2011 flooding. In addition, the higher flow rates increased the scouring ability of the river leading to the erosion of the riverbed and the destruction of the vegetation alongside.

## APPENDIX C : UNICITY RIVER QUALITY INDICES

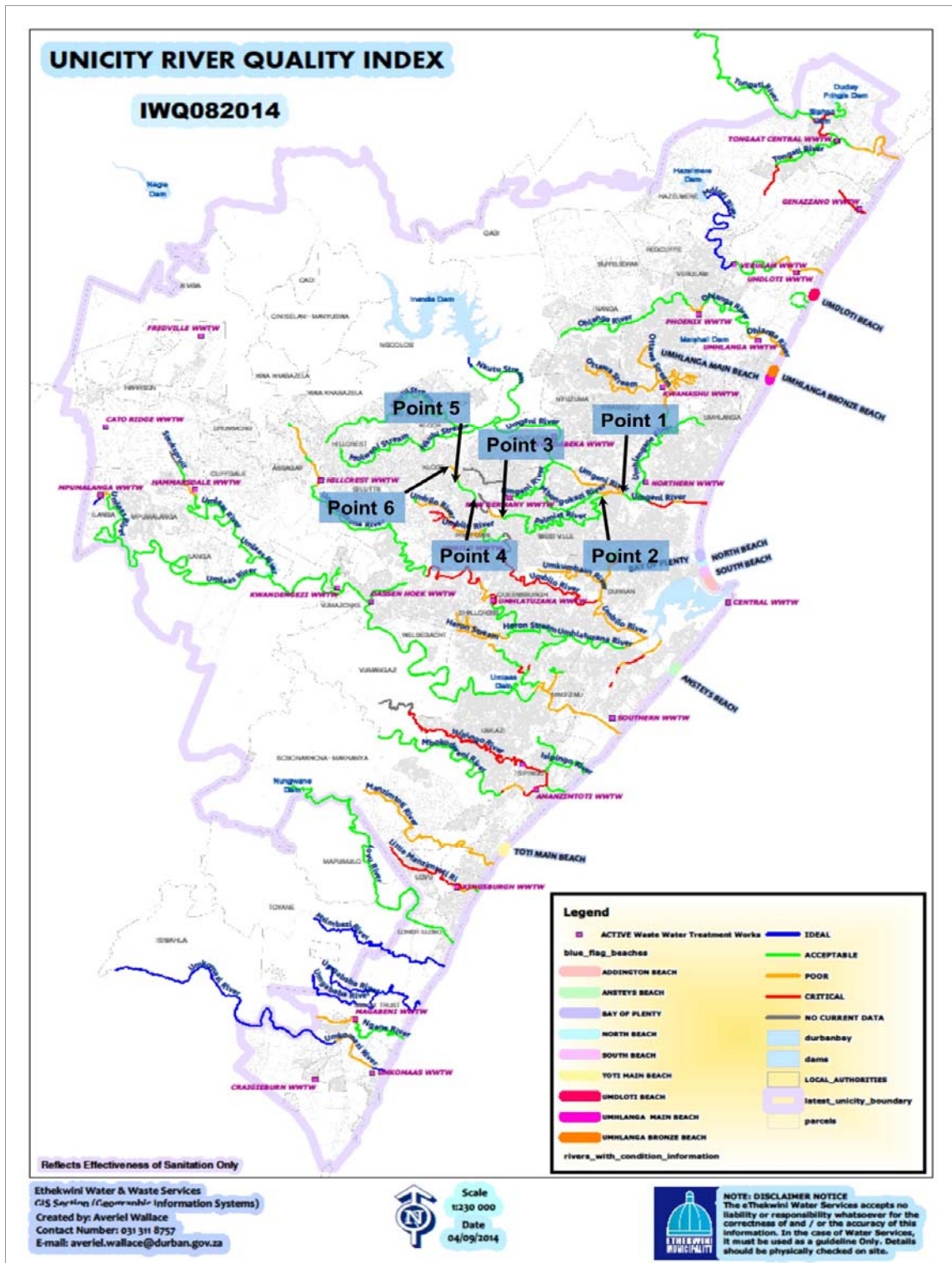


Figure C-1: Unicity River Quality Index August 2014 (Source: EWS, 2016).

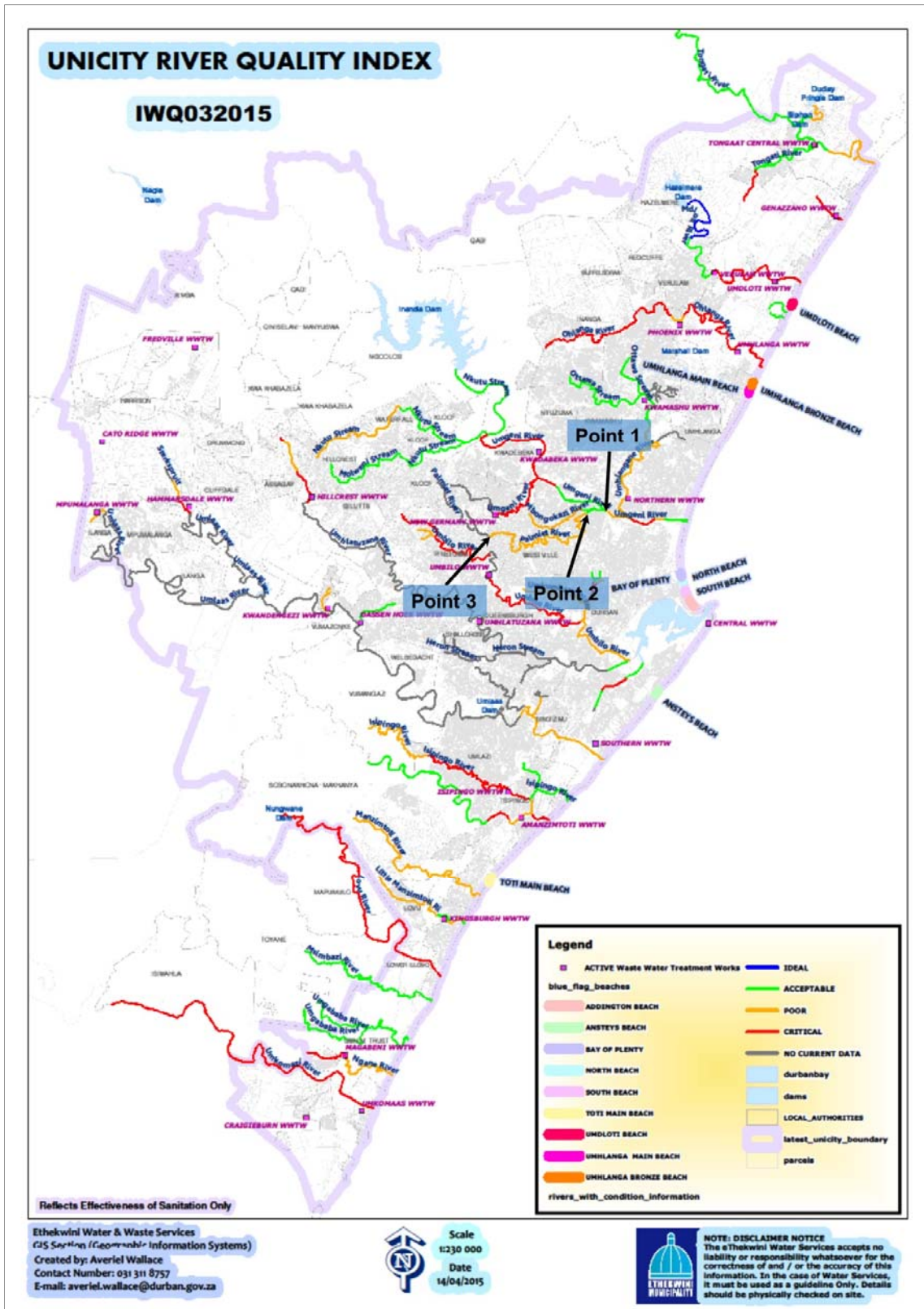


Figure C-2: Unicity River Quality Index March 2015 (Source: EWS, 2016).

## APPENDIX D : ILLUSTRATIVE SCORING GUIDELINE

### D.1.1 Indigenous Vegetation Removal



Figure D-1: [0.5 – 1]  
New Germany Nature Reserve (Unit 4).

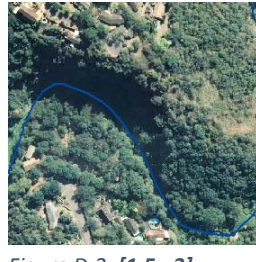


Figure D-2: [1.5 - 3]  
Westville Residential Area (Unit 6).



Figure D-3: [3.5 - 5]  
Pinetown/New Germany Industrial Area (Unit 2).

### D.1.2 Exotic Vegetation



Figure D-2: [0.5 - 1].



Figure D-5: [1.5 - 3].



Figure D-6: [3.5 - 5].

### D.1.3 Bank Erosion



Figure D-7: [0.5 - 1] Cowies Hill Residential Area (Unit 3).



Figure D-8: [1.5 - 3] Westville North Residential Area (Unit 3).



Figure D-9: [3.5 - 5] Quarry Road Informal Settlement (Unit 7).

### D.1.4 Channel Modification



Figure D-10: [0.5 - 1] Palmet Nature Reserve (Unit 5).



Figure D-11: [1.5 - 3] Westville North Residential Area (Unit 4).



Figure D-12: [3.5 - 5] Westville North Residential Area (Unit 4).

### D.1.5 Flow Modification



Figure D-13: [0.5 - 1] Palmet Nature Reserve (Unit 6).

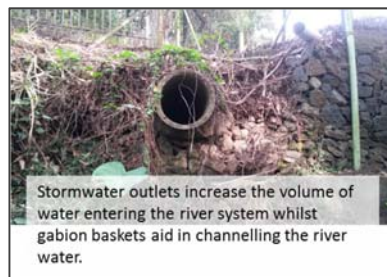


Figure D-14: [1.5 - 3] Behind Atholl Heights School (Unit 4).



Figure D-15: [3.5 - 5] Section 2 New Germany Nature Reserve (Unit 4).

### D.1.6 Water Quality



Figure D-16: [0.5 - 1] Westville North Residential Area (Unit 4).



Figure D-17: [1.5 - 3] Quarry Road Informal Settlement (Unit 7).



Figure D-18: [3.5 - 5] Birdhurst Weir (Unit 3) (Source: D'Eathe, 2016).

### D.1.7 Rubbish Dumping



Figure D-19: [0.5 - 1] Edge of the Pinetown Industrial Area (Unit 2).

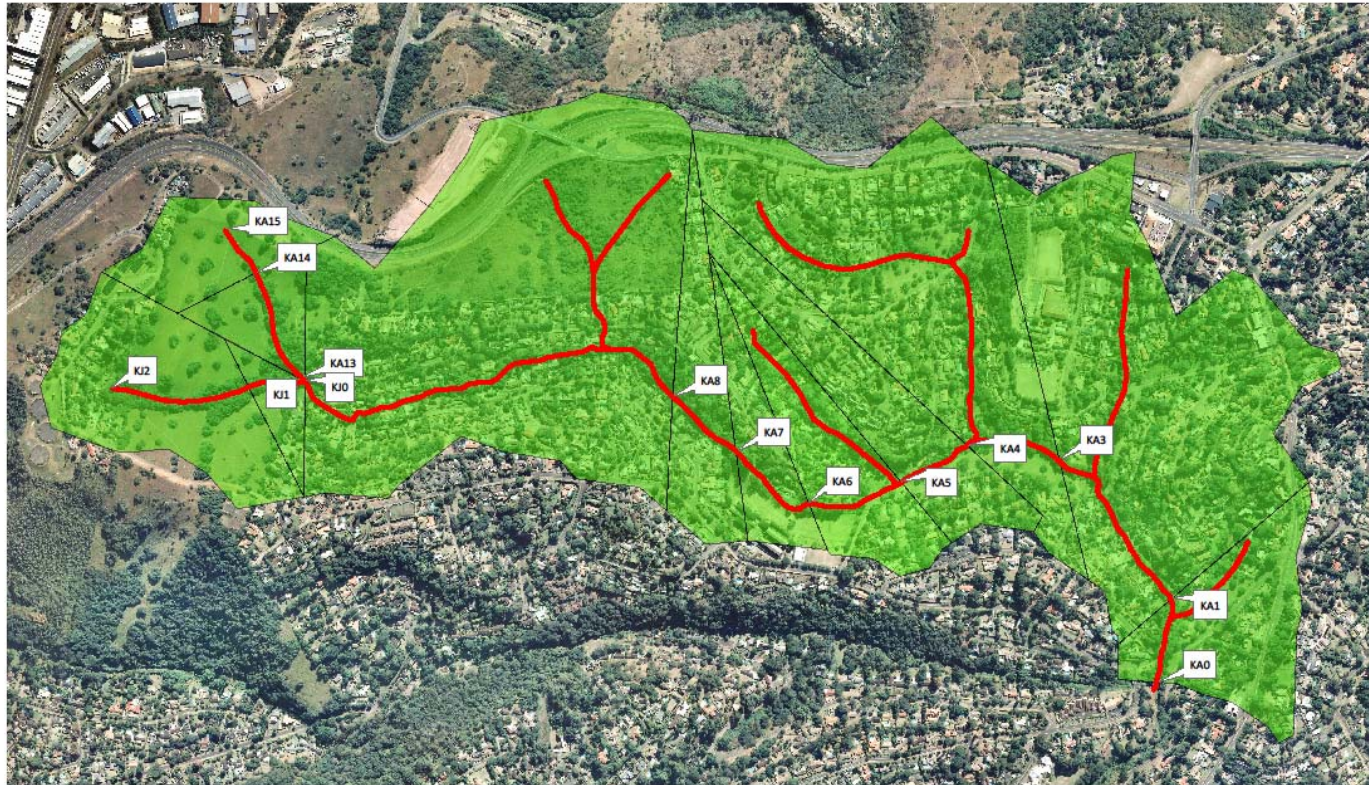


Figure D-20: [1.5 - 3] Pinetown/New Germany Industrial Area (Unit 2).



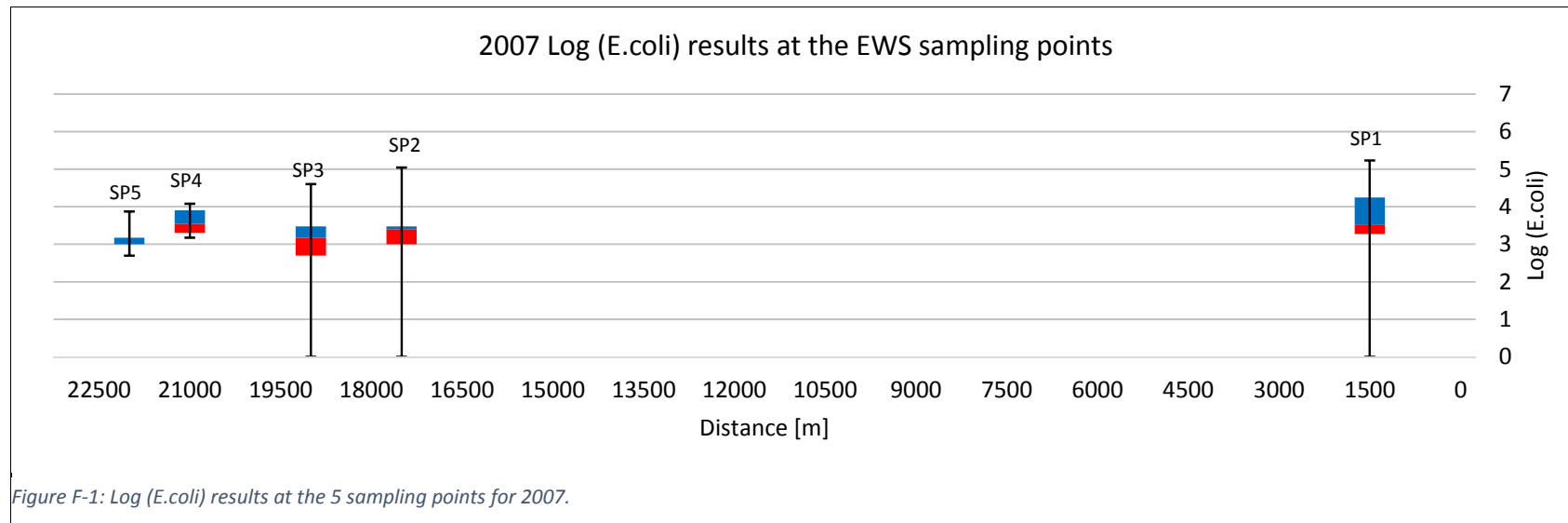
Figure D-21: [3.5 - 5] Quarry Road Informal Settlement (Unit 7).

## APPENDIX E : SAMPLE STRIP MAP



## APPENDIX F : WATER SAMPLING

Figure F-1 to Figure F-9 illustrates the distribution of the water sampling results at the 5 sampling points.



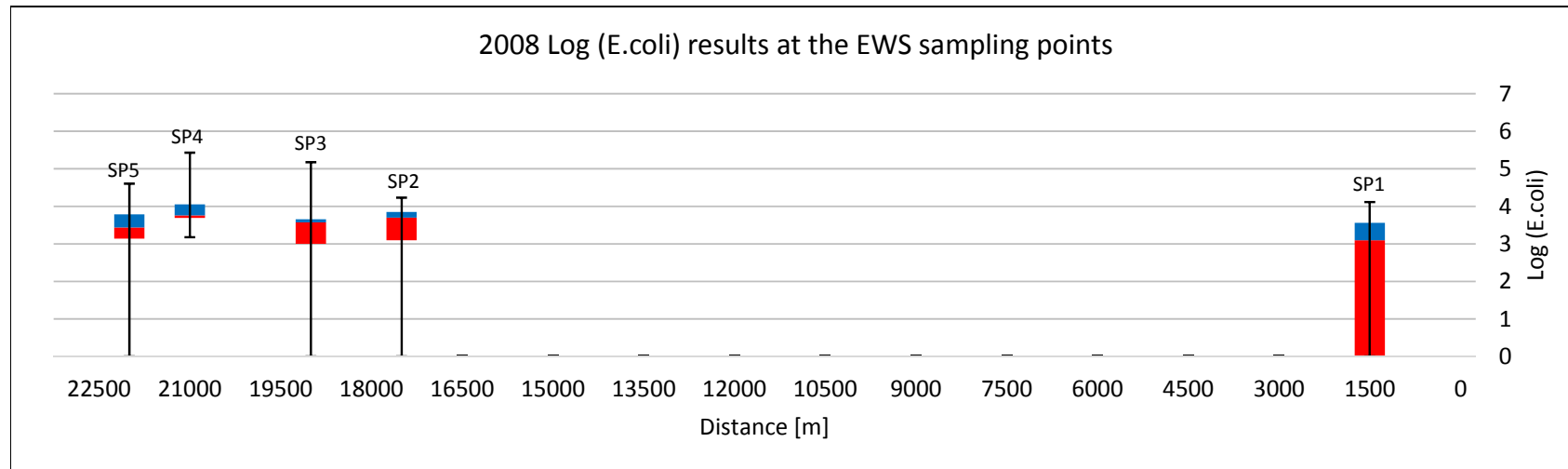


Figure F-2: Log (E.coli) results at the 5 sampling points for 2008.

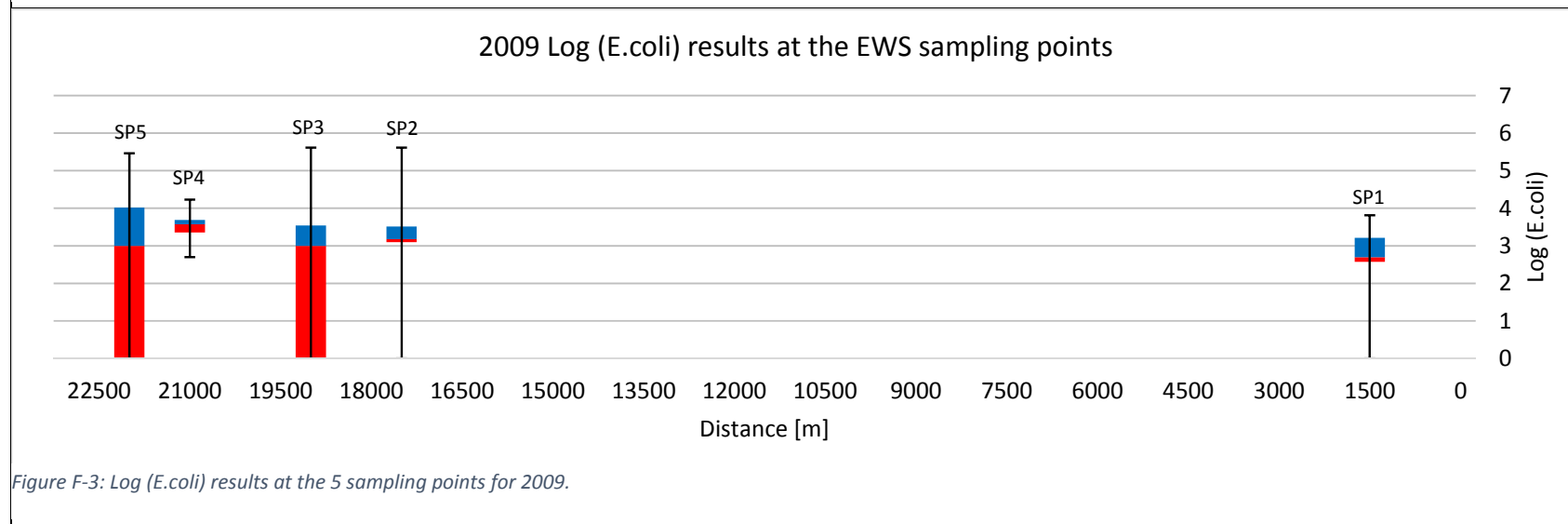


Figure F-3: Log (E.coli) results at the 5 sampling points for 2009.

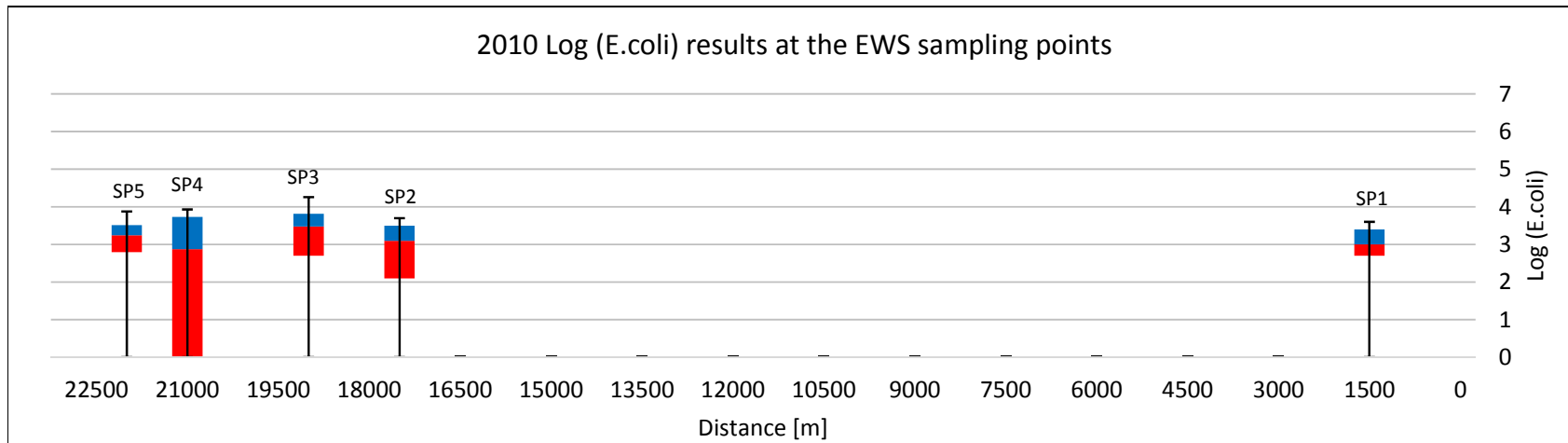


Figure F-4: Log (E.coli) results at the 5 sampling points for 2010.

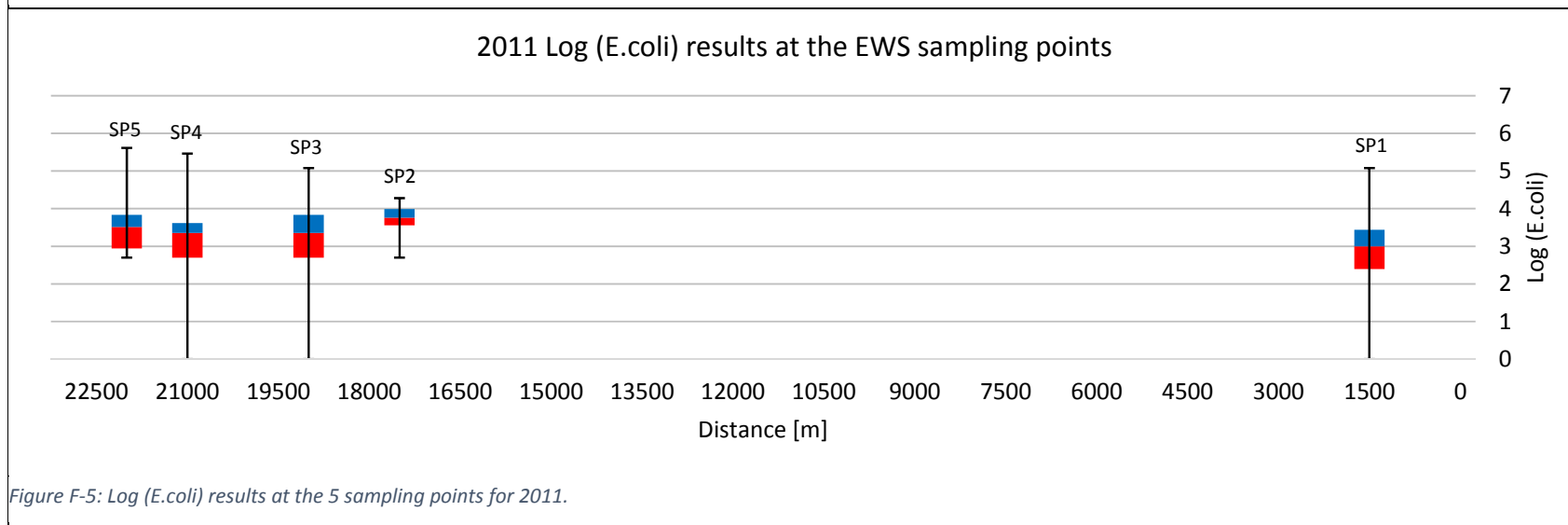


Figure F-5: Log (E.coli) results at the 5 sampling points for 2011.

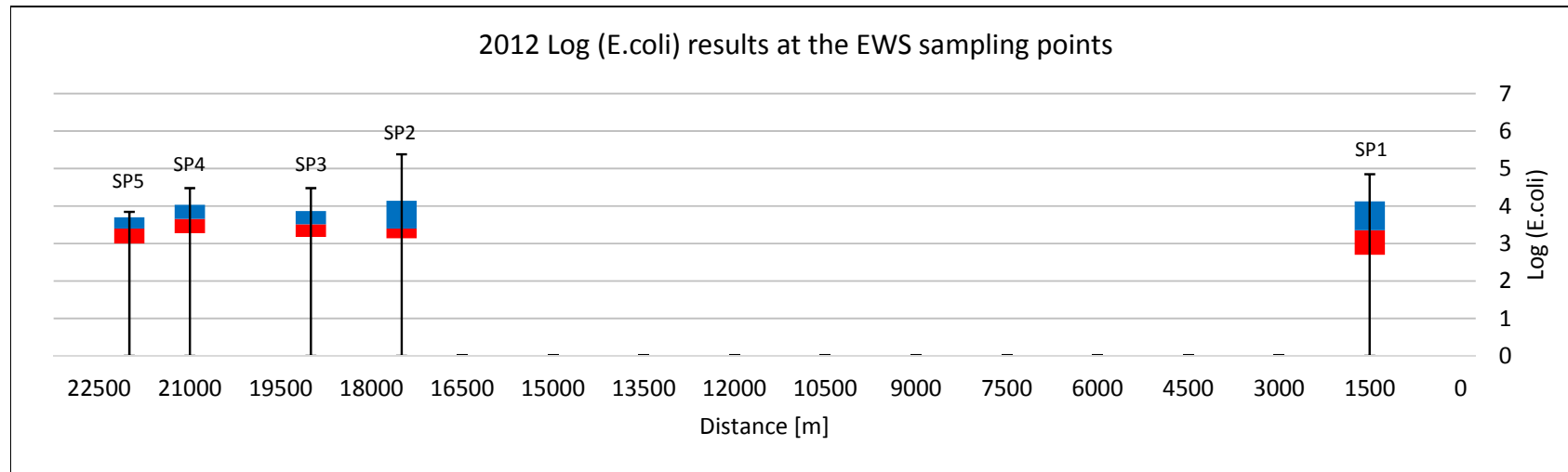


Figure F-6: Log (E.coli) results at the 5 sampling points for 2012.

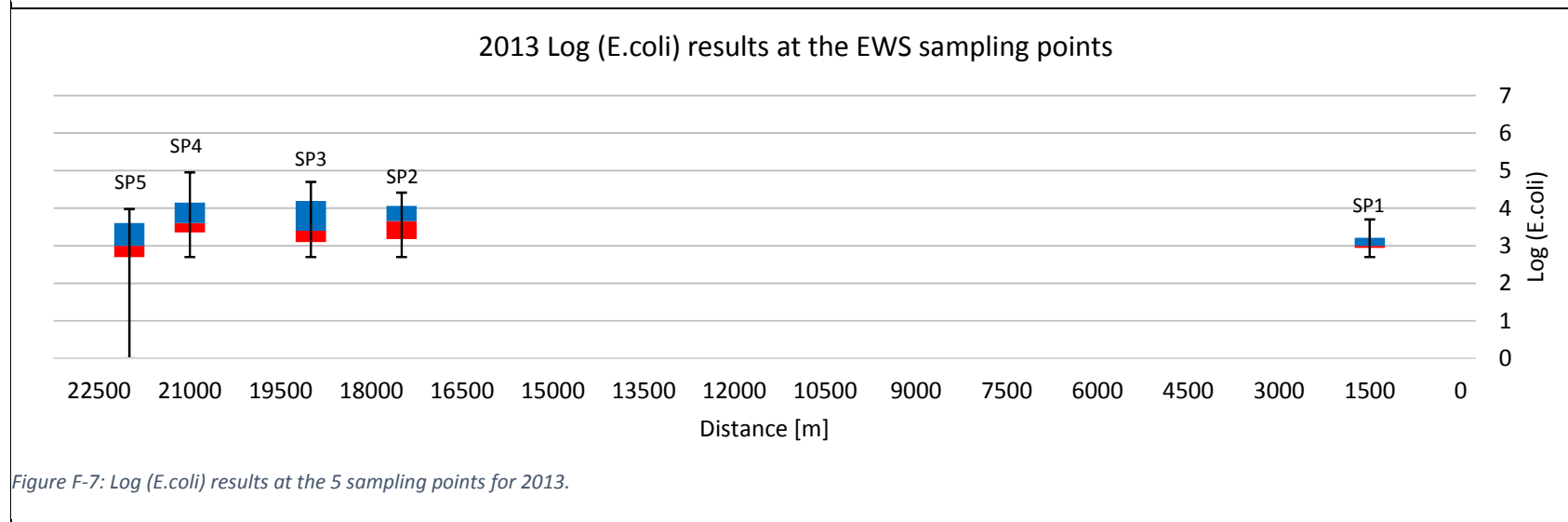


Figure F-7: Log (E.coli) results at the 5 sampling points for 2013.

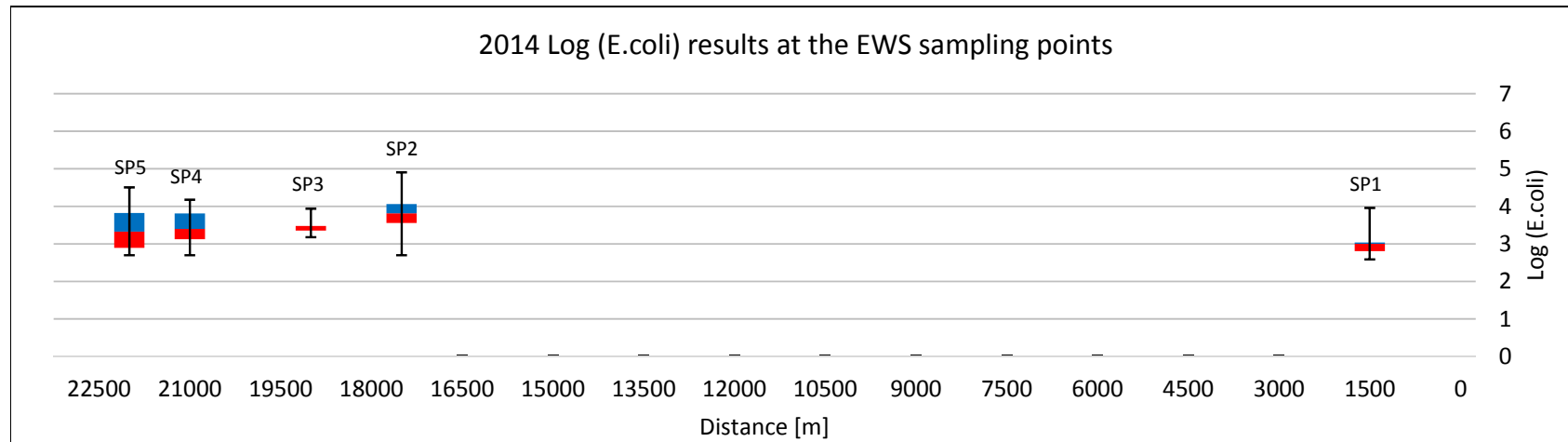


Figure F-8: Log (E.coli) results at the 5 sampling points for 2014.

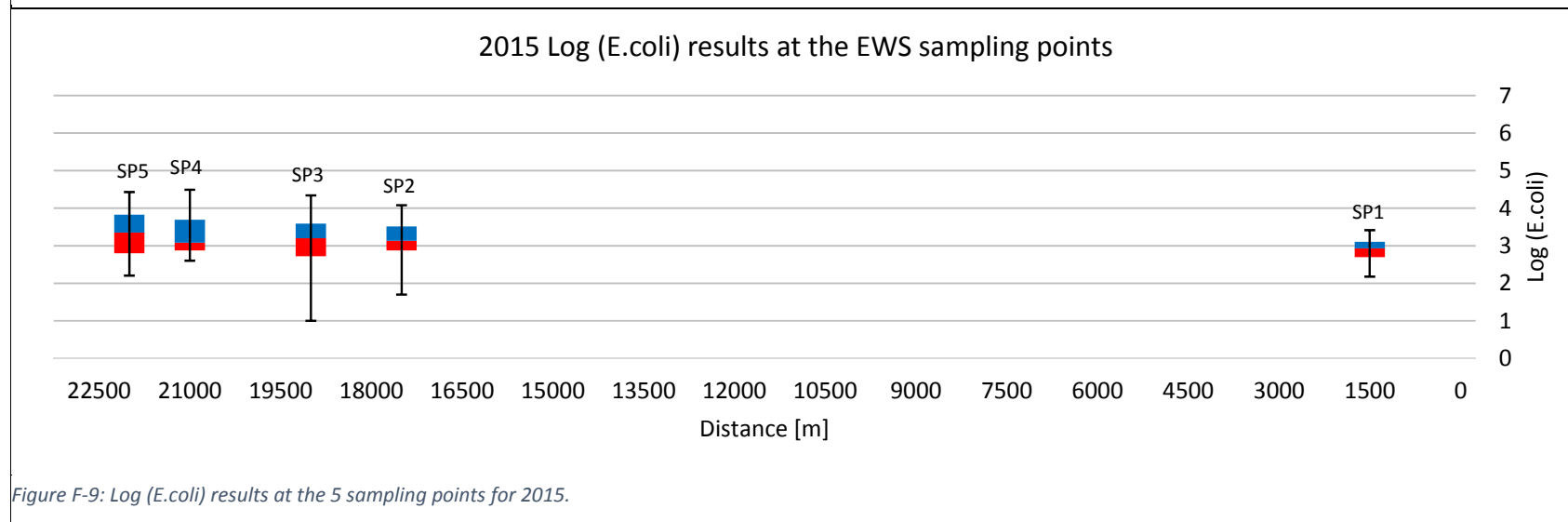


Figure F-9: Log (E.coli) results at the 5 sampling points for 2015.

The following are a few points to consider:

- The years 2007 to 2012, across the majority of sampling points, have a large range in E.coli results. E.coli values that lie in the upper ends can be attributed to major pollution events arising from failures at the pump stations or blockages and overflows in the sewer network.
- The range in E.coli results from the years 2013 to 2015 is significantly less than the years 2007 to 2012. However, it is important to take note that the reduced range is a result of the increase in minimum E.coli results.
- The years 2007 to 2015, across the majority of sampling points, indicate that 50 % of the E.coli results lie above the 3.3 mark on the log scale, i.e. 2 000 cfu/100 ml. According to the EWS thresholds, presented in **Chapter 4**, E.coli values above 2 000 cfu/100 ml is classified as poor leading into the critical regions.

Raw sampling data regarding organic loading has been summarized and illustrated by **Figure F-10** to **Figure F-18**. According to the EWS, peaks in organic loading greater than 1.56 on the log scale, i.e. 36 mg/l, is most likely attributed to industrial effluent. Thus, should problems arise with sewer pipes and connecting infrastructure and the water is discharged into the Palmiet River, there will be elevated levels of organic loading in the river. In addition, there have been industries who have been prosecuted for illegally dumping their industrial effluent into the Palmiet River.

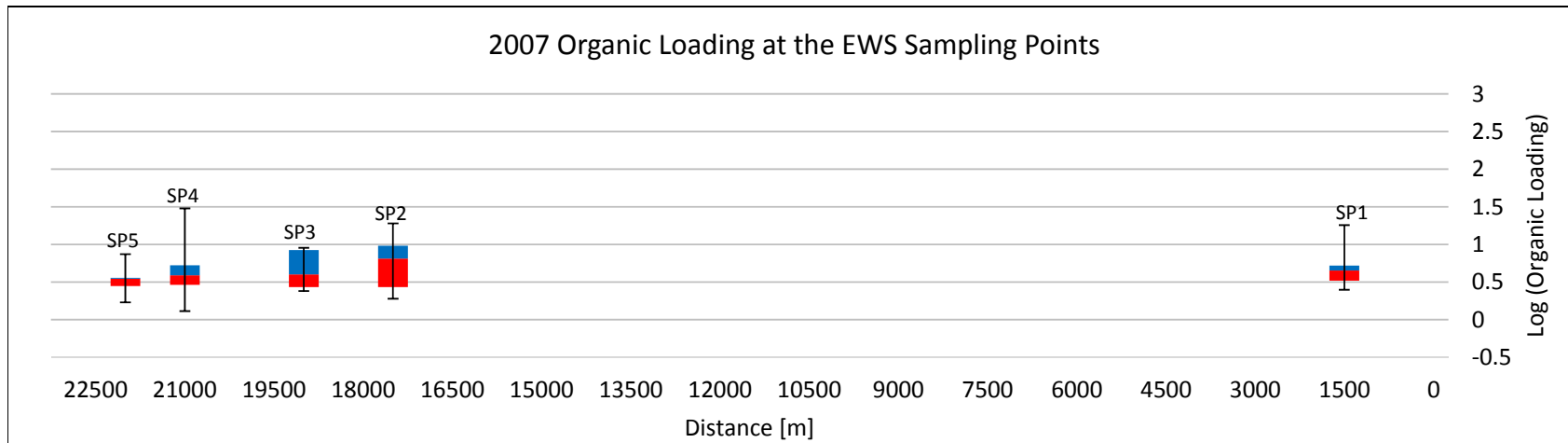


Figure F-10: Log (Organic Loading) results at the 5 sampling points for 2007.

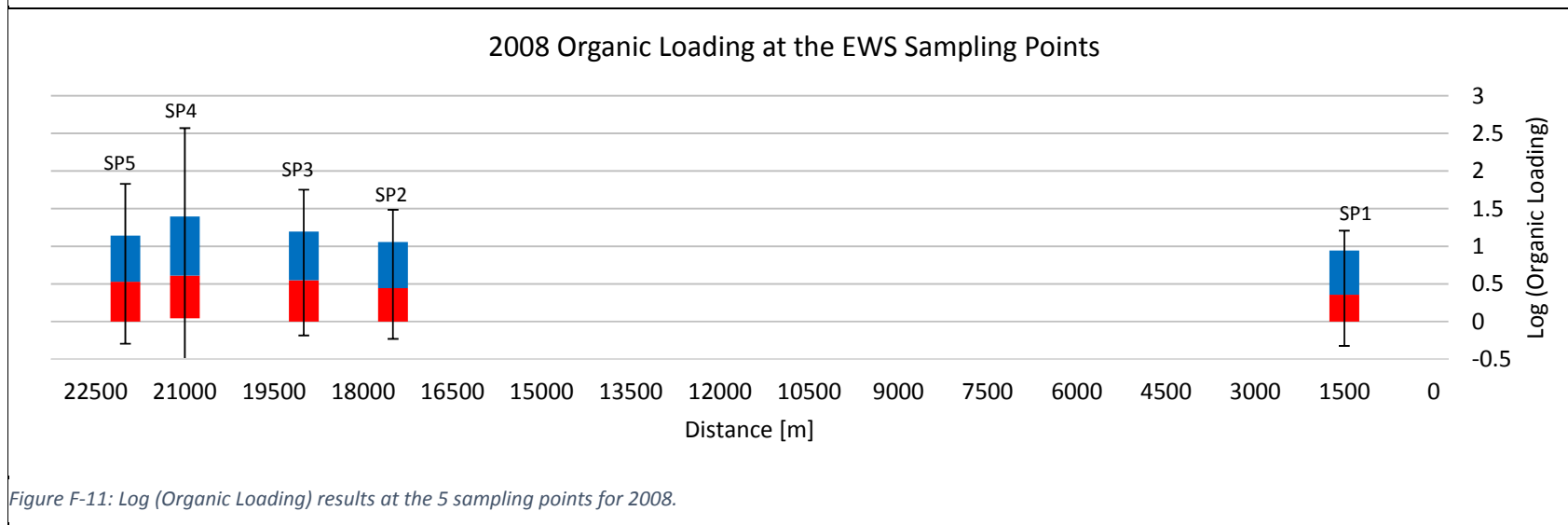


Figure F-11: Log (Organic Loading) results at the 5 sampling points for 2008.

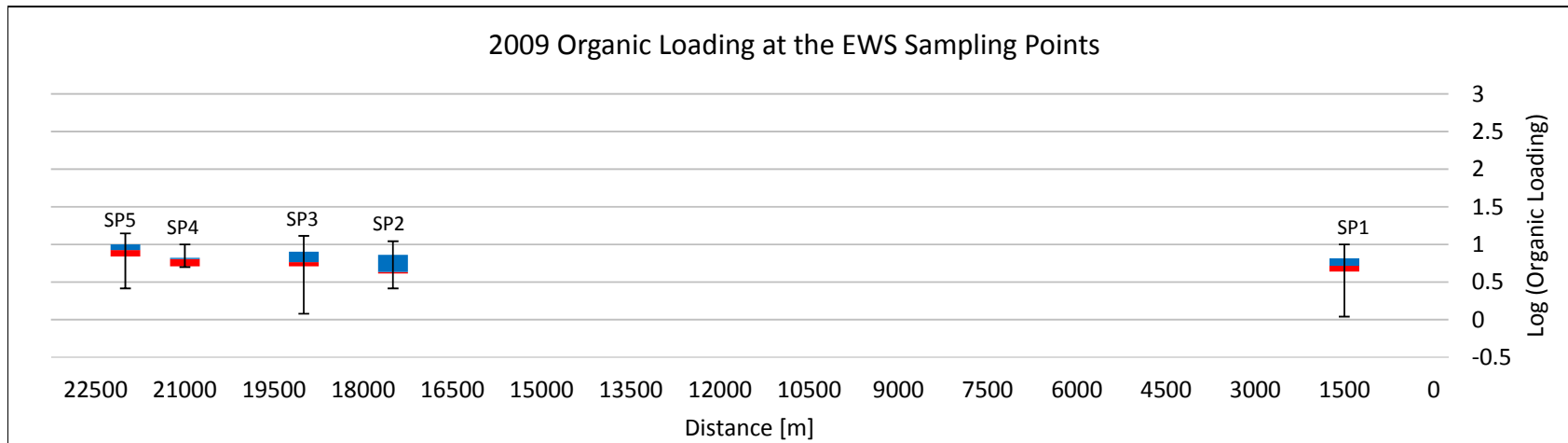


Figure F-12: Log (Organic Loading) results at the 5 sampling points for 2009.

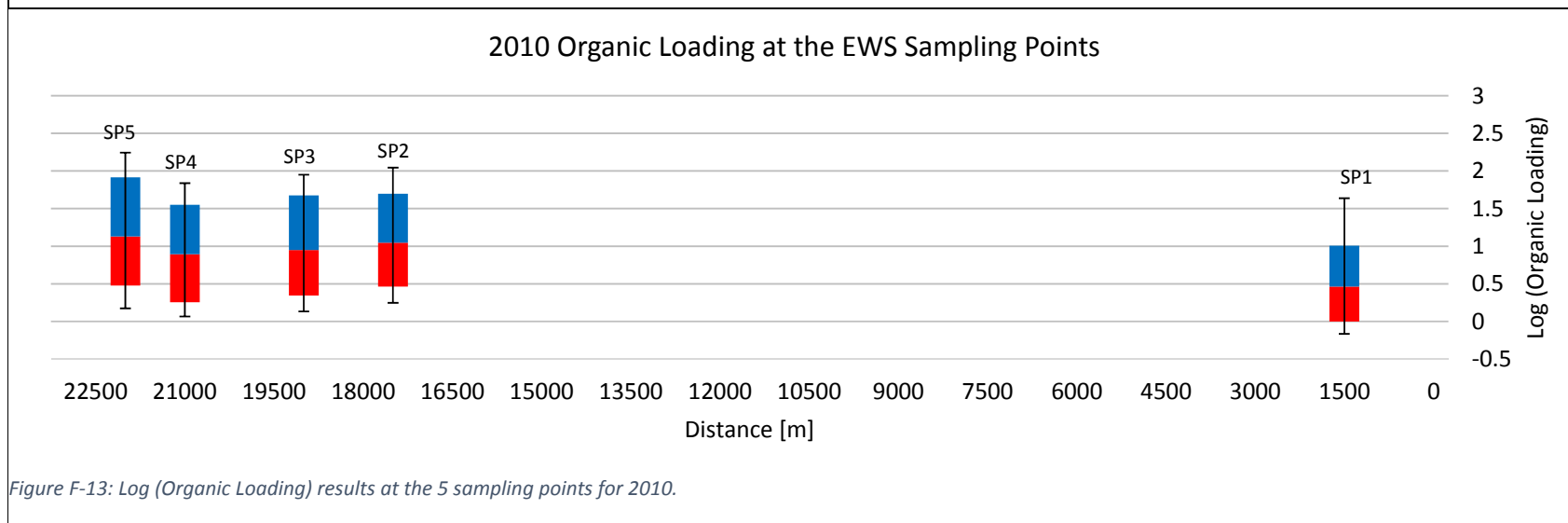


Figure F-13: Log (Organic Loading) results at the 5 sampling points for 2010.

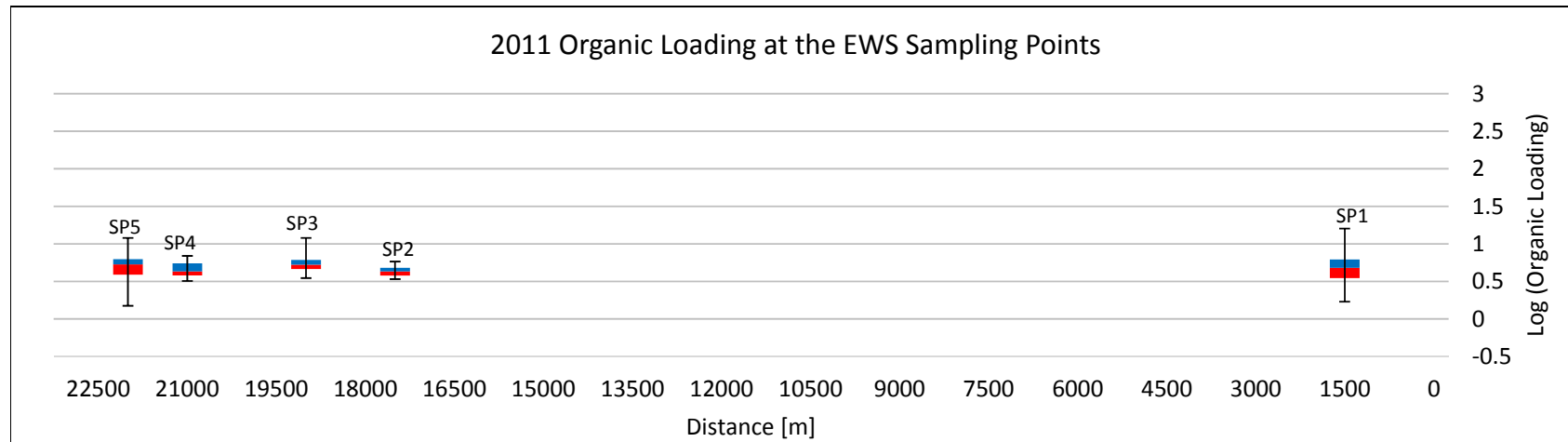


Figure F-14: Log (Organic Loading) results at the 5 sampling points for 2011.

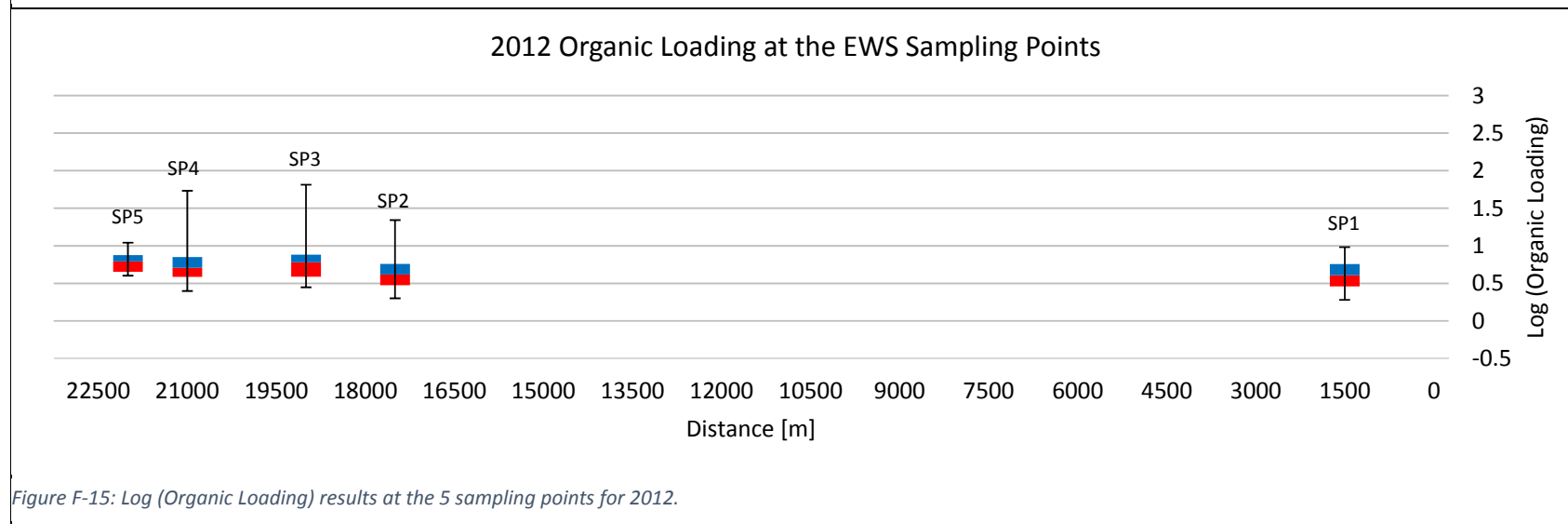


Figure F-15: Log (Organic Loading) results at the 5 sampling points for 2012.

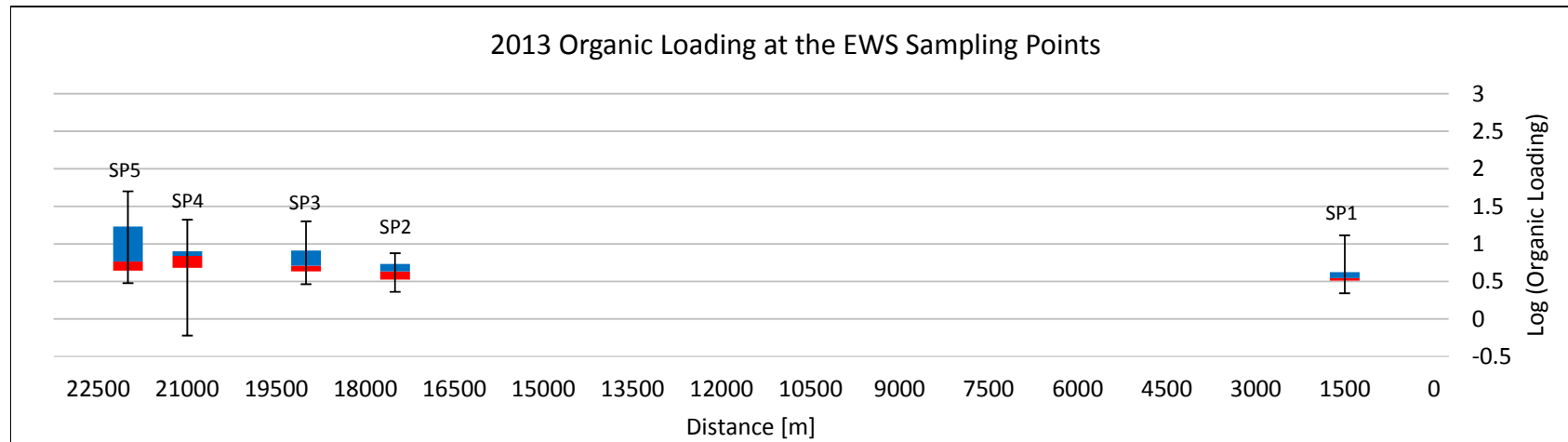


Figure F-16: Log (Organic Loading) results at the 5 sampling points for 2013.

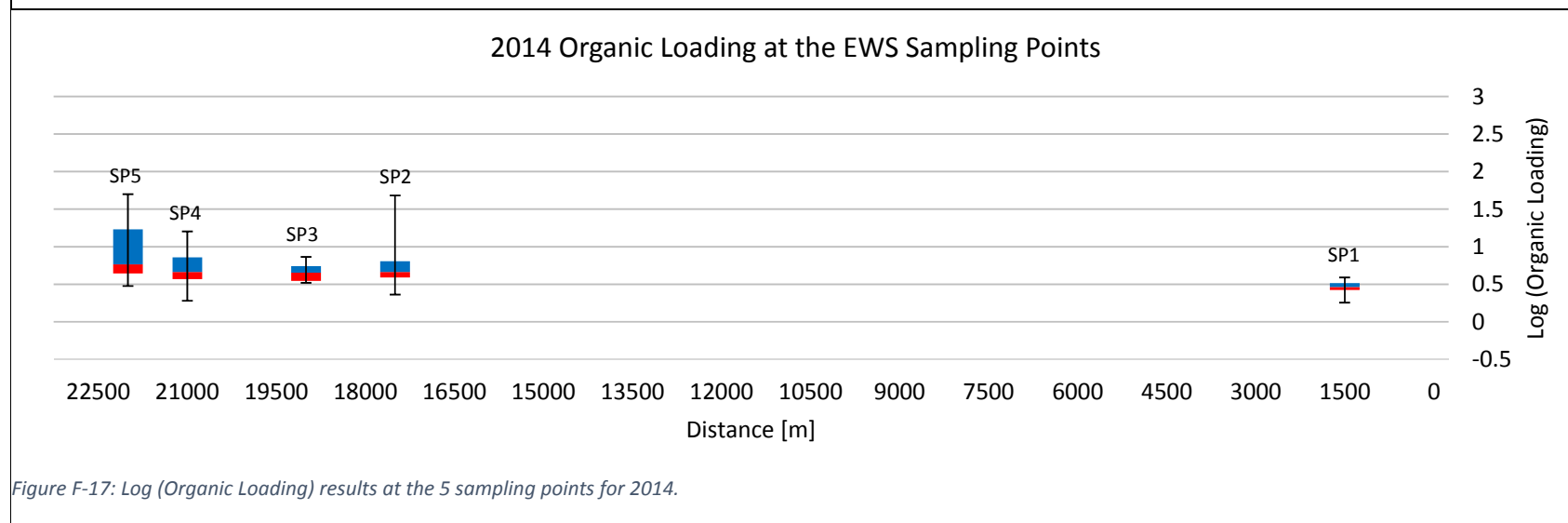
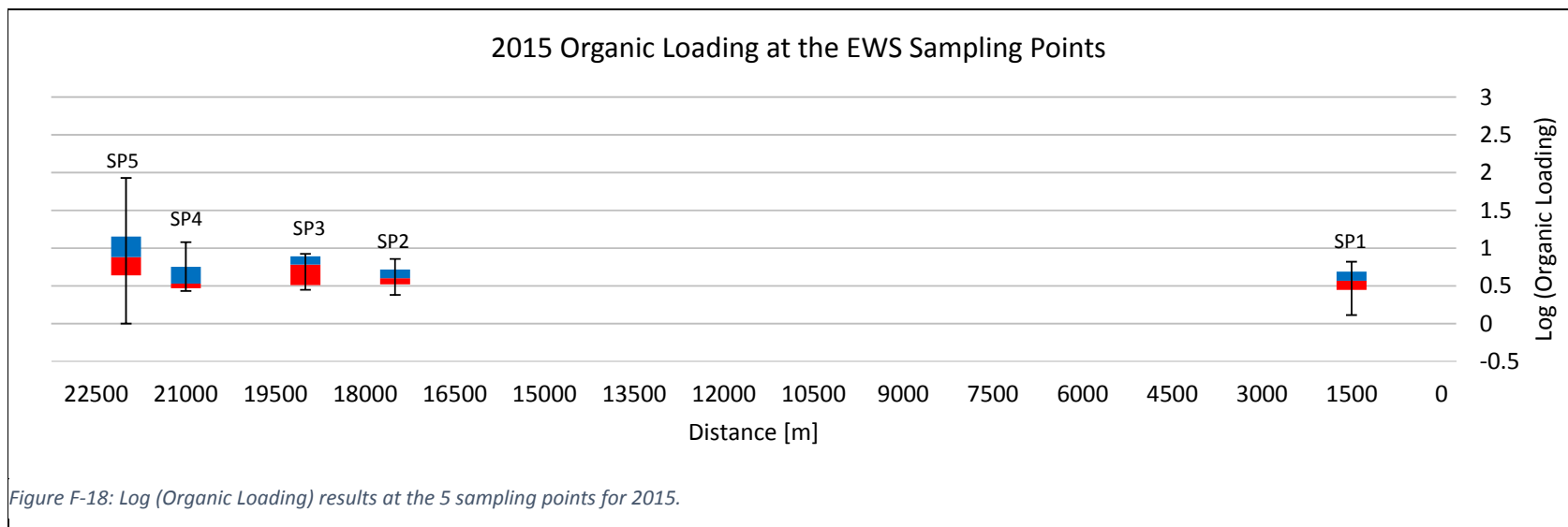


Figure F-17: Log (Organic Loading) results at the 5 sampling points for 2014.



The year 2010 was in the worst year in terms of organic loading with more than 25 % of the organic loading levels, across SP2, SP3, SP4 and SP5, lying above the 1.56 mark on the log scale, i.e. 36 mg/l. With the exception of year 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 borders in the poor region.

**Figure F-19** to **Figure F-27** illustrates the box and whisker plots used to illustrate the range in turbidity results across the sampling points from the year 2007 to the year 2015.

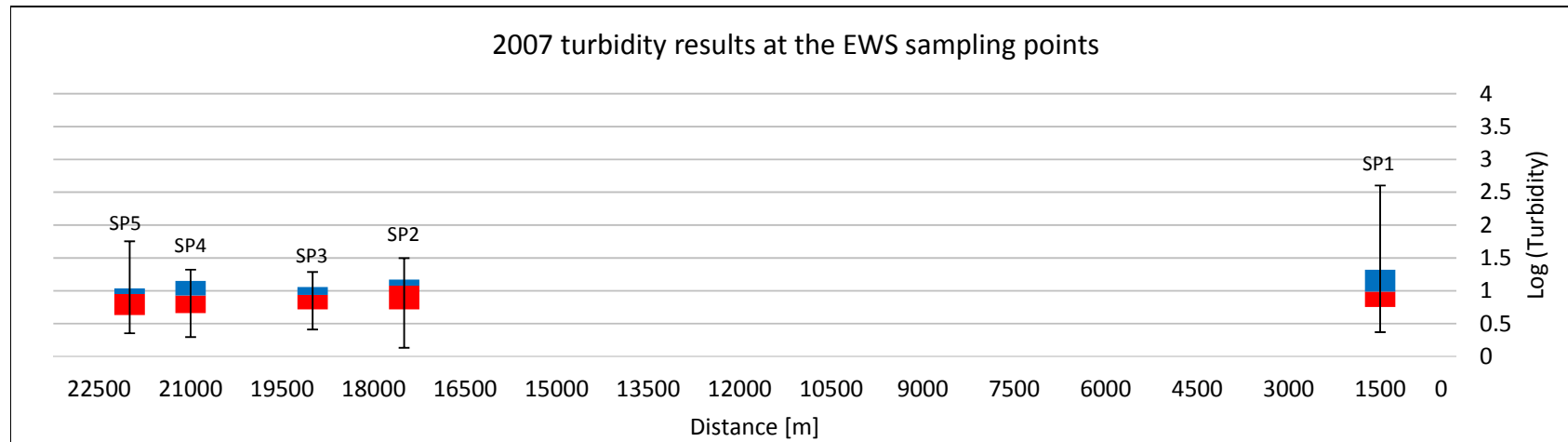


Figure F-19: Log (Turbidity) results at the 5 sampling points for 2007.

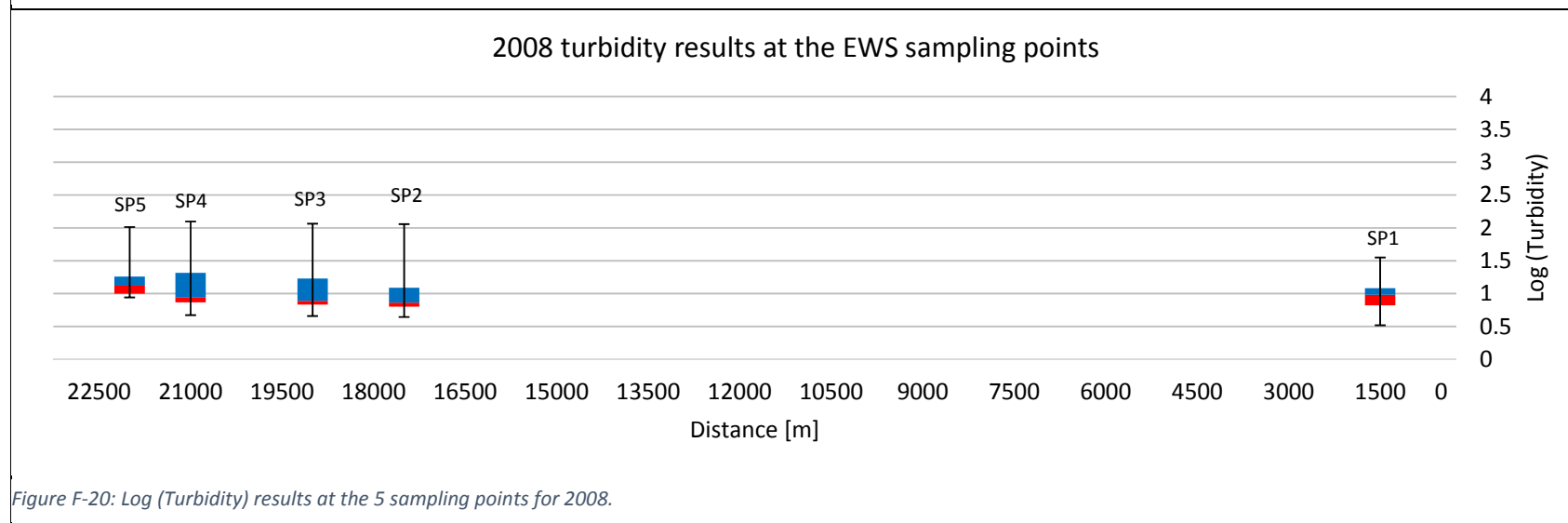


Figure F-20: Log (Turbidity) results at the 5 sampling points for 2008.

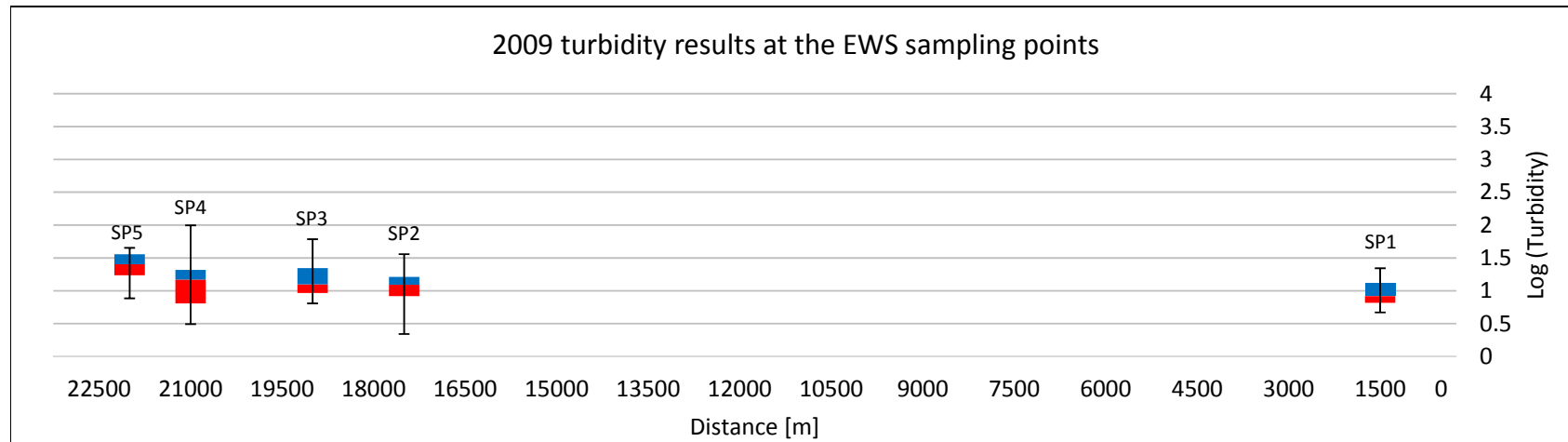


Figure F-21: Log (Turbidity) results at the 5 sampling points for 2009.

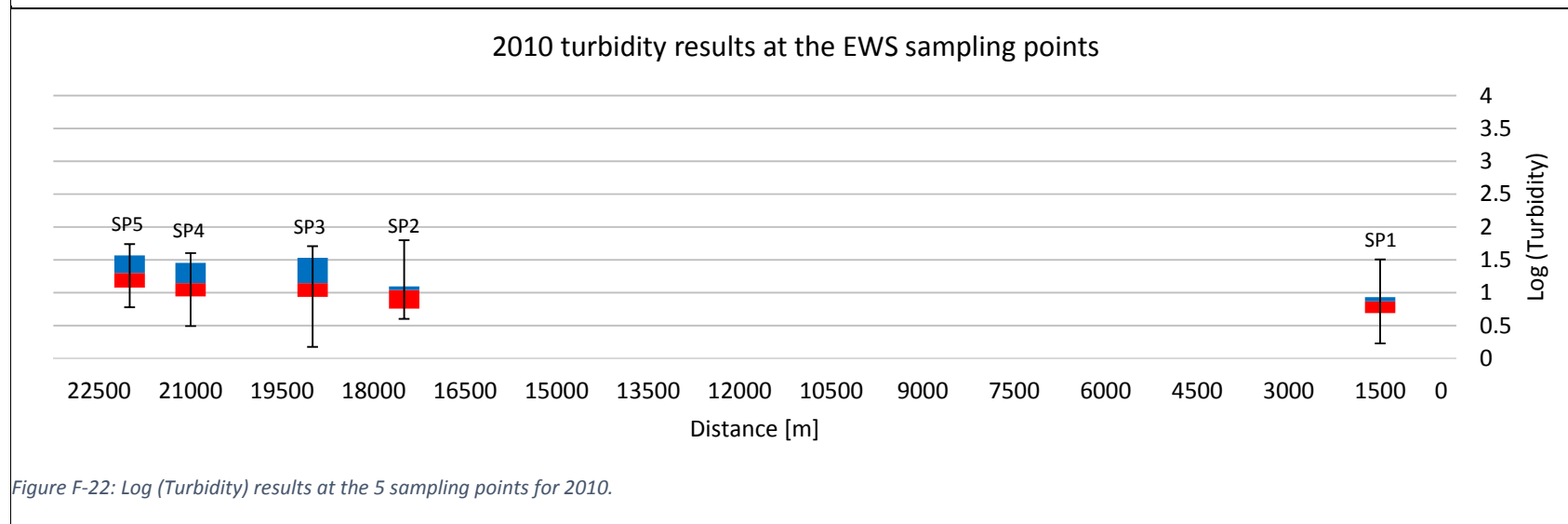


Figure F-22: Log (Turbidity) results at the 5 sampling points for 2010.

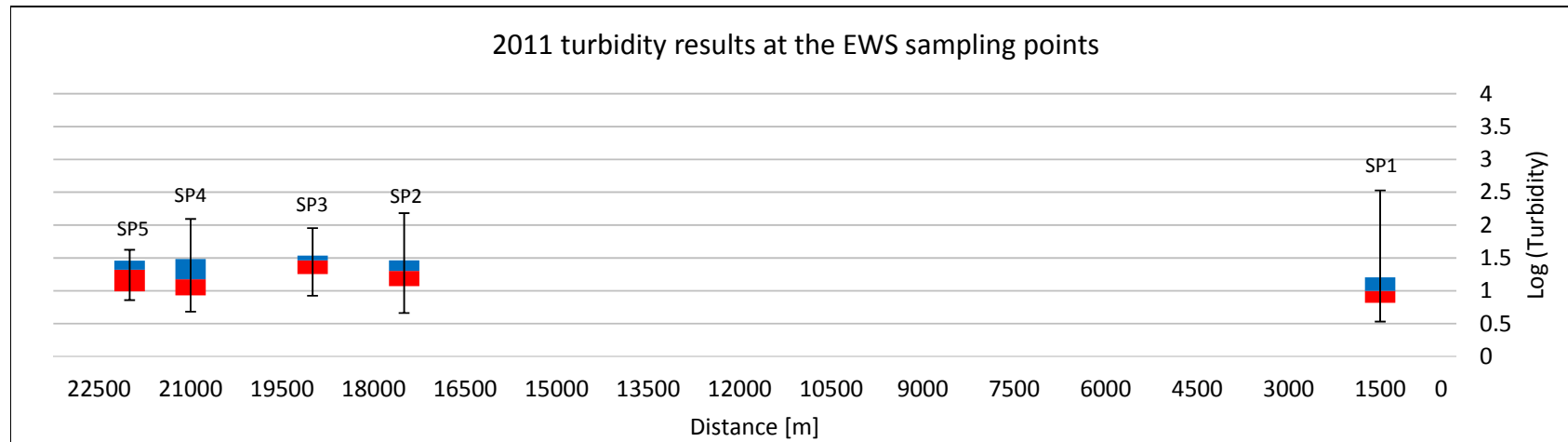


Figure F-23: Log (Turbidity) results at the 5 sampling points for 2011.

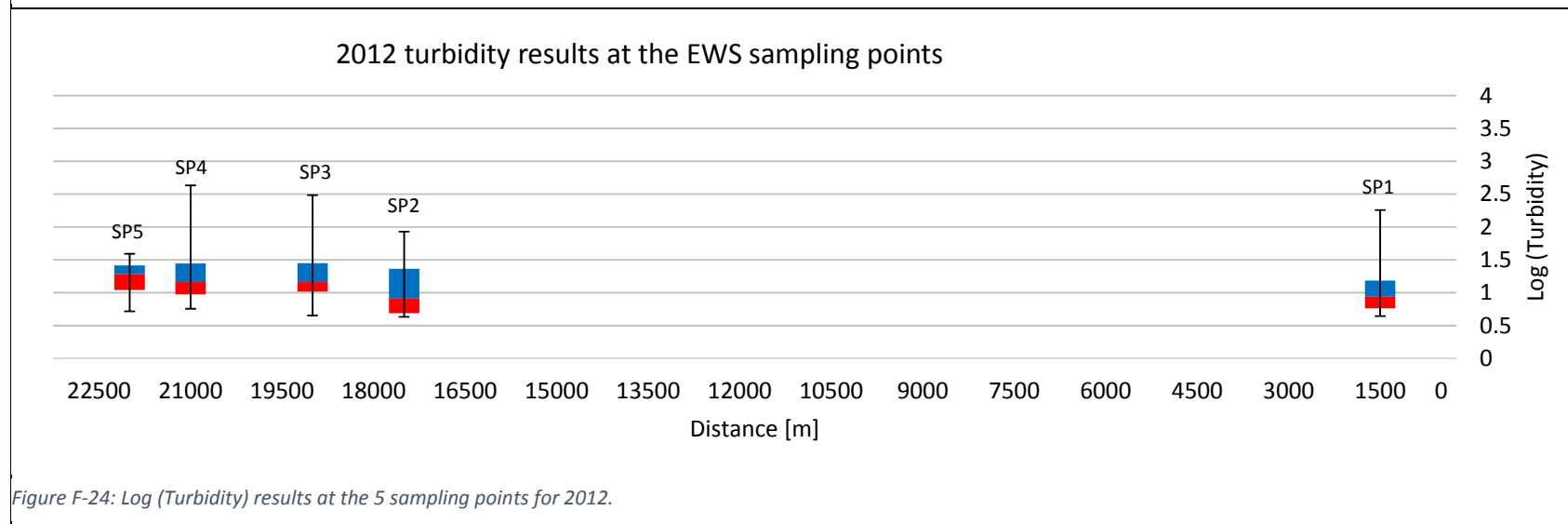


Figure F-24: Log (Turbidity) results at the 5 sampling points for 2012.

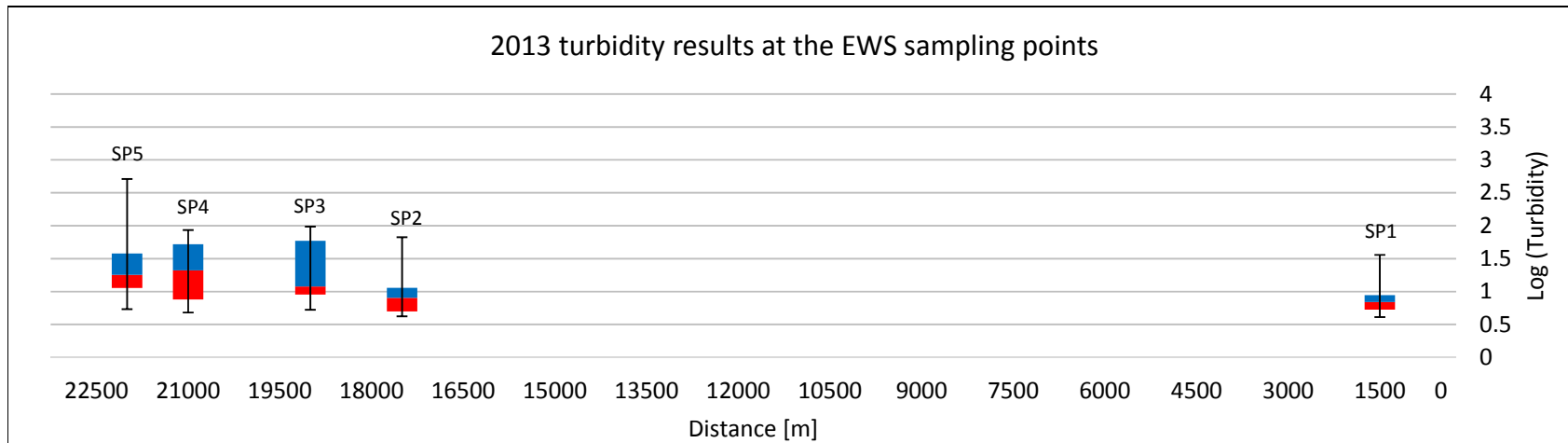


Figure F-25: Log (Turbidity) results at the 5 sampling points for 2013.

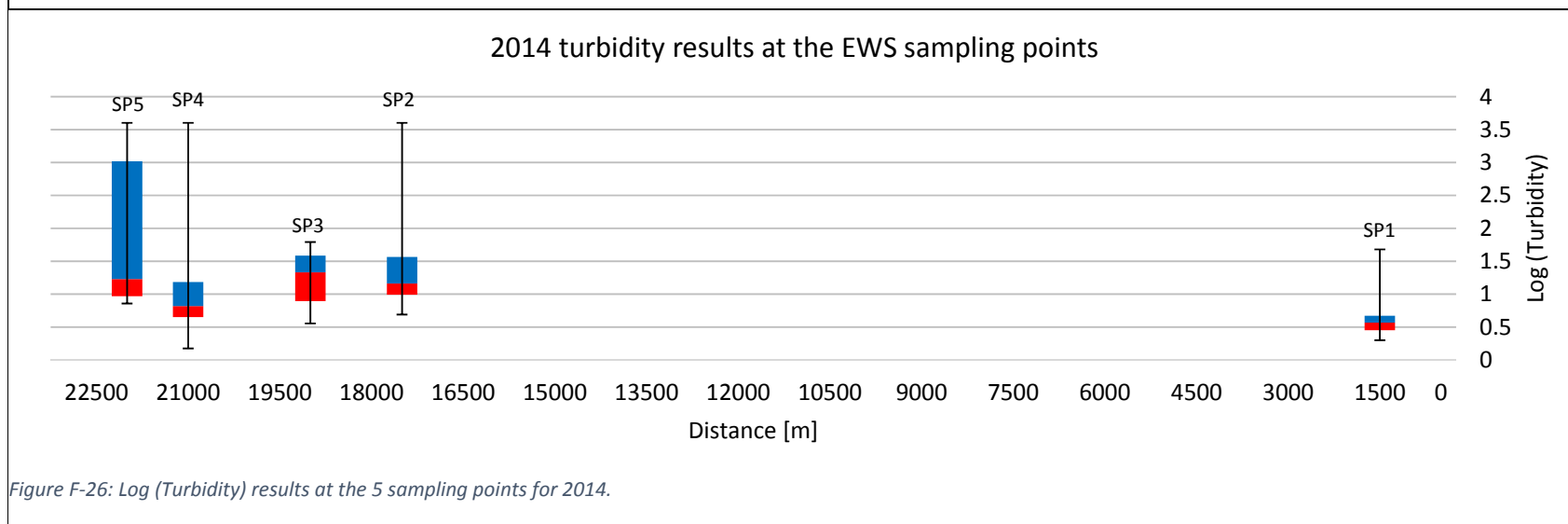
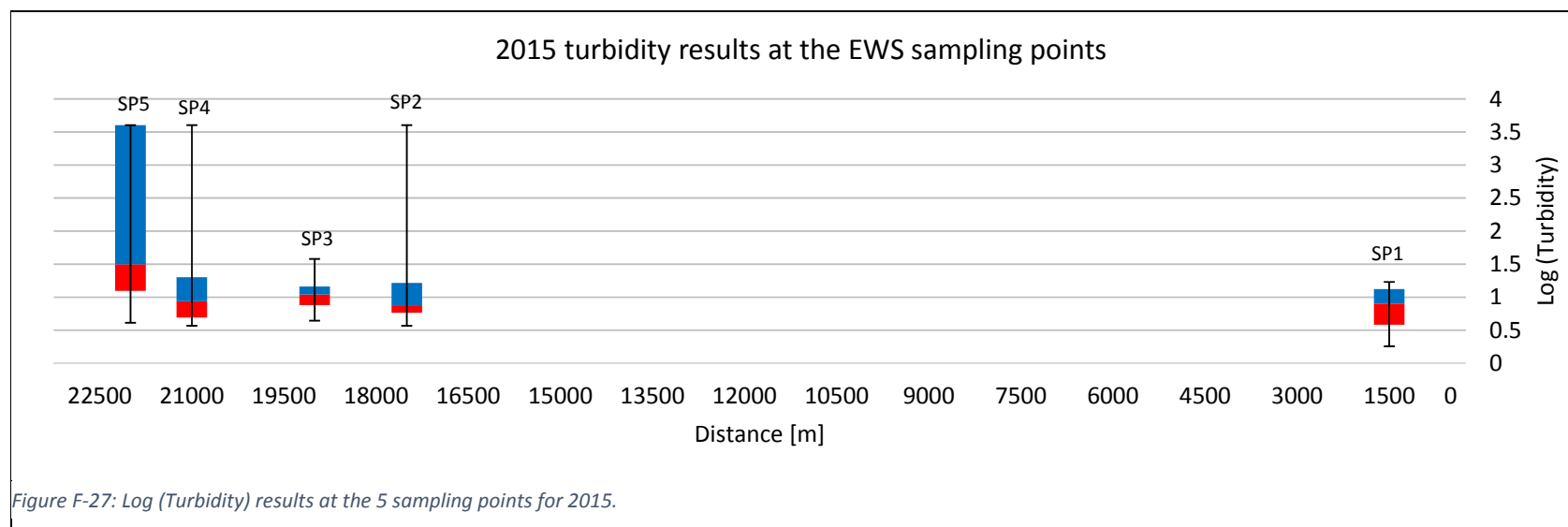


Figure F-26: Log (Turbidity) results at the 5 sampling points for 2014.



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 at the 2 mark on the log scale, i.e. 100 NTU. The upstream industrial area has introduced numerous pollutants into the river from the sewer network failures as well as from runoff carrying pollutants. These have all played a role in affecting the turbidity results. In addition, there have been areas upstream of SP3 where the riverbanks have been severely eroded, these areas will be discussed in sub-sequent sections.

However, there has been a significant increase in the upper limits in turbidity levels from 2013 to 2014 and 2015 at SP2, SP4 and SP5. The turbidity levels are a result of the increased soil particles within the Palmiet River. Whilst there has not been an increase in hardened surfaces from 2006 to 2016, the accumulated effects of the increased flow rate has left parts of the riverbanks at varying degrees of failure. As a result, the riverbanks have become more prone to erosion with little stimulus.

## **APPENDIX G : OVERVIEW OF EACH UNIT**

### **G.1 Relationship between Infrastructure and the Palmiet River and Riparian Zone**

The impacts along the Palmiet River and riparian zone are often linked and contribute in some ways to other impacts.

#### **G.1.1 Indigenous Vegetation Removal**

The cause of the indigenous vegetation removal is easily identified by the increase in infrastructure and the decrease in the natural areas. The classified Landsat imagery further validates this point. Within the Palmiet Catchment, the indigenous vegetation has been removed and replaced by buildings, roads, parking areas, factories and houses.

In addition, in order to implement the stormwater and sewer system, the natural area had to be excavated which resulted in the loss of the indigenous vegetation of the area. However, the vegetation has managed to grow back in the areas where the sewer and stormwater networks were implemented. The vegetation growing along the riverbanks have also been washed away with the eroding of the riverbank.

The natural land has been severely fragmented, of particular concern is Unit 2. When observed from above, the natural landscape has been drastically transformed by the factories and buildings constructed in the area. This has resulted in the loss of riparian corridors and connectivity channels between the different habitats.

#### **G.1.2 Exotic Vegetation**

Whilst this impact is not a result of the increase in infrastructure, the exotic vegetation, primarily the alien vegetation, plays a role in reducing the functionality of the riparian zone of the Palmiet Catchment. The alien vegetation was introduced to the area by homeowners who bought the plants due to their aesthetics. These plants then spread to the surrounding areas due to the ideal climatic conditions of the Palmiet Catchment and sufficient water supply.

### **G.1.3 Bank Erosion**

Bank Erosion is an impact, which is a direct result of the increased flow rate of the Palmet River. Hard infrastructure interventions, which have been implemented to stabilise the riverbanks, have also caused problems along the Palmet River. Gabion baskets, for example, are often only placed along one side of the riverbank and as a result, the scouring force of the Palmet River has eroded the opposing riverbanks. In addition, the development of infrastructure, such as the implementation of sewer lines, directly alongside the Palmet River has aided in destabilizing the riverbank to an extent, making the riverbank more susceptible to erosion.

### **G.1.4 Channel Modification**

The natural meandering Palmet Rivers has been diverted and channelized to flow around the surrounding infrastructure in certain areas. With the river meandering through private property, it was taking up space, which, historically, was needed for the implementation of infrastructure. Therefore, the course of the Palmet River has been altered by the use of hard infrastructure solutions, such as cemented walls and gabion baskets. These hard infrastructure solutions along the riverbanks have reduced infiltration into the surrounding riverbanks and has aided in directing the flow of water downstream. Therefore, the hard infrastructure solutions along the riverbanks is partially responsible for the increased scouring ability of the Palmet River. The hard infrastructure solutions have also reduced the ability of the natural vegetation to grow along the riverbanks.

### **G.1.5 Flow Modification**

One of the biggest problems within the Palmet River is the modified flow of the river. The only beneficial infrastructure implemented to attenuate the flow rate of the Palmet River is the weirs observed at isolated points along the Palmet River.

The conventional stormwater design transports all runoff directly into the Palmet River. The increased runoff transported by the stormwater network, the sewer overflow pipes and the hard infrastructure interventions implemented along the riverbanks all aid in increasing the volume of water entering the Palmet River. The hard, impermeable surfaces reduces the time taken for the runoff to enter the river system. As a result, the larger volume of runoff entering the Palmet River system over a shorter duration has significantly increased the scouring ability of the Palmet River.

A typical residential house will naturally discharge stormwater collected, from the roofs of houses, into the Palmiet River. However, in the industrial areas, the stormwater collected is an accumulation from the roofs of buildings as well as the stormwater collected from the impermeable surfaces surrounding the buildings.

### **G.1.6 Bed Modification**

The Palmiet Riverbed has been primarily modified, resulting in the exposure of bedrock, due to the increased scouring force of the Palmiet River brought on by the conventional stormwater design system. In addition, in order to stabilise bridges built over the Palmiet River, the riverbed both upstream and downstream of these bridges have been reinforced with concrete.

### **G.1.7 Water Quality**

Problems in the sewer systems is the main contributor to the decreased water quality within the Palmiet River. The 3 pump stations have been prone to failures resulting in the discharge of untreated sewage directly into the Palmiet River, once the storage capacity at the pump station has been exceeded. In addition, blockages in the sewer pipes, primarily caused by individuals flushing items down the toilet, which they should not, has resulted in sewage, containing both household wastewater and trade effluent, overflowing into the Palmiet River. Certain individuals have also illegally connected their stormwater to the sewer network, as a result, during heavy rainfall events, the sewer networks overflow at the manholes as they are unable to cater for the increased volumes.

Runoff travelling across the impermeable surfaces is often contaminated with oil and other chemicals, these pollutants are then discharged through the stormwater network into the Palmiet River. In addition, companies within the industrial area wash down their storage and parking areas with chemical detergents. These detergents then flow into the stormwater drains and are discharged into the Palmiet River.

### **G.1.8 Rubbish Dumping**

Rubbish dumping is an impact, which is attributed to the lack of service delivery in the informal settlements and human ignorance in the residential and industrial areas of the Palmiet Catchment.