COMBINED EFFECT OF URBANISATION, INDUSTRIALISATION AND POPULATION GROWTH ON WATER QUALITY OF THE PALMIET RIVER AND ITS TRIBUTARIES IN THE OVERBERG WEST SUB-CATCHMENT OF THE BREEDE-GOURITZ WATER MANAGEMENT AREA: AN INTEGRATED CATCHMENT RISK ASSESSMENT

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Combined Effect of Urbanisation, Industrialisation and Population Growth on Water Quality of the Palmiet River and its Tributaries in the Overberg West Sub-Catchment of the Breede-Gouritz Water Management Area: An Integrated Catchment Risk Assessment

Report to the

Water Research Commission

by

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EXECUTIVE SUMMARY

Background

Managing the combined effect of urbanisation, industrialisation and population growth on water resources is a challenging task. The increasing demands for water for different uses require a broad range of water management strategies and tools. It is acknowledged that there are serious water quality impacts and threats to water users and human health in the Breede-Gouritz Water Management Area (BGWMA) (Khan in DWA, 2011). According to the Western Cape Department of Environmental Affairs and Development Planning (2011), water quality in the BGWMA becomes progressively poorer in a downstream direction, which could possibly be attributed to an increase in anthropogenic activities. Therefore, an integrated approach is needed to obtain knowledge on the involved anthropogenic, hydrological and biochemical processes within this sub-catchment in order to manage any effects.

This research focused on developing a generic risk assessment framework for river pollution in the Overberg West sub-catchment of the BGWMA. The framework covers pollutant source/s, identification and type/s, pollutant transport modelling, hazard estimation, exposure assessment, risk mapping and risk management. The purpose was to integrate data and information from the integrated risk assessment into the decision-making structures of the Breede-Gouritz Catchment Management Agency (BGCMA) and other relevant authorities. It is envisaged that the outcomes of this research will be used to aid the regulatory function of water resource quality monitoring and reporting.

Rationale

Water resources in the BGWMA will be coming under increasing stress from population growth and increased urbanisation. Of significant concern is the contamination of water resources by municipal solid waste, waste water and urban run-off that contribute high pathogen and nutrient loads to the system. In order to address and find solutions to these challenges, a probabilistic approach that focus on environmental analysis and modelling is needed. One such probabilistic approach is an integrated catchment risk assessment (ICRA) (Ocampo-Duque et al., 2013).

However, existing approaches do not exactly present an integrated risk assessment that considers all of the possible factors for environmental and human health risks of hazardous materials (Topuz et al., 2011). Artigas et al. (2012) state that there is a gap in scientific knowledge for efficient policymaking decisions in water quality management. This lack of knowledge results in uncertainty in risk assessment of chemicals to biodiversity and ecosystem services. Modern analytical chemistry methods provide us with the ability to detect and quantify any chemical in the environment. The main issue is not only to assess existing environmental contamination, but also to predict adverse impacts on water resources linked with an ever-changing anthropogenic use of chemicals.

Aims

The overall aim of the study is to conduct an ICRA to determine the impacts of the combined effects of urbanisation, industrialisation and population growth on water quality in the Palmiet River and its tributaries in the Overberg West sub-catchment of the Breede Water Management Area. Specifically, the study aimed to conduct an environmental hazard assessment, characterise the hazards, develop an integrated fate and transport model, develop a quantitative microbial risk assessment and chemical risk assessment model to predict and evaluate the risks, determine best management options and translate these into management and policy recommendations.

Methodology

The research was conducted in the Palmiet River and its tributaries (Klipdrift and Swannies Rivers) that pass through the urban area of Grabouw in the Overberg West sub-catchment of the BGWMA. This site was selected because industrial, agricultural and domestic waste water and run-off resulted in elevated organic loads in the rivers downstream, causing eutrophication and low dissolved oxygen levels.

Primary data was generated by collecting and analysing water and sediment at various sections on the Swannies, Klipdrift and Palmiet Rivers to measure the biological, chemical and physical quality of the water. The results of the samples were verified against a revised mathematical transport model.

Secondary data was obtained from sampling records and water quality analysis reports of the BGCMA.

Results and discussion

The most pronounced hazards found in Grabouw are linked to agriculture, abattoirs, and the manufacturing and motor industries. Rivers frequently receive contaminated waste water and particulate waste either directly or indirectly from urban, industrial and agricultural activities. Specific pollutants (related to anthropogenic activities surrounding the Palmiet River and tributaries) were identified and their toxicity, significance and effects are described. The research found that these posed a threat to health and the environment.

The medium and compartments relevant to modelling the exposure, fate and transport of pollutants in the Palmiet sub-catchment of Grabouw are as follows: (1) the pollutants from anthropogenic activities is released to surface water (2) through sorption embedded into the sediment, or (3) released directly onto the surface soil. The pollutants are transported either via the storm water system into the waste water treatment system and then into the river system; or via the storm water system into a wetland and then into the river system; or via the storm water system into the river system; or directly into the river system.

Laboratory analysis revealed that pollutants for especially certain pesticides and trace elements enter the river system at high levels. The concentration levels were used as input into a practical statistical model risk assessment to predict direction and spread for a distance of approximately 7 km. The application of the practical model for fate and transport revealed that pollutant concentrations tend to decrease initially and then increase back to that same high level.

The application of a mathematical model indicates that the trends in concentrations at various distances (up to 35 m, 40 m, 6500 m and 7000 m downstream) tend to increase and become diluted as the tributaries join the main river and as it flows over dense vegetation, which acts as filters. The concentration then decreases but only to approximately the same levels at which it entered the system.

Conclusions

Conceptual models (to display environmental pathways) are ideal tools to link and show relationships between the emission of the pollutant and the receiving water bodies. Risk assessment is seldom considered when determining the quality of rivers and streams. The application of an integrated risk assessment required the use of predictive models. Once the pollutant enters the water body, an effective mathematical transport model is needed to predict the pollutant concentration levels and how it is distributed and spread over various distances.

The model used in this research tends to be useful in small river systems and one need to expand the model to predict how pollutants are transported over larger distances.

Recommendations for future research

The following are therefore recommended:

Policy

- Local authorities must be required to include a risk assessment strategy for water resources in their compulsory environmental management plans.

- Instead of just routine monitoring, local authorities and catchment management agencies need to develop surveillance systems to establish exposure risk relations and estimate impact.
- Resource water quality objectives must be set for anthropogenic specific parameters. In other words, authorities need to submit a list of all anthropogenic activities and associated pollutants within a specific geographic radius of a water resource.

Future research

- This practical model was applied to a small-scale river system (the main focus was on Grabouw and not the entire catchment). More research is needed on large-scale rivers to determine how variability affects the outputs of the model.
- Research is also needed to determine the impact of the identified pollutants on the aquatic ecosystems in the Swannies, Klipdrift and Palmiet Rivers.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

2,4-D	Dichlorophenoxy acetic acid
ANOVA	Analysis of variance
BGCMA	Breede-Gouritz Catchment Management Agency
BGWMA	Breede-Gouritz Water Management Area
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
Deca-BDE	Decabromodiphenyl ether
EC	Electrical conductivity
ERA	Ecological risk assessment
ICRA	Integrated catchment risk assessment
PAH	Polycyclic aromatic hydrocarbon
PAN	Pesticide action network
PBDE	Polybrominated diphenyl ether
TDS	Total dissolved solids
TSS	Total suspended solids
US EPA	United States Environmental Protection Agency
WHO	World Health Organization
WWTW	Waste water treatment works

1 INTRODUCTION

1.1 Background

Water resources have been under intense pressure because of population growth, a dramatic increase in tourism, intensification of agriculture and the already visible effect of climate change (Nikolaidis et al., 2014). Global human population and urban development are increasing at unprecedented rates. This creates tremendous stress on local, regional, and global water quality (Duh et al., 2008). More than half of the world's population live in urban areas. By the middle of this century, seven out of ten people will live in a city. This means that urban areas will absorb most of the population growth over the next four decades and most of this increase will predominantly be in cities located in developing countries. Many of the rapidly growing cities in developing countries, particularly in Africa, already face problems related to water and have limited capacity to overcome these problems. Such cities will be major hotspots for water crises in the future (United Nations World Water Assessment Programme, 2014).

Rapid urbanisation and industrialisation contribute to large-scale modification of the drivers for hydrologic and biogeochemical processes. These modifications have worsened water challenges (Fang & Xie, 2010; Park et al., 2013; Wang et al., 2014). Urban and economic growth have massive impacts on aquatic environments, which ultimately become river sinks for waste water discharges. Among possible sources is the discharge of untreated industrial effluent and domestic sewage into rivers. The development of industrial activities, rapid urbanisation, population growth and the inadequacy of waste management strategies have all increased pollution problems (Hayzoun et al., 2014), which in turn, affect water quality.

Despite attempts to reconcile the tension between environmental and urban development agendas, extensive environmental degradation remains a major challenge facing development processes and leading to unacceptable levels of negative impacts (Hegazy, 2014). The mapping of diffuse urban water quality, labelled rivers as heavily modified water bodies and being at risk in terms of water quality status with the majority being urban receiving waters affected by the deterioration of their physical, hydromorphic, water quality and ecological parameters (Ellis et al., 2012). This created considerable justification to seek an acceptable impact assessment methodology to evaluate urban discharges to be used in conjunction with mitigating measures.

The development and application of a structured and transparent impact assessment methodology for urban surface run-off quality complements the procedure already being applied to pluvial flood risk assessment. Such an impact assessment also needs to be specified in terms of receiving water quality standards and objectives to provide management support to the ecological concepts. Therefore, to develop an efficient and sustainable exposure mitigation related to environmental management, more in-depth research is needed regarding the relationship between environmental management of areas, exposure and effects at relevant levels of biological integration. New probabilistic tools that help link exposure and effect with high level of certainty must also be developed (Ocampo-Duque et al., 2013).

One such probabilistic tool is a risk assessment. Risk assessment is now essential when prioritising environmental and human health protection and has become a dominant public policy tool for making decisions based on limited resources (Butt et al., 2014). It has become necessary to take an integrated or holistic approach to environmental issues affecting catchments because, although simple risk problems can be addressed by routine-based measures, the more complex risk situations require this new process. The use of best available information and understanding (on how river ecosystems functions) will resolve some of the complexities. We need to accept and learn to cope with this by applying integrative water management (Müller-Grabherr, et al., 2014). In other words, integrated catchment risk assessment (ICRA) that could be used to make informed decisions regarding the protection and management of water resources within a catchment.

An ICRA methodology, based on the weight-of-evidence approach, is a probabilistic approach that provides valuable and much needed reliable data. An ICRA process identifies hazards and priorities, increases public awareness of potential problems, and provides guidance for corrective measures and legal controls by organising, configuring and arranging scientific information. Clarifying factors and having quantitative results in the risk assessment process are key to determining environmental hazards and simplify the decision-making process to develop management strategies. However, existing approaches, as with the Breede-Gouritz Water Management Area (BGWMA), do not exactly present an ICRA that considers all the possible factors for environmental and human health risks of hazardous materials (Topuz et al., 2011). A risk based-approach, as Ojima et al. (2014) state, simply means that risks are identified, and estimates are made for their probability of occurrence and impact. This framework is also a means to quantify what is known, identify where uncertainties exist and help managers and decision makers develop strategies by having a better knowledge of risks.

1.2 Motivation for the Research

Of significant concern is the contamination of water resources by municipal solid waste, waste water and urban run-off, which contribute high pathogen and nutrient loads to the system. Contamination includes the discharge of inadequately treated waste water effluent from waste water treatment works (WWTW), and irrigation with untreated winery and other industrial effluent. Diffuse pollution from poorly serviced informal settlements and the use of soak ways on riverbanks are also concerning. Storm water run-off from informal settlements and poorly serviced urban areas has further increased microbial counts in receiving rivers.

It is essential to monitor the quality of the water resources in the BGWMA adequately as it will come under increasing stress from population growth, increased urbanisation, new contaminants, and climate change. These are projected to affect water quality and exacerbate many forms of water pollution from sediments, nutrients, dissolved organic carbon, pathogens, pesticides, salt, as well as thermal pollution (Bates et al., 2008). The board of the then Breede Overberg Catchment Management Agency identified several risks that may affect the catchment management agency and its operations.

The risks have been grouped into three main areas: external challenges, financial challenges and organisational challenges. External challenges include the threat of climate change, pollution incidents and other threats arising from the current state of water infrastructure. Also included are social developmental risks and demands created by population and economic growth. This makes water quality monitoring data critical for decision-making, and existing efforts by the various monitoring institutions must be confirmed and intensified where necessary (Western Cape Department of Environmental Affairs and Development Planning, 2011).

Ongoing monitoring and reliable data are the cornerstones to improve water quality. Water and sanitation managers, governments and communities need to know what pollutants are in the water, how they entered, their resulting effects and, what the most effective management approaches for improving water quality are (UN Water, 2011). The integration of water quality monitoring variables is essential in environmental decision-making. It is well-known that the assessment of water quality still relies heavily upon subjective judgments and interpretation. Therefore, probabilistic approaches are commonly applied in environmental analysis and modelling to control uncertainty propagation (Ocampo-Duque et al., 2013).

Artigas et al. (2012) state that there is a gap in scientific knowledge for efficient policymaking decisions in water quality management. This lack of knowledge results in uncertainty when doing risk assessments of chemicals to biodiversity and ecosystem services. Obviously, risks of contaminants can only be mitigated efficiently by changing exposure. Modern analytical chemistry methods provide the ability to detect and quantify any chemical in the environment. However, the main issue is not only to assess existing environmental contamination but also to predict adverse impacts on ecosystems linked with an ever-changing anthropogenic use of chemicals. Furthermore, to prevent contaminants from entering the environment by pollution prevention and reuse measures. Understanding the processes, including bioavailability and biotransformation, is in this context more important than decreasing detection limits. Therefore, to develop an efficient and sustainable exposure mitigation related to environmental management, more in-depth research is needed regarding the relationship between environmental management of areas, exposure and effects at relevant levels of integration.

1.3 The Study Site

The research was conducted in the Palmiet River and its tributaries within the Overberg West sub-catchment of the BGWMA (Figure 1).

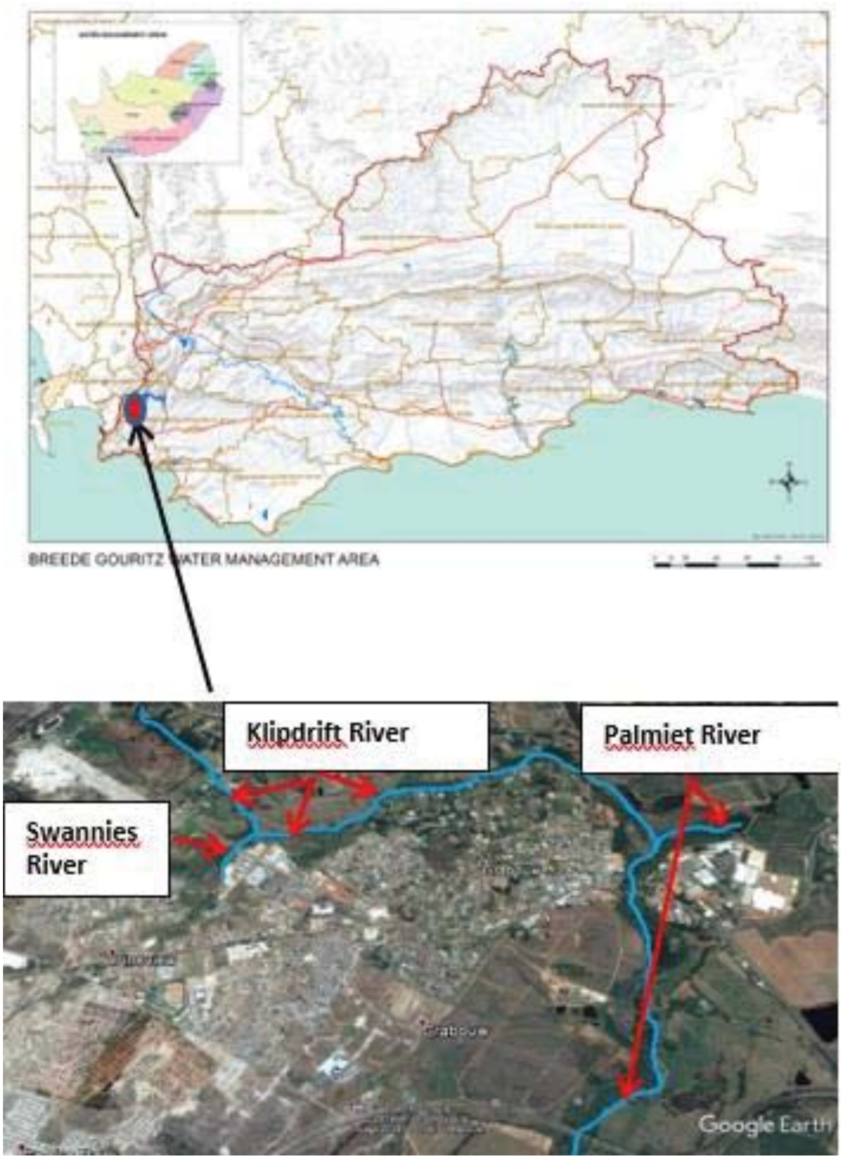

Figure 1: Study site

The Palmiet River system is one of the most intensively farmed regions in the Overberg. Of the 11 400 ha of irrigated land in the Overberg, 66 % (7600 ha) fall within the Palmiet River catchment (DWAF, 2004). In this sub-catchment, industrial, agricultural and domestic waste water and run-off near urban areas such as Grabouw resulted in elevated organic loads in the rivers downstream, causing eutrophication and low dissolved oxygen levels. Litter in these areas is also a problem. Treated waste water discharges from urban areas have decreased the downstream water quality (River Health Programme, 2011).

The Palmiet River rises in the Hottentots Holland Mountains at an altitude of 1010 m above mean sea level. The river is about 70 km long and fed by 11 perennial tributaries and numerous seasonal streams. The river meanders south from Nuweberg through the Elgin Basin where it is joined by the Klein Palmiet and Kromme Rivers. It enters the Kogelberg Nature and flows in a south-westerly direction to be joined by the Dwars and Louws tributaries. The river then flows in a south-easterly direction to discharge into the Atlantic Ocean via a small estuary near Kleinmond. The Palmiet River has five major instream dams and many smaller farm dams (River Health Programme, 2003).

According to Mpokopi (2017), the Palmiet River flows through the town of Grabouw. Grabouw, which forms part of the Theewaterskloof Local Municipality, is located within the Overberg District Municipality in the Western Cape province of South Africa. Grabouw is a mid-sized town some 65 km south-east of Cape Town along the N2 highway. Grabouw is the commercial centre for the Elgin Valley, the largest single export fruit-producing area in southern Africa. Census 2001 listed the town's population as 21 593. However, Census 2011 showed that this number has increased to 30 337, which simply indicates population growth in the area. This would possibly be a challenge to how waste is managed in the selected residential areas. Visual observations in the study area showed waste pilling on the streets. This might influence water tributaries of the Palmiet River, which were also observed to have been contaminated. Based on the constitution of the Republic of South Africa, municipalities have a stipulated duty to render waste management services to local communities.

Grabouw is classified as the second-highest order node in Theewaterskloof. It is therefore anticipated that the town will experience continued growth within its central business, industrial and residential areas. Grabouw experienced very high levels of population growth over the last 5–10 years. Limited expansion opportunities exist regarding high-income and subsidised residential developments. Grabouw is strategically placed along the N2 highway as the main point of entrance/exit, firstly, to the Cape Metropolitan region, secondly, to the Overberg and the Southern Cape and, thirdly, as the point of convergence of routes serving the agricultural production areas (economic base of the sub-region) and of towns and rural centres in the sub-region.

High levels of seasonal migration into Grabouw, which are linked to fruit farming and other agro-industrial activities, have resulted in high population growth rates, which create increasing demands for basic services such as water, electricity, sanitation and housing. A high level of poverty is also singled out with 78% of the population earning less than R3500 per month.

The Palmiet River (and its tributaries), which runs through Grabouw, is an important ecological corridor. There are wetlands and/or floodplain areas associated with the Palmiet River system that are similarly an important part of this ecological corridor.

1.4 Aims

The overall aim of the study was to conduct an ICRA to determine the combined effects of urbanisation, industrialisation and population growth on water quality in the Palmiet River and its tributaries in the Overberg West sub-catchment of the BGWMA. Specifically, the study aimed to:

- Conduct an environmental hazard assessment to identify and quantify the sources of selected micro-pollutants (organic waste, nutrients and pathogens) in the sub-catchment.
- Characterise the hazards by gathering, generating and evaluating data of the pollutants and conclude on their toxicological effect and environmental fate.
- Develop an integrated fate and transport model by identifying the principal/dominant flow pathways, determining the dominant hydro-chemical processes controlling the fate and transport of the contaminants, and the potential of polluting.
- Develop a quantitative microbial risk assessment and chemical risk assessment model to predict and evaluate the risks emanating from contaminations and pollution.
- Determine best management options and translate these into management and policy recommendations.

1.5 Capacity Building and Research Outputs

As part of the capacity building for the project, three students embarked on postgraduate studies (Table 1).

Table 1: Student capacity building

Student	Degree	Thesis Title	Status
Monique Natus	Master Environmental Management	Sediment yield, transport dynamics and deposition of pollutants in the Palmiet River, Grabouw, Western Cape.	Ongoing: Monique is in the process of writing her thesis. It is envisaged that her thesis will be submitted for examination in September 2017.
Bulelwa Mkuyana	Master Environmental Management	Reducing agricultural non-point source pollution in the Elgin region.	Ongoing: Bulelwa is currently collecting data. It is envisaged that the collection and analysis will be completed by August 2017. Writing up will follow and submission for examination will take place in December 2017.
Aseza Mpokopi	Master Environmental Management	An evaluation of waste management practices in the Theewaterskloof Municipality, Grabouw, Western Cape.	Ongoing: Aseza is in the final stages of data analysis and his thesis will be submitted for examination in October 2017

The following papers are being prepared for publication and conference proceeding purposes:

- The diffusion of chemicals in the Palmiet River and its tributaries: Applying scientific knowledge for water quality management.
- Toxic deposition of pollutants in the Palmiet River, Grabouw, Western Cape.
- Waste management practices in the Theewaterskloof Municipality, Grabouw, Western Cape.

2 THE ICRA FRAMEWORK

2.1 Ecological Risk Assessment

Risk assessment is a process that provides a flexible framework within which the risk of adverse effects can be evaluated in a systematic science-based manner. The risk assessment allows for defendable decisions to be made on whether a particular risk is acceptable or not. It also provides the means to evaluate possible ways to reduce a risk from unacceptable to acceptable. Risk assessment is now widely used in many fields including the environment where it is known as environmental or ecological risk assessment (ERA) (Arthur, 2008).

ERA is the assessment of environmental effects of certain stressors (risk factors) and their immediate and long-term damage or harm to an ecosystem. The implementation of ERA is achieved by using models at various organisational scales including sub-organism, population, community, whole ecosystem, and socio-ecological system. ERA has been used to provide an impetus to many types of management activities, including the management of watersheds/catchments (Chen et al., 2013). An ERA approach is deemed to be appropriate when managers need to evaluate, prioritise and find solutions to the most serious of multiple potential hazards and threats to water and its catchment. Coupled with this is the urgent need to incorporate the effects of human activities on biodiversity, ecosystem functions and services into the ERA framework (Chan et al., 2010; Schäfer, 2012).

The traditional ERA framework as depicted in Figure 2 consists of consists of three major phases: (1) problem formulation (2) analysis and (3) risk characterisation.

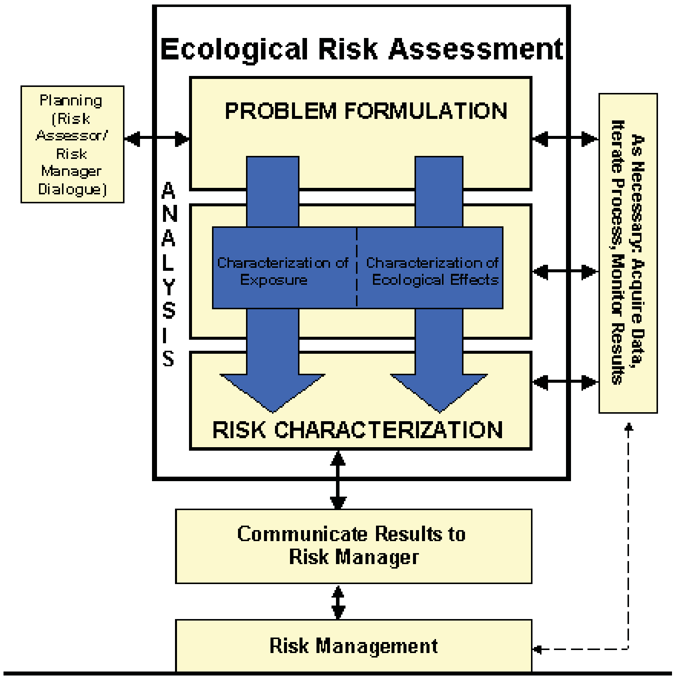

Figure 2: Framework for risk assessment (Source: US EPA, 1998)

Problem formulation provides the foundation for the ERA. It is an iterative process for generating hypotheses concerning why ecological effects occurred from human activities. The problem formulation articulates the purpose and objectives of the risk assessment and defines the problem and regulatory action.

In the analysis phase, exposure to stressors (exposure characterisation), and the relationship between stressor levels and ecological effects (ecological effects characterisation) are evaluated.

The risk characterisation is the final phase in which exposure and ecological effects characterisations are integrated into an overall conclusion (risk estimation). In this phase the levels of exposure (estimated environmental concentrations) are compared to toxic effects.

2.2 Integrated Risk Assessment

The integrated risk characterisation includes the assumptions, uncertainties, and strengths and limitations of the analyses. It makes a judgment about the nature of and existence of risks.

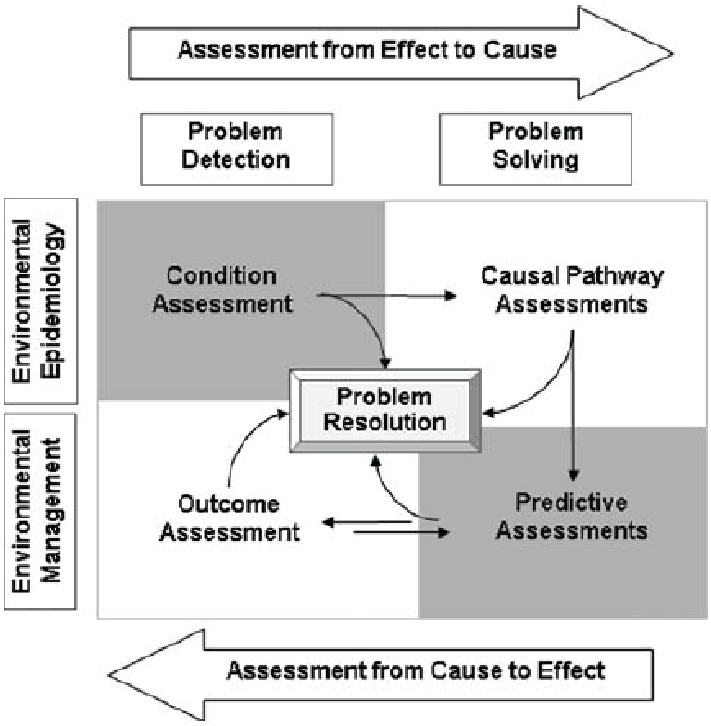

Figure 3: Integrated risk assessment framework (Source: Cormier & Suter, 2008)

The traditional method of risk assessment provided good service in support of policy, mainly in relation to standard setting and regulation of hazardous chemicals or practices. However, it has now become apparent that many of the risks facing society are systemic in nature and fit within wider social, economic and environmental contexts (Briggs, 2008). A new framework for environmental assessment is needed because no existing framework explicitly includes all types of environmental assessments. Cormier and Suter (2008) propose an integrative framework (Figure 3) that focuses on resolving environmental problems by integrating different types of assessment. The integrative assessment includes the following phases:

- Problem detection.
- Problem solving.
- Environmental epidemiology.
- Environmental management.
- Condition assessments to detect chemical, physical, and biological impairments.
- Causal pathway assessments to determine causes and identify their sources.
- Predictive assessments to estimate environmental, economic, and societal risks, and benefits associated with different possible management actions.
- Outcome assessments to evaluate the results of the decisions of an integrative assessment.

Problem detection

The assessments use the results of environmental monitoring to determine if environment degradation is due to any cause (condition assessment) or to a failed management action (outcome assessment).

Problem solving

The assessments determine causes (causal pathway assessments) and evaluate solutions to environmental problems (predictive assessments).

Environmental epidemiology

The assessments use epidemiological approaches to determine whether an ecosystem or its constituent organisms (including humans) are impaired (condition assessment) and the causes and sources of those impairments (causal pathway assessment).

Environmental management

The predictive assessments in this row estimate the consequences of alternative management actions (risk assessment), and the relative desirability of those actions based on those environmental risks, plus benefits, costs, stakeholder preferences, legal constraints, and other considerations (management assessment). After an action has been selected and implemented, outcome assessments determine the performance of the action taken to remediate the cause and its effectiveness in resolving the problem. Thus, this row characterises possible future environments that may result from alternative management actions and then evaluates the actual outcomes.

Causal pathway assessments

Determine the probable causes of the environmental impairments revealed by condition assessments. They consider the proximate cause, the source, and the causal pathways that connect them.

Condition assessments

Analyse monitoring data to determine whether environmental goals are being achieved that protect human health and ecosystems. Assessments of physical, chemical, and biological conditions may be performed independently or together.

Predictive assessments

Estimate changes that will occur under alternative actions to resolve the environmental problem. They include risk assessments and management assessments. Risk assessments estimate effects due to exposures and changes in effects due to management actions that change exposures. Management assessments predict the acceptability of actions by evaluating the risks in light of social, economic, and legal considerations.

Outcome assessments

Evaluate the success of a management action in achieving environmental goals. Where risk and management assessments predict the likely performance of different actions, outcome assessments estimate and measure the actual performance and effectiveness of management actions in the environment.

Water resource managers need to know what pollutants are in the water, how they entered, and effective approaches to deal with it. There has been a policy shift in water quality standards and norms in that, instead of testing water quality at a single point, integrated risk assessment is increasingly being applied to the assurance of water quality (UN Water, 2011). The application of an integrated risk assessment framework to understand and manage risks to water bodies in catchments requires the use of water quality monitoring models.

It is important to note that this research adapted and combined aspects of the US EPA (1998) traditional ERA and Cormier and Suter II (2008) integrative framework into the ICRA for the Palmiet sub-catchment and its tributaries as illustrated in Figure 4.

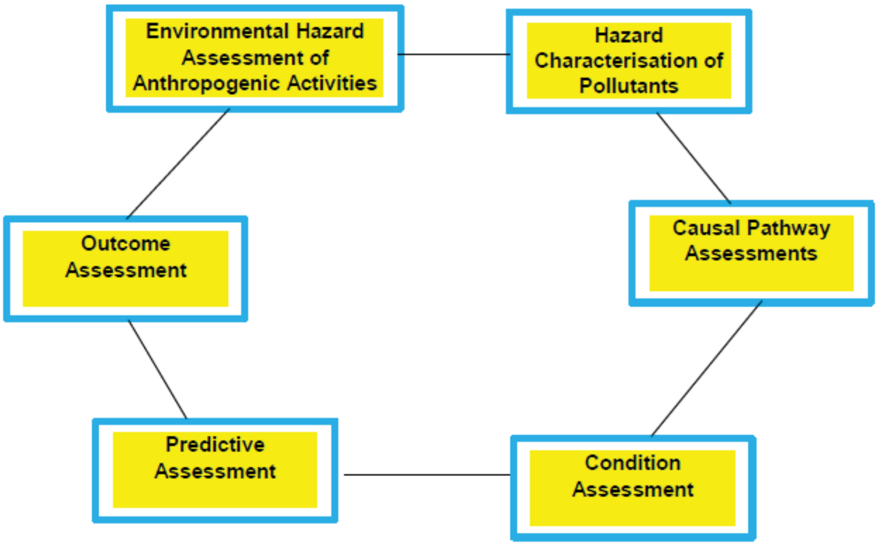

Figure 4: ICRA framework for the Palmiet sub-catchment

3 RESULTS AND DISCUSSION

3.1 Environmental Hazard Assessment of Anthropogenic Activities Surrounding the Palmiet River and Tributaries

The identification, listing, description and matching potential pollutants to each anthropogenic activity surrounding the Palmiet River and its tributaries will now be discussed.

Humans increasingly modify ecosystems because of population growth, technology, and consumption. Human destruction of habitats through direct harvesting, pollution and atmospheric changes are threatening, and if not addressed, ecosystems will be affected irreversibly. Finally, many other human activities could cause the transformation of our environment (Benitez, 2005).

The ecological equilibrium is nowadays perturbed by recent changes due to urban demographic growth, the entry of society in modernity, transformations of usages and practices at local and global scales (Duwig et al., 2014). Various anthropogenic activities in catchments have tremendous ecological and socio-economic importance, and it aptly depicts the way people are treating aquatic ecosystems (Rashid et al., 2013).

Rivers frequently receive contaminated waste water and particulate waste either directly or indirectly from urban, industrial and agricultural activities. This exerts considerable pressures on aquatic ecosystems, which deteriorate water and habitat quality on which aquatic organisms depend (Morrissey et al., 2013; Wang et al., 2012). This situation creates the need for an elaborate characterisation of waste waters and water bodies, and the evaluation of treatment facilities of municipal and industrial waste in order to assess the status and control of water pollution (Tchakonté et al*.,* 2014). It thus becomes important to identify and describe the distribution of major human activities and the link with water pollution and quality.

3.1.1 Major anthropogenic activities

Most of the economic activities of Overberg West sub-catchment takes place in Grabouw (also known as the Elgin Valley), which is the largest economic centre situated in Theewaterskloof Municipality. Its economy cannot be reviewed in isolation of the broader municipal wide economy, the district economy, the provincial economy and the national economy. In addition, as a major export producer of fruit, the global economy affects the local economy directly. The economy is primarily agrarian (almost 50% including the agro-processing activities in the region) with growing tourism, construction, financial and business services sectors (DBSA, 2011). Intensive irrigation takes place along the Breede, Riviersonderend and Palmiet River catchments. Irrigated crop types include orchard crops, vineyards for wine and table grapes, citrus, as well as some cash crops and lucerne (DWA, 2011). The economic sectors are described in Table 2.

Table 2: List of key sectors Overberg West sub-catchment

Key Economic Sectors	Description
Agriculture, Forestry and Fishing	The Theewaterskloof economy is dominated by agriculture – both primary production and manufacturing. Agricultural production generates 36.5% of the local economy, making this the predominant sector.
Manufacturing	Manufacturing in the area is largely agro-processing (90% of turnover). Beverages account for 41% of the manufacturing sector with well-known fruit juice brands. A further 37% of the area’s manufacturing is classified as processed, canned fruit and vegetables.

Key Economic Sectors	Description
Construction	Theewaterskloof has been known for its artisan pool drawn from both Genadendal and Grabouw. The presence of the Overberg Training College that provides construction-related training, the established carpentry business in the area and the ready pool of labour make it an ideal site for construction businesses to locate and from which to source workers.
Wholesale and Retail; Catering and Accommodation	The wholesale and retail trade, as well as the catering and accommodation sector have been the fastest-growing sectors in the area. Most of this growth has been concentrated around the local tourism industry. The retail sector is very dependent on the agricultural sector and much of the local money in circulation is earned from this sector.
Transport and Communication	The transport sector has also been a growth driver. Again, this can be attributed to the general upturn in the sector and to the location of several freight transport businesses and public transport in the area.
Financial and Business Services	The business services sector has been a steady growth driver in the local economy and deserves to be encouraged. The growth can largely be attributed to the upturn in the property market and the large agricultural service industry.

3.1.2 Hazardous sources assessed

Grabouw is no longer a secondary settlement in the Theewaterskloof Municipality but serves a highly productive, labour-intensive agricultural and vibrant tourism economy. It is also a dormitory town of the City of Cape Town and has the highest development priority and social need rating and second-largest population in the district (CNdV Africa, 2013). Most of the development activities take place along the Palmiet River corridor as depicted in Figure 5.

Figure 5: Urban development (Source: CNdV Africa, 2013)

The hazardous sources related to the anthropogenic activities in Grabouw (which occur within each category of the economic and urban related sectors) are set out Table 3.

Table 3: Anthropogenic activities in Palmiet sub-catchment

Sector	Hazardous Sources Related to Anthropogenic Activities
Agriculture	Deciduous fruit industry: Planting, growing, harvesting and processing of deciduous fruits. Fruit packed in cartons, fruit juice concentrate in drums and fruit juice in containers ready for consumption.
	Free range chicken slaughtering and packaging.
	Red meat: Slaughtering and trading.
Manufacturing	Steel bin, wooden and plastic pallet repairing.
Industrial	Scrapyards.
	Automotive spray-painting and panel beating.
	Municipal yard (same as scrapyard).
Transport	Goods and public transport; and earth moving.
Urban Related	Waste water treatment.
	Settlement and population distribution.

3.1.3 Hazard identification: Potential pollutants to each anthropogenic activity

Agricultural hazards

Deciduous fruit

The main land use activities within the Overberg West sub-catchment are irrigated agriculture (orchards and vineyards) and forestry. Deciduous fruit is mainly grown such as pome fruit (apples and pears), stone fruit (apricots, peaches, nectarines and plums) as well as table grapes. The total number of deciduous fruit producers is about 2225 with the Western Cape having the largest concentration growers, which represent 74% of the total area planted to deciduous fruit (Greeff & Kotzé, 2007). The establishment of vineyards and fruit orchards in this sub-catchment has resulted in a loss of riparian vegetation, decreased flow (particularly during summer) and an increase in levels of nutrients in the water and algal blooms (DWAF, 2011).

The fruit and vegetable industry typically generates large volumes of effluents and solid waste. The effluents contain high organic loads, cleansing and blanching agents, salt, and suspended solids such as fibres and soil particles. They may also contain pesticide residues washed from raw materials (Cheremisinoff et al., 2008).

Pesticides comprise a broad range of substances commonly used to control insects, weeds, fungi and plant diseases. They are frequently classified by target organism or mode of use as insecticides, herbicides, fungicides, or fumigants. Insecticides are often sub-classified by chemical type as organophosphates, organochlorines, carbamates, and pyrethroids (Kamel & Hoppin, 2004). South Africa is the largest user of pesticides in sub-Saharan Africa and many studies have highlighted the occurrence of pesticides in water resources. Poor management of water treatment facilities in combination with a relatively high dependency on untreated water from boreholes and rivers create the potential of exposing human communities to pesticides and their associated health effects (Dabrowski et al., 2014).

The largest sector consuming pesticides in South Africa is agriculture, with only a smaller proportion devoted to vector control for public health and for domestic pest control operations. Evidence for environmental contamination, arising from agricultural application, come from a number of studies that have found the presence of pesticides in water sources in South Africa (Dalvie et al., 2009).

Nutrients, sediments and pesticides potentially enter aquatic environments via run-off, leaching and spray drift and pose a risk to the communities that inhabit them. Of all non-point source pollutants, insecticides are among the most crucial chemical stressors, simply because of their extremely high toxicity to many non-target aquatic organisms such as fish and macro-invertebrates (Dabrowski & Balderacchi, 2013).

The study by Dabrowski and Balderacchi (2103) was conducted in the Lourens River in the Western Cape, also a deciduous fruit area. The study included the following pesticides: Carbendazim, flusilazole, alpha-cypermethrin, beta-cyfluthrin, chlorpyrifos, cypermethrin, endosulfan, methyl-parathion, prothiofos, trifloxystrobin, carbaryl, dimethomorph, thiacloprid, azinphos-methyl and propiconazole.

Apart from pesticides, the chemicals depicted in Table 4 are also related to the agro-processing (fruit juices) industry:

Table 4: Chemicals in the agro-processing industry

Purpose	Chemical
Laboratory control for quality and effluent analysis	Ether, chloroform, acids, alkalis, culture media for microbial growth
pH control and corrosion inhibition	Dilute hydrochloric acid, sodium hydroxide
Additives and preservatives	Sodium metabisulfite, sodium benzoate, citric acid, sulphur dioxide
Detergents and antiseptics for cleaning and sterilisation	Sodium hydroxide, nitric acid, sodium hypochlorite

(Source: Adapted from the Egyptian Environmental Affairs Agency, 2002)

Abattoir hazards: poultry and red meat

Abattoirs are classified as high-throughput, low-throughput or rural depending on the amounts of units slaughtered per day (Molapo, 2009).

Poultry (free range)

In the poultry industry/abattoir, a unit is equivalent to one chicken (South Africa, 2004). The classification amounts range from > 2000/day for high-throughput, < 2000/day for low-throughput to < 50/day for rural. The amounts and types of waste produced by the abattoirs are thus linked directly to the number of units slaughtered per day and the stage of slaughter and/or processing. The waste can be categorised as either high-risk materials, which are waste that are suspected of posing serious health risks, or low-risk materials, which pose no risk (Salminen & Rintala, 2002).

The nature of the waste can either be solids, which include condemned organs, meat, carcass, bone, feathers and manure, or effluent/liquid waste, which includes dissolved solids (including fats), blood, sludge and wash water. The major waste, however, is blood, which makes up 6% of the total waste count. The moisture content of the waste largely determines whether it is solid (< 84%), liquid (> 96%) or slurry (between 90% and 94%) (Mijinyawa & Dlamini, 2006).

Poultry litter (the mixture of bedding material made up of, among others, straw, saw dust, rice hulls and/or paper, manure and feathers) also contributes to the amount of waste produced, mainly contributing proteins, carbohydrates and fats (Glatz et al., 2011; Kelleher et al., 2002; Poultry Hub, 2006), with subsequent nitrogen in the form of uric acid and undigested proteins, which under aerobic condition breaks down to ammonium. Ammonia is present either as gas or ammonium ions, the latter with high levels of corrosiveness due to its pH levels.

Phosphorous, used in broiler production, is also present in manure (Kelleher, et al., 2002). There are also trace levels of chlorine (Cl), calcium (Ca), magnesium (Mg), sodium (Na), manganese (Mn), iron (Fe), copper (Cu), zinc (Zn) and arsenic (As) (ibid; Hopey, 2008). In addition to the heavy metals described, poultry litter furthermore contains antibiotic residues, cysts, larvae and a wide range of microbial pathogens (UPC, undated).

The type and size of chicken further determine the types and amounts of wastes produced. Laying hens produce more calcium- and phosphorous-rich excreta than, for example, broilers (Gerber et al., 2007). In hatcheries, the waste may include empty egg shells, infertile eggs, dead embryos, late hatchings and dead chickens (Glatz et al., 2011).

Antimicrobials are used among others as prophylaxis or to enhance growth. Gerber et al. (2007) suggest that as much as 75% of these, administered to confined poultry, are released into the environment via poultry excreta.

Pathogenic microorganisms present in waste waters from poultry abattoirs include *Salmonella* sp., *Staphylococcus* sp., *Clostridium* spp. and *Campylobacter* spp. (Salminen & Rintala, 2002). Jiangrang et al. (2003) and Gerber et al. (2007) suggest the following being present: *Lactobacillus*, with the majority of the rest being related to Clostridiaceae (11%), *Streptococcus* (6.5%), *Enterococcus* (6.5%), *Lactobacillus* (8%), and *Bacteroides* (5%) as well as *Campylobacter* in the gut of broiler chickens, *Cryptosporidiae* and *Giardia* spp. (Bowman et al., 2000).

Large amounts of water are used in the poultry abattoir, subsequently producing large volumes of waste water. Gerber et al. (2007) suggest that this waste water has a high biochemical oxygen demand (BOD) and chemical oxygen demand (COD) due to the presence of organic materials such as blood, fat, flesh, and excreta. Hormones and antibiotics are also introduced via feed and these may also be present in poultry manure (Steinfeldt et al. in FAO, 2006).

Waste in the red meat industry

Animal/livestock production and farming is estimated to contribute largely (18%) to the amount of global green-house gas emissions, which are characterised as follows: 37% total methane, 65% nitrous oxide and 9% CO_2 emissions (CIWF, 2008). As with the poultry industry, the bulk of waste results from animal holding/housing, hides, hair, evisceration, carcass washing and trimming, clean-up operations (US EPA, 2004), as well as paunch manure (Gulliver & Gulliver, 2001).

McWilliams (2010) suggests that around 60% of the waste resulting from red meat slaughter includes offal, bones, tendons, blood and plasma. Animals that die on the farm are disposed by either burial (which allows leaching of, among others, chloride, ammonium, nitrate and coliforms into the ground, thereby contaminating groundwater sources) (ibid) or by incineration (which releases heavy metals and other pollutants such as sulphur dioxide, carbon monoxide and nitrogen oxides into the atmosphere).

Manufacturing hazards

Wood and plastic pallets

Pallets are used to transport, ship and store a large amount of goods. Pallets are an indispensable component of global trade and millions of pallets enter the global supply chain every year. As various arguments over the environmental impacts of different types of pallets and management practices continue to rage within the pallet industry, there appears to be a growing volume of information in support of all sides of these arguments (Bhattacharjya & Walters, 2012).

The hazardous aspects of pallets are in the material used. Wooden pallets are frequently infested with beetles and therefore need to be fumigated on a regular basis. Current approved treatment is methyl bromide fumigation (Anil, 2010). Plastic pallets contain a hazardous fire-retardant component called decabromodiphenyl ether, which also known as DecaBDE. DecaBDE is an extensively used fire retardant found in a variety of plastic, electronic, textile, upholstery and building products. It is one of a class of brominated flame retardant chemicals, the polybrominated diphenyl ethers (PBDEs), and one of three commercial formulations that served until a few years ago as effective and inexpensive flame retardants.

There is increasing evidence of decaBDE's widespread environmental persistence, presence in breast milk and children's blood, and potential liver, thyroid, and neurodevelopmental toxicity, raising concerns about its human health and environmental effects (Kerr & Soltys, 2014).

Motor industry hazards

Scrapyards

The recent pace of urbanisation and industrialisation in many parts of developing countries of the world has led to increased generation of scrap materials, which are often dumped in parts of urban centres where heavy metals and other components leach into the ecosystem causing damage. Activities at scrapyards such as dismantling motor vehicles and machinery, metal cleaning, sorting and recovery especially for non-ferrous metal values, pose potential risk such as the presence of toxic substances, which may affect human health, plant growth and animal life (Adedeji et al., 2014).

Scrapyards contain waste oil, oxidation products, sediments, water and metallic particles resulting from machinery wears, used batteries, organic and inorganic chemicals used in oil additives and metals. Heavy metals such as cadmium (Cd), copper (Cu), chromium (Cr), lead (Pb), manganese (Mn), nickel (Ni) and zinc (Zn), which are often contained as additives in some lubricants and gasoline, are non-degradable in soil. Some of them have been classified as priority pollutants (Ololade, 2014). The activities, pollution sources and pollutants found at scrapyards are listed in Table 5.

Table 5: Activities, pollution sources and pollutants

Activity	Pollutant source	Pollutant
Illicit connection to storm sewer	Sanitary water	Bacteria, total suspended solids (TSS), carbonaceous BOD
	Floor drains	Oil and grease, heavy metals, chlorinated solvents, fuel, ethylene glycol
	Vehicle wash waters	Oil and grease, detergents, metals, chlorinated solvents, phosphorus, TSS
	Radiator flushing waste water	Ethylene glycol
Vehicle dismantling	Oil, antifreeze, batteries, gasoline, diesel fuel, hydraulic fluids, electrical switches	Oil and grease, ethylene glycol, heavy metals, mercury
Used parts storage	Batteries, chrome bumpers, wheel balance weights, tires, rims, filters, radiators, catalytic converters, engine blocks, hubcaps, doors, drivelines, galvanised metals, mufflers	Sulphuric acid, galvanised metals, oil and grease, heavy metals, petroleum hydrocarbons (e.g. benzene, toluene, ethylbenzene, xylene), TSS
Outdoor vehicle and equipment storage	Leaking engines, chipping/corroding bumpers, chipping paint, galvanised metal, batteries	Oil and grease, arsenic, organics, heavy metals (e.g. aluminium, iron, lead), TSS, lead/battery acids
Vehicle and equipment maintenance	Parts cleaning	Chlorinated solvents, oil and grease, heavy metals (e.g. iron), acid/alkaline wastes
	Waste disposal of greasy rags, oil filters, air filters, batteries, hydraulic fluids, transmission fluids, radiator fluids, degreasers	Oil, heavy metals, chlorinated solvents, acid/alkaline wastes, heavy metals, ethylene glycol
	Spills of oil, degreasers, hydraulic fluids, transmission fluid, and radiator fluids	Oil, arsenic, heavy metals (e.g. lead), organics, chlorinated solvents, ethylene glycol
	Fluids replacement including oil, hydraulic fluids, transmission fluid, and radiator fluids	

Activity	Pollutant source	Pollutant
Vehicle, equipment, and parts washing areas	Washing and steam cleaning waters	Oil and grease, detergents, heavy metals, chlorinated solvents, phosphorus, salts, TSS
Liquid storage in above ground storage tanks	External corrosion and structural failure	Fuel, oil and grease, heavy metals (e.g. iron, aluminium, lead)
	Installation problems	
	Spills and overfills of oils, coolants, fuels, solvents, and other fluids by operator error	

Spray-painting and panel beating

Paint comprise pigment and a vehicle. The pigment, or solid component dispersed in paint, provides the colour in the paint and allows a film to form on the surface of a material. The vehicle is the liquid portion of the paint, which includes components such as binders, extenders, flow additives and volatile components known as thinners (solvents). The materials used in paint may be potentially hazardous to the environment. Paint (which is a mixture of solvents, pigments, and additives) forms aerosols, mists, and vapours during spray operations. Some painting additives and pigments contain highly toxic materials such as hexamethylene diisocyanate and toxic metals. Paints, primers, and primer washes may contain water-insoluble chromium VI compounds (US Army, 2012).

Transport hazards

Vehicles

The transport sector is a major source of water pollution and hydrologic disruptions. Motor vehicles are a major contributor to non-point source pollution as small quantities of various pollutants are emitted during vehicle use or improperly disposed at many different locations. Several studies link heavy metals (such as Pb, Zn, or Cu) or hydrocarbon loadings of surface water with transportation (Nixon & Saphores, 2007).

Impacts from vehicle transportation include polluted surface and groundwater, contaminated drinking water, increased flooding and flood control costs, wildlife habitat damage, reduced fish stocks, loss of unique natural features, and aesthetic losses. Vehicles leak hazardous fluids, including crankcase oil, transmission, hydraulic, and brake fluid, and antifreeze. Transportation impacts derive chiefly from run-off from roadways and parking lots, where petroleum hydrocarbons, lead and sediment are common constituents of such run-off. Leaking underground fuel storage tanks may be attributed to both transportation and industrial functions (Hogan, 2014; Litman, 2009).

Vehicle washing is the cleaning of public vehicles (school buses, vans, municipal buses, fire trucks, and utility vehicles), and industrial vehicles (moving vans, trucks, and tractors). The vehicle wash water can carry sediment and contaminants to surface waters, which can contaminate groundwater by infiltration or by drainage to subsurface wells and/or septic systems. The contaminants in vehicle wash water can cause a variety of health effects, including kidney damage, circulatory system problems, increased cancer risk, and delays in physical or mental development. Once a water supply becomes contaminated, it is very difficult and costly to treat (US EPA, 2001).

Urban related hazards

WWTW

The chemical water quality functioning of river systems is important in relation to ecological status. Effluent from sewage treatment works can contribute significant inputs of nutrients. Sewage effluent is enriched in certain pollutants relative to background aquifer sources. In particular, there are large enrichments in salt (Na and Cl), nutrients (soluble reactive phosphorus, total dissolved phosphorus, PP, NH_4 and NO_3) and also some enrichment in Mg and SO_4 (Neal et al., 2005).

The discharge of sewage effluent that has not gone through proper treatment processes causes adverse effects on the aquatic ecosystem. Improper treatment of sewage entering the aquatic ecosystems deteriorates the water quality of the receiving water body. The major problems associated with the discharge of substandard effluent include oxygen depletion due to oxidation of organic matter, increase in nutrients (such as nitrogen and phosphorus) and faecal contamination (Seanego & Moyo, 2013).

Municipal sewage waters also contain pharmaceutical products, heavy metals, ammonia, personal care products, endocrine disruptors and microorganisms – all which are usually released to the aquatic environment, implying deleterious consequences for organisms' health and fitness (Bianchi et al., 2014). Water treatment works commonly use aluminium sulphate as a coagulant. These residues are greatly increasing the concentrations of aluminium in the water system, which create a great risk of aluminium toxicity for fish (Muisa et al., 2011).

Sewage sludge is increasingly applied to agricultural land. Contaminants in waste water raises the issue of the extent to which various chemicals are present in sewage sludge, which consequently might be transferred to land and later transferred (through run-off) to receiving water bodies. Substances found in sewage sludge include trace metals, pharmaceuticals, polycyclic aromatic hydrocarbons (PAHs), emerging and regulated organic pollutants (Jones et al., 2014).

Urban settlements and population distribution

Growing urbanisation places pressures on many environmental assets such as waterways and ecosystems. It is evident that urban development contributes to the degradation of water quality (Marinoni et al., 2013). Urban settlements are global phenomena that characterise the general intensification of land use, causing many environmental related changes. Surface water ecosystems have been identified as being particularly vulnerable to these changes. Hazardous sources include macro- and micronutrients originating from urban area activities and scattered settlements, petroleum hydrocarbons and chlorinated solvents discharging from contaminated sites (e.g. industrial sites, old landfills and former gasoline stations) to streams, and waste water treatment. Each of these sources discharges compounds with differing physicochemical properties (Rasmussen et al., 2013).

Informal settlements are characterised by on-site sanitation facilities that are not linked to formal sewage systems. Waste water leaching from on-site sanitation systems to alluvial aquifers underlying informal settlements may end up contributing to high nutrient loads to surface water upon groundwater exfiltration. Aquifers in informal settlements areas could become contaminated high concentrations of Cl, Na, Ca, HCO_3, DOC and nutrients (NH_4, PO_4 and NO_3) (Nyenje et al., 2014).

Population growth and urban development also put tremendous pressure on existing water infrastructure. Urbanisation puts increasing pressure on existing drainage systems resulting in higher peaks and frequencies of storm water discharge contaminated with pollutants from different surfaces (Mikovits et al., 2014).

3.1.4 Potential pollutants to each anthropogenic activity

The potential pollutants linked to anthropogenic activity in the Palmiet sub-catchment are depicted in Table 6.

Table 6: Potential pollutants

Sector	Hazardous Sources Related to Anthropogenic Activities	Potential Pollutants/Contaminants
Agriculture	Deciduous fruit industry	Total dissolved solids (TDS), organophosphates, organochlorines, carbamates, pyrethroids, carbendazim, flusilazole, alpha-cypermethrin, beta-cyfluthrin, chlorpyrifos, cypermethrin, endosulfan, methyl-parathion, prothiofos, trifloxystrobin, carbaryl, dimethomorph, thiacloprid, azinphos-methyl, propiconazole, ether, chloroform, acids, alkalis, culture media for microbial growth, dilute hydrochloric acid, sodium hydroxide, sodium metabisulfite, sodium benzoate and citric acid, sulphur dioxide, nitric acid, sodium hypochlorite
	Free range chicken slaughtering and packaging	Phosphorous, chlorine (Cl), calcium (Ca), magnesium (Mg), sodium (Na), manganese (Mn), iron (Fe), copper (Cu), zinc (Zn) arsenic (As), *Salmonella* sp., *Staphylococcus* sp., *Clostridium* spp., *Campylobacter* spp., BOD, COD
	Red meat: slaughtering and trading	Chloride, ammonium, nitrate and coliforms
Manufacturing	Renovating and repairing steel bins, wooden and plastic pallets	Methyl bromide, polybrominated diphenyl ethers and deca-bromine
Industrial	Scrapyards	Bacteria, TSS, carbonaceous BOD, ethylene glycol, phosphorus, mercury, petroleum hydrocarbons, arsenic, aluminium, iron, lead
	Automotive spray-painting and panel beating	Hexamethylene diisocyanate, chromium VI compounds
Transport	Goods and public transport; and earth moving	Pb, Zn, or Cu, hydrocarbon loadings
Urban related	Waste water treatment	Na, Cl, NH_4, NO_3, Mg, SO_4, phosphorus, aluminium, pharmaceuticals, PAHs
	Settlement and population distribution	Cl, Na, Ca, HCO_3, DOC, NH_4, PO_4, NO_3

3.2 Hazard Characterisation of Pollutants from Anthropogenic Activities Surrounding the Palmiet River and Tributaries

Hazard characterisation is a process that includes a thorough evaluation of all available data to identify and characterise potential hazards. Hazard characterisation reviews the toxicity data available about a pollutant in order to identify and characterise the hazards related to a particular compound or exposure situation. This involves determining the adverse effects or precursors of adverse effects from all available data and the most relevant endpoints (US EPA, 2012).

Hazard characterisation typically consists of a qualitative or quantitative description of the inherent properties of a pollutant with the potential to cause adverse effects (WHO, 2010). Typical environmental scenarios are characterised by continuous exposure to many pollutants. Of special concern is that a non-negligible number of pollutants is constituted by bio-active compounds (i.e., pesticides), which are continuously released into the environment and whose long-term effects on the receiving ecosystems are relatively unknown (Ginebreda et al., 2014). We now set out to identify and/or confirm known or suspected pollutants and their sources and prioritise them in order of being hazardous (potential to deteriorate water quality).

3.2.1 Pollutants and their sources

Potential pollution sources in Grabouw that pose threats to drinking water are similar to those stated by Ademe and Alemayehu (2014), namely, open field defecation, animal waste, plant residues, economic activities (agricultural, industrial and other businesses) and even wastes from residential areas and transportation systems. Natural and artificial/manmade factors as well as human waste, which is often disposed in nearby surface water bodies, are responsible for the pollution of water.

3.2.2 Prioritisation of pollutants in order of hazard (potential to deteriorate water quality)

Pesticides

The pollutants described in the Table 7 were selected as priority based on the research findings (of pesticides used in the deciduous fruit industry) of Burger and Nel (2008) and Ncube et al. (2012):

- Simazine.
- Endosulfan.
- Diphenylamine.
- 2,4-D (dichlorophenoxy acetic acid).
- Chlorpyrifos-ethyl.
- Deltamethrin.
- Lindane Gamma-BHC.
- Linuron.
- Parathion.
- Dieldrin.
- Heptachlor.

These chemicals were then located on the Pesticides Action Network (PAN) Pesticides Database for chemicals to ascertain their aquatic ecotoxicities. PAN bad actors are chemicals that are one or more of the following:

- Highly acutely toxic.
- Cholinesterase inhibitor.
- Known/probable carcinogen.
- Known groundwater pollutant.
- Known reproductive or developmental toxicant.

Table 7: Pollutants in the agricultural sector and their aquatic ecotoxicities

Pollutant	PAN Dirty Dozen	PAN Bad Actor	WHO Acute Toxicity	Aquatic Ecotoxicity				
				Amphibians	Aquatic Plants	Fish	Insects	Nematodes and Flat Worms
Diphenylamine	No	No	Moderate			Accumulation, Biochemistry, Enzyme(s), Mortality		
2,4-D	No	No	Moderate	Behaviour, Biochemistry, Development, Intoxication, Mortality, Population	Accumulation, Behaviour, Biochemistry, Cell(s), Development, Genetics, Growth, Injury, Morphology, Mortality, Physiology, Population	Accumulation, Avoidance, Behaviour, Biochemistry, Cell(s), Development, Enzyme(s), Feeding Behaviour, Genetics, Growth, Histology, Intoxication, Morphology, Mortality, No Effect Coded, Physiology	Development, Genetics, Mortality, Population	
Chlorpyrifos-Ethyl	No	Yes	Moderate	Accumulation, Avoidance, Behaviour, Biochemistry, Development, Enzyme(s), Genetics, Growth, Morphology, Mortality	Accumulation, Biochemistry, Ecosystem Process, Physiology, Population	Accumulation, Avoidance, Behaviour, Biochemistry, Cell(s), Development, Enzyme(s), Feeding Behaviour, Genetics, Growth, Histology, Injury, Intoxication, Morphology, Mortality, Physiology, Population, Reproduction	Accumulation, Behaviour, Biochemistry, Development, Enzyme(s), Genetics, Growth, Intoxication, Mortality, No Effect Coded, Physiology, Population, Reproduction	Behaviour, Immunological, Mortality, Population, Reproduction
Deltamethrin	No	No	Moderate	Accumulation, Mortality, Physiology	Accumulation	Accumulation, Behaviour, Biochemistry, Cell(s), Development, Enzyme(s), Feeding Behaviour, Genetics, Growth, Histology, Injury, Intoxication, Morphology, Mortality, Physiology, Population	Accumulation, Development, Feeding Behaviour, Growth, Intoxication, Mortality, Population	Enzyme(s), Population

Pollutant	PAN Dirty Dozen	PAN Bad Actor	WHO Acute Toxicity	Aquatic Ecotoxicity				
				Amphibians	Aquatic Plants	Fish	Insects	Nematodes and Flat Worms
Lindane Gamma-BHC	Yes	Yes	Moderate	Accumulation, Behaviour, Cell(s), Development, Growth, Histology, Morphology, Mortality, Physiology	Accumulation, Biochemistry, Enzyme(s), Growth, Physiology, Population	Accumulation, Avoidance, Behaviour, Biochemistry, Cell(s), Development, Enzyme(s), Feeding Behaviour, Genetics, Growth, Histology, Hormone(s), Immunological, Intoxication, Morphology, Mortality, Physiology, Reproduction	Accumulation, Behaviour, Development, Enzyme(s), Genetics, Growth, Histology, Intoxication, Mortality, Physiology, Population, Reproduction	Development, Intoxication, Mortality, Population, Reproduction
Linuron	No	Yes	Unlikely	Hormone(s), Reproduction	Accumulation, Biochemistry, Development, Growth, Mortality, Physiology, Population	Behaviour, Biochemistry, Cell(s), Genetics, Histology, Morphology, Mortality, Physiology, Population	Intoxication, Mortality	Mortality, Population
Parathion	Yes	Yes	Extreme	Accumulation, Enzyme(s), Mortality	Accumulation, Enzyme(s), Histology	Accumulation, Behaviour, Biochemistry, Cell(s), Development, Enzyme(s), Feeding Behaviour, Growth, Histology, Intoxication, Morphology, Mortality, No Effect Coded, Physiology, Population, Reproduction	Accumulation, Behaviour, Development, Enzyme(s), Growth, Intoxication, Mortality, Population, Reproduction	Intoxication, Mortality, Population
Dieldrin	Yes	Yes	Not Listed	Accumulation, Development, Enzyme(s), Growth, Morphology, Mortality, Physiology	Accumulation, Mortality	Accumulation, Behaviour, Biochemistry, Development, Enzyme(s), Feeding Behaviour, Growth, Histology, Hormone(s), Intoxication, Morphology, Mortality, No Effect Coded, Physiology, Population, Reproduction	Accumulation, Biochemistry, Development, Growth, Intoxication, Mortality	Mortality
Heptachlor	Yes	Yes	Moderate	Behaviour, Development, Mortality	Accumulation	Accumulation, Behaviour, Biochemistry, Cell(s), Enzyme(s), Growth, Histology, Mortality, No Effect Coded, Physiology, Reproduction	Intoxication, Mortality	

3.2.3 Other chemicals of significance

Other chemicals of significance related to the agricultural and other activities in Grabouw include phosphorous, ammonia, calcium, chloride and nitrate. The Ireland Environmental Protection Agency Parameters of Water Quality: Interpretation and Standards: 2001 was consulted to explain the significance of these chemicals (see Table 8).

Table 8: Chemicals of significance

Chemical	Significance
Phosphorous	The significance of phosphorus is principally regarding the phenomenon of eutrophication (overenrichment) of lakes and, to a lesser extent, rivers. Phosphorus gaining access to such water bodies, along with nitrogen as nitrate, promotes the growth of algae and other plants leading to blooms, littoral slimes, and diurnal dissolved oxygen variations.
Ammonia	From the viewpoint of human health, the significance of ammonia is marked because it indicates the possibility of sewage pollution and the consequent possible presence of pathogenic microorganisms.
Calcium	Despite the potential health benefits of calcium abundance, there are problems associated with hardness.
Chloride	Possible contamination: Sewage contains large amounts of chloride, as do some industrial effluents.
Nitrates	Origin: Oxidation of ammonia: agricultural fertiliser run-off. High nitrate levels in waters to be used for drinking will render them hazardous to infants as they induce the blue baby syndrome (methemoglobinemia).
Arsenic	Highly toxic to humans, some arsenical compounds are carcinogens.

3.2.4 Manufacturing, industrial, transport and urban related activities

The pollutants and its ecological effect related to manufacturing, industrial, transport and urban related activities are depicted in Table 9.

Table 9: Ecological effect of pollutants from the manufacturing, industrial, transport and urban related activities

Pollutant	Ecological Effect
PBDE	Does not dissolve easily in water but sticks to particles and settles to the bottom of river or lakes and accumulate in fish (ATSDR, 2004).
Chromium VI compound	Hexavalent chromium [Cr(VI)] present in water has been found to be associated with adverse biological effects at all levels of biological organisation (Mishra & Mohanty, 2009).
Mercury	From an environmental toxicology perspective, methylmercury (MeHg) is the most important of the different chemical forms of Hg. Methylmercury biomagnifies through food chains, is absorbed efficiently from the diet and highly toxic to wildlife (Scheuhammer et al., 2015).
Petroleum (aliphatic hydrocarbons)	The ERA of petroleum hydrocarbons is of interest to researchers, environmental regulators and legislators. The long-term persistence of petroleum hydrocarbons in the environment highlights the need for further environmental impact studies across a similar or longer period of time (Zhu et al., 2015).

Pollutant	Ecological Effect
Lead	Lead entering aquatic ecosystems adsorbs to sediments and has the potential to cause adverse effects on the health of benthic organisms. Even at small levels, lead burdens impairment of biochemical and cellular pathways.
PAH	Some members of this group are carcinogenic, mutagenic, and teratogenic and can produce cascades of adverse effects on aquatic organisms (Karami et al., 2012).

3.3 Causal Pathway Assessment

3.3.1 Environmental pathways

The environmental routes and pathways are key because the risk will not be reduced if the pathways are unclear (Xu & Shu, 2012). Figure 6 illustrates how the pollutants leave the source (anthropogenic activities) and enter the river systems in Grabouw. The pollutants are transported in one of the following manners:

- Via the storm water system into the WWTW and then into the river system; or
- Via the storm water system into a wetland and then into the river system; or
- Via the storm water system into the river system; or
- Directly into the river system.

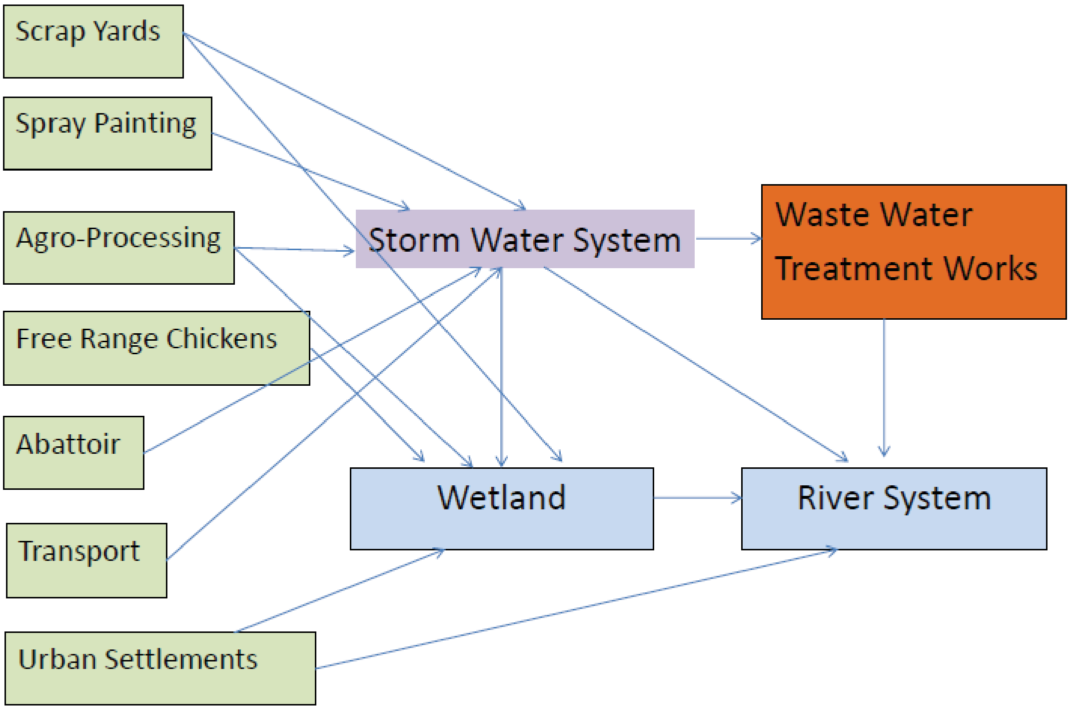

Figure 6: Environmental pathways

A clearer picture emerges in the following conceptual models.

3.3.2 Conceptual site models

Scrapyards

Scrapyards in Grabouw dismantle cars for the purpose of selling second-hand parts. However, the accumulation of wrecked cars (Figure 7) and solid waste (Figure 8) has the potential of causing water contamination due to pollutants such as solvents, heavy metals, oil and grease in storm water run-off.

Figure 7: Wrecked vehicles

Figure 8: Solid waste dumping

Due to the downward slope, the run-off finds its way into the storm water system or enters the river system directly as illustrated in Figure 9.

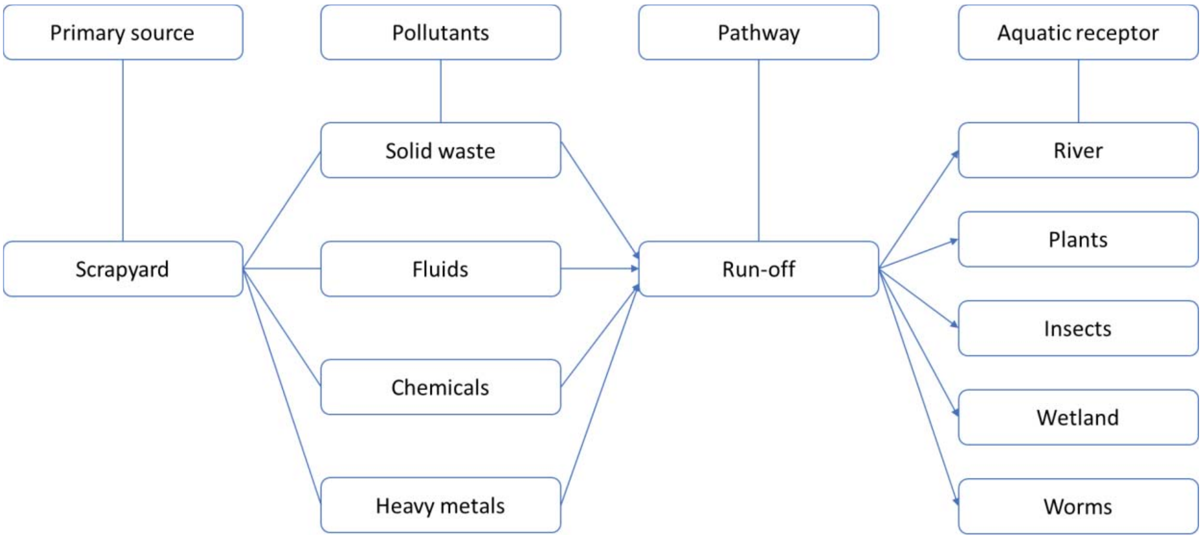

Figure 9: Scrapyard conceptual model

Spray-painting

Vehicles are spray-painted indoors (Figure 10) but the resulting waste water lands on a cement floor and drains to the storm water system.

Figure 10: Vehicle preparation

The waste water eventually finds its way via the municipal storm water system to the WWTW. Vapours (volatile organic compounds) escape through the ventilation system and doorways.

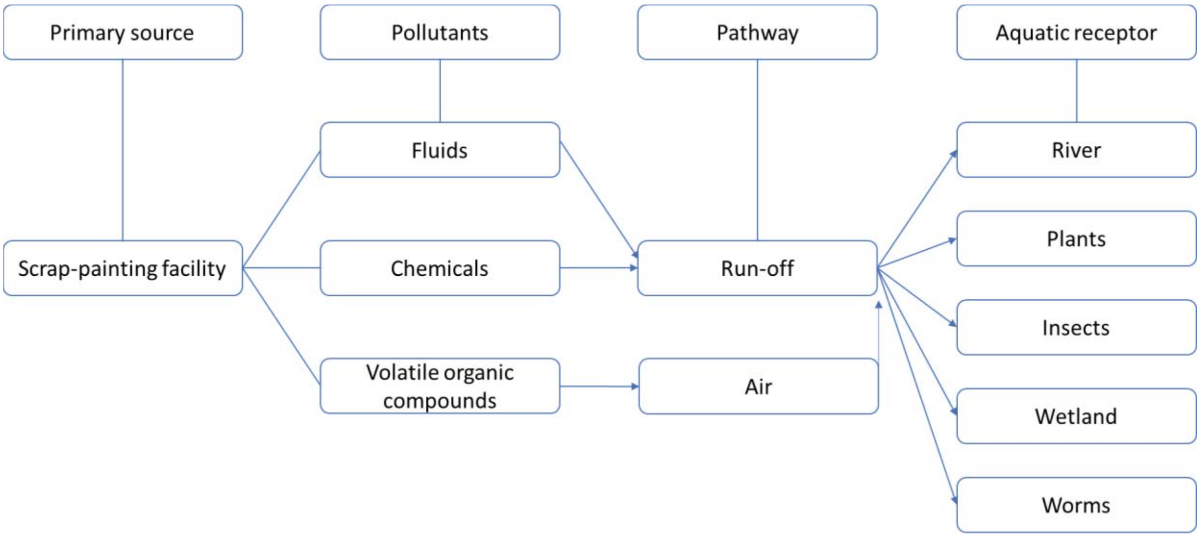

Figure 11: Spray-painting conceptual model

Agro-processing

The agro-processing industry in Grabouw centres mainly on preparing and packaging deciduous fruit for export and the local market, as well as processing for fruit juices.

Fruits regarded as waste are left in crates before being transported to a waste digester system for sanitising (Figure 12). Once digestion is completed, the sanitised waste is then stored openly on the premises (Figure 13).

Figure 12: Fruit waste in crates

Figure 13: Sanitised waste in the open

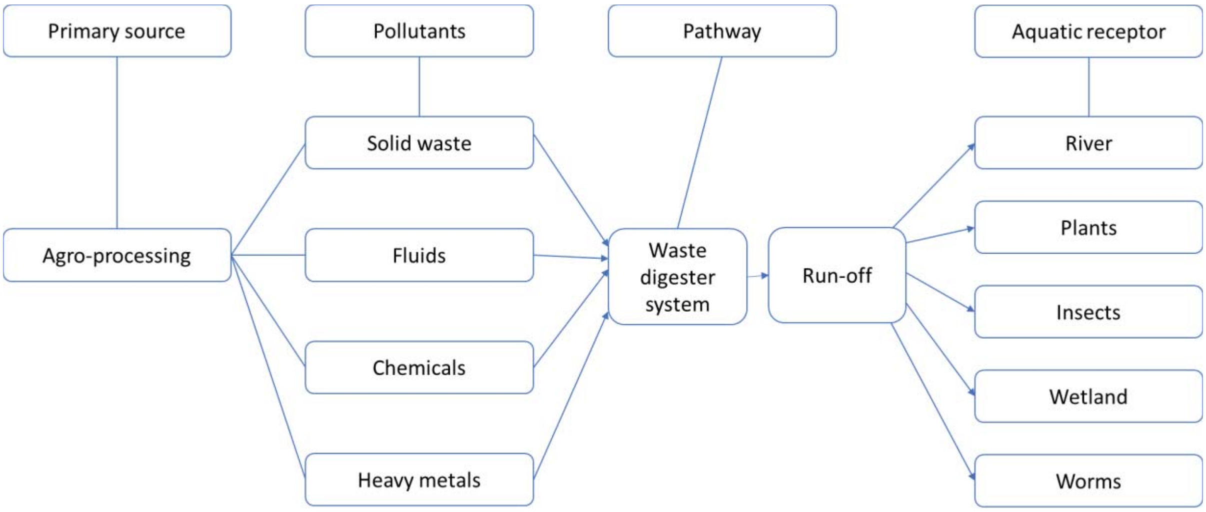

Figure 14: Agro-processing conceptual model

Free range chickens

Free range chickens are prepared and slaughtered according to acceptable and approved abattoir practices for poultry. The effluent from this practice flows into a septic tank (Figure 15) where it is then pump directly to the WWTW. However, during the crate-cleaning processes, some of the liquid waste (due to spillage) does land on the ground and enters the adjacent wetland (Figure 16).

Figure 15: Septic tank

Figure 16: Spillage

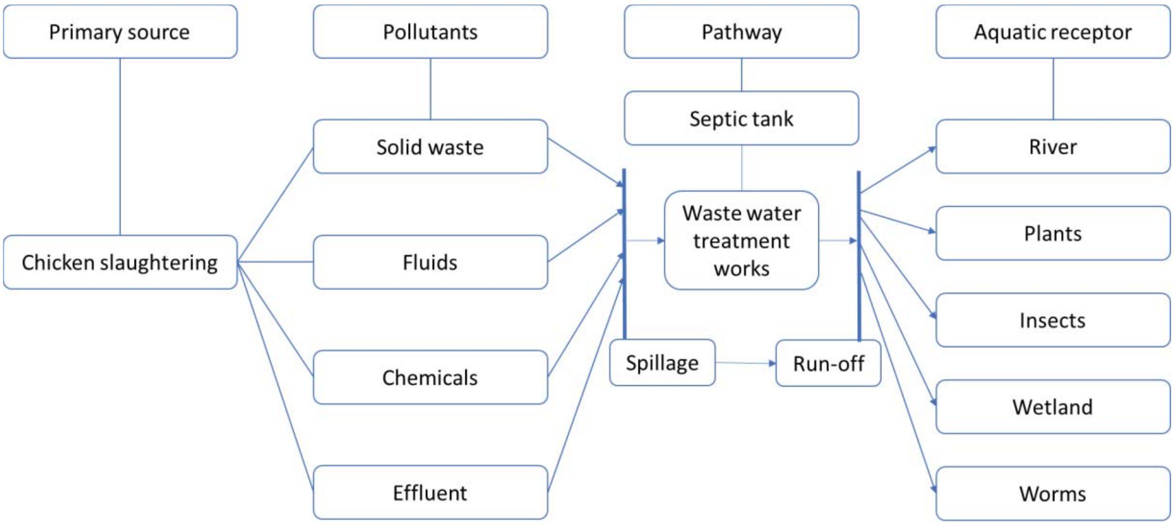

Figure 17: Free range chicken conceptual model

Transport

Transportation impacts derive chiefly from run-off due to the washing of vehicles. Oil and sediment are common constituents of such run-off. The vehicles are washed, and the run-off waste water enters the storm water system, which leads directly (via an unchannelled system) to the river.

Figure 18: Storm water system (presence of oil)

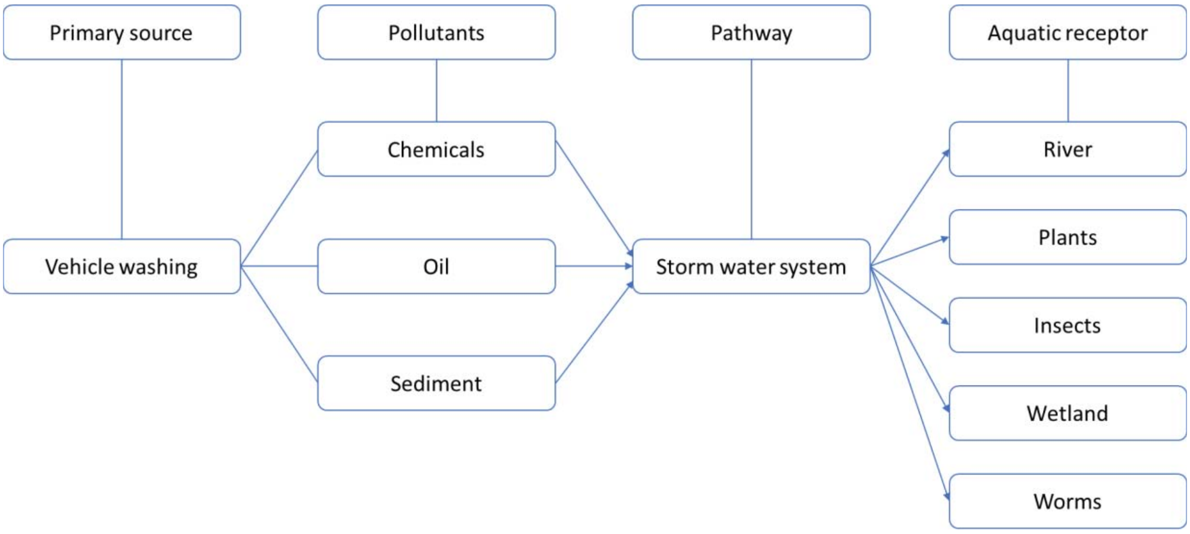

Figure 19: Vehicle washing conceptual model

Red meat abattoir

Cattle, sheep and pigs are prepared and slaughtered according acceptable and approved methods. The effluent resulting from these methods are pumped into the municipal system and then directly to the WWTW. The solid waste (contents of animal intestines, manure and condemned carcasses) are transported to the waste digester system for sanitising.

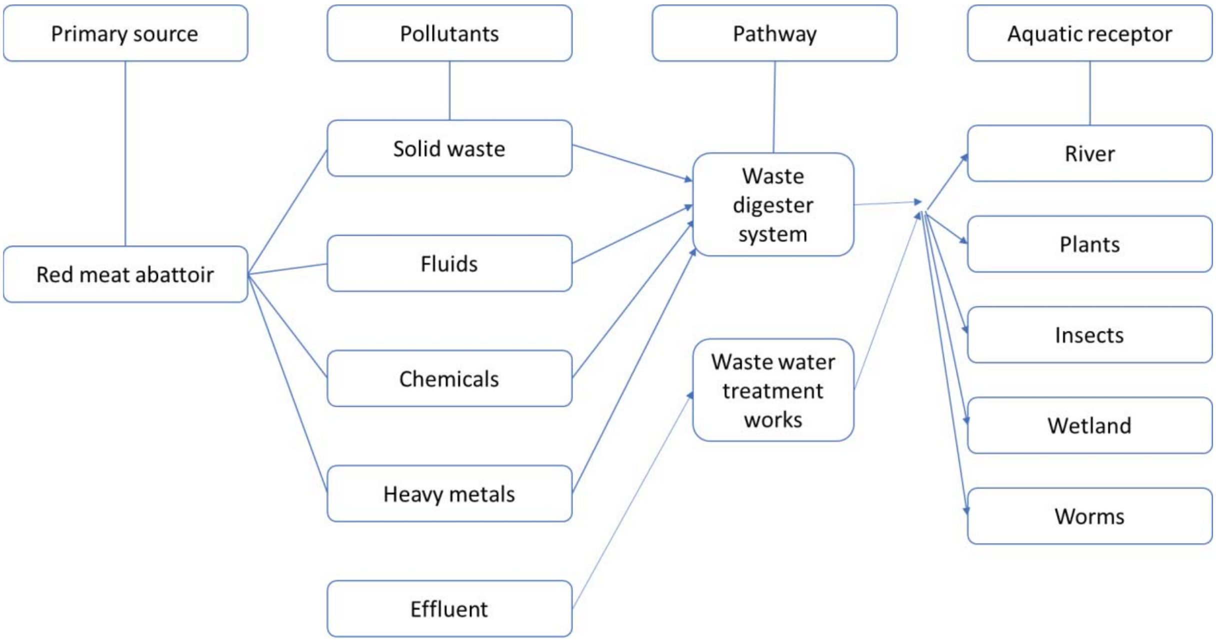

Figure 20: Red meat abattoir conceptual model

Urban settlements and WWTW

The town of Grabouw absorbs most of the population growth, which this puts tremendous pressure on infrastructure (waste water treatment system), services (waste management) and the environment (water resource). Waste management practices are not at acceptable levels.

This results in indiscriminate dumping of solid municipal waste (Figure 21 and Figure 22).

Figure 21: Indiscriminate dumping of solid waste in river

Figure 22: Dumping in river

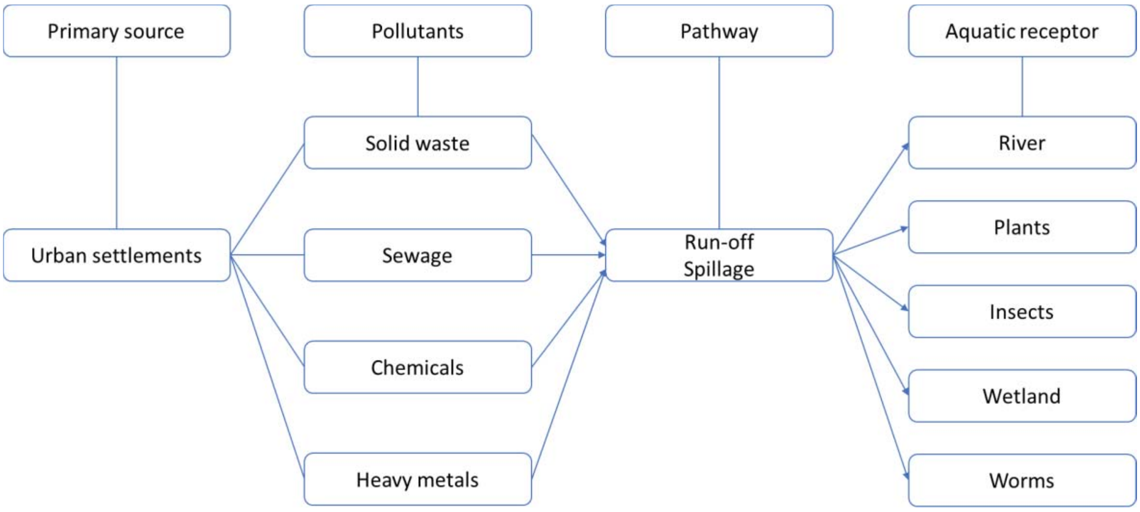

Figure 23: Urban settlements conceptual model

The sewage and waste water treatment systems have reached capacity and raw sewage is allowed to spill directly into the river system (Figure 24 and Figure 25).

Figure 24: Raw sewage overflowing into the river

Figure 25: Raw sewage in river

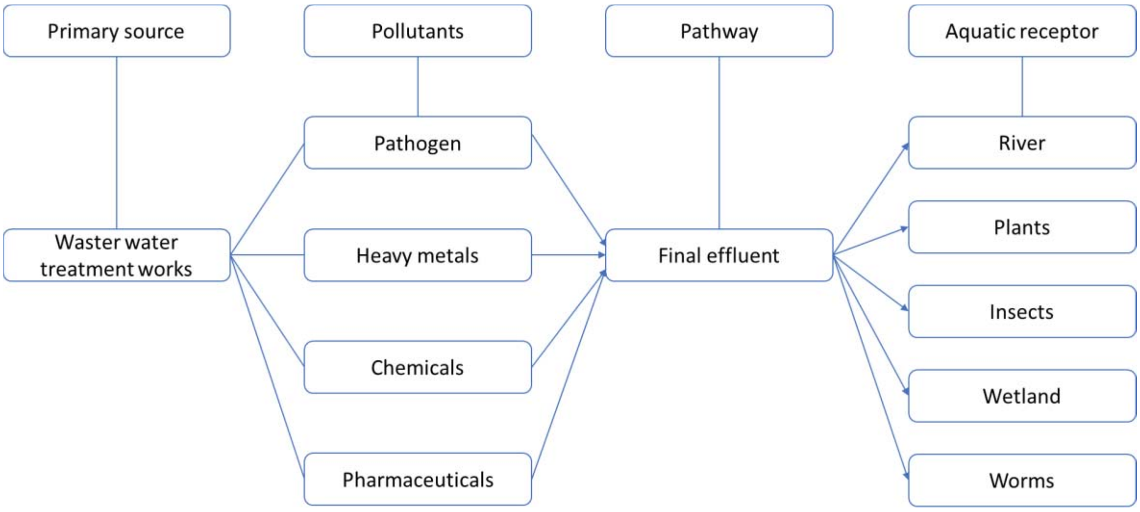

Figure 26: WWTW conceptual model

A pollutant's final distribution and concentration in a specific medium depends on numerous and highly complex interacting processes that are not easily to estimate. Fate and transport models have been developed to estimate the pollutant transport among and within environmental medium. Exposure on the other hand also necessitates modelling as a means of calculating exposure. Once pollutants are released to the environmental medium, it is distributed and partitioned to various environmental compartments and thereby may cause more than one type of environmental impact.

The ability to cause impact depends on the pollutants' physical, chemical and biological properties of the compound and medium to which it is released (Sonnemann et al., 2003). In the water column, substances may be degraded abiotically via photodegradation and/or hydrolysis or biotically by aerobic or anaerobic organisms. Highly sorptive substance may partition to the bed sediment (Boxall, 2012). The risk assessment needs to consider whether the exposure pathway is via contaminants that become adsorbed and resident in soil, or whether the exposure is through impact on receiving waters, which itself is dependent upon local hydrogeology (Clothier et al., 2010).

Causal pathways could also be illustrated by means of a Bayesian network. Although the Bayesian network structure is a probabilistic graphical representation that describes the joint probability distribution over a set of random variables, one could apply it to illustrate the nodes and relationship between the anthropogenic activities. This brings the structure of the Bayesian network closer to human intuition in that an arc between nodes implies there is a direct relation between those variables. It is assumed that in a Bayesian network, an arc from x to y means that x is a direct cause of y, then at least one of a number of causal assumptions is being made (Daly et al*.,* 2011).

The Bayesian network structure for combined effects of urbanisation, industrialisation and population growth is depicted in Figure 27.

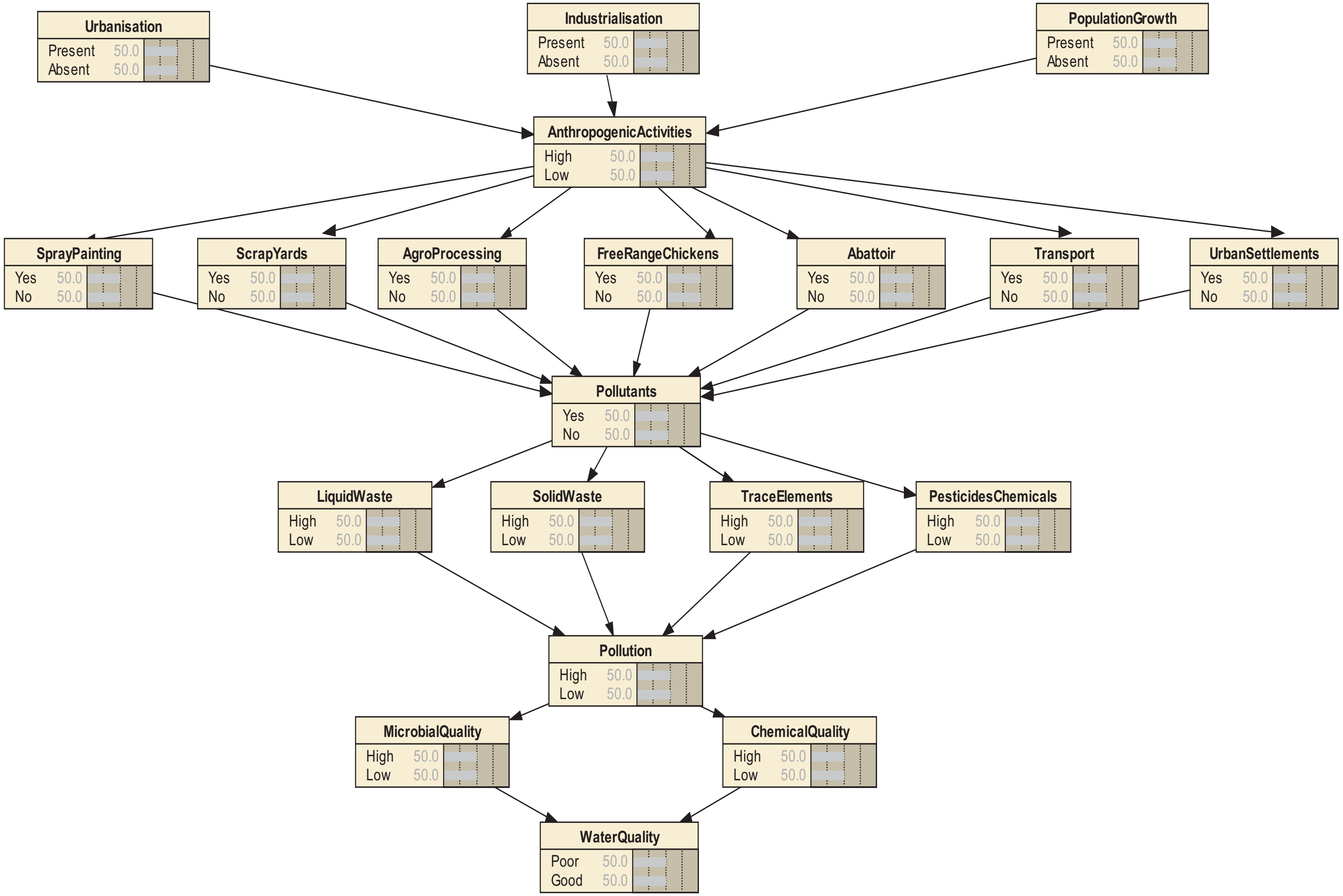

Figure 27: Palmiet sub-catchment Bayesian network graph

3.4 Condition Assessment/Risk Characterisation

Understanding water quality at larger scales, as well as groundwater and surface water interactions impacted by land and climate are essential to our future investments for protection and restoration. In the past years, we have seen a great acceleration of population growth, land use change, use of fertilisers, and water pollution. This has led to a global situation of continued water quality degradation as demonstrated by widespread recalcitrant chemical contamination, increased eutrophication, hazardous algal blooms and faecal contamination associated with microbial hazards and antibiotic resistance (Young et al., 2015).

The management goal for this specific ERA is to protect the Palmiet River and its tributaries from the combined effect of urbanisation, industrialisation and population growth. To this end, a condition assessment was performed that involved taking measurements of existing conditions in the water bodies and extrapolating field/laboratory data. The analysis provided more details about the relationships between stressors and effects, first summarised in the conceptual models.

The methodology used was site-specific risk assessment. The use of site-specific forms of assessment is recognised as international best practice. Site-specific environmental risk assessments estimate the kind, likelihood, and magnitude of the environmental effects associated with a particular stress, for example, an anthropogenic activity on one or several interconnected ecosystems within a defined geographical area (Tarazona, 2014). In most recognised risk assessment procedures, the approach is based on the evaluation of chemical physical and toxicological parameters, applied to more or less standardised scenarios where the territory, at different scale levels (local, regional, continental), is described without considering the spatial variability of data. The management of surface water must be based on a site-specific assessment of water quality that is dependent on land use. Therefore, for water body management purposes, such as planning local or national policies, the ecotoxicological risk for the aquatic ecosystem must be strictly related to the local condition and characteristics (Sala & Vighi, 2008).

In accordance with approved sampling plans, water and sediment samples were collected and submitted to external accredited laboratories of the University of Stellenbosch, Council for Scientific and Industrial Research (Pretoria) and the Agricultural Science Consultants Research respectively. The water and sediment sampling dataset for this risk assessment comprised the results of 68 water samples taken at the various points as illustrated in the map (Figure 28).

Using a differential GPS, coordinates were taken at each sampling location. Results were accurate to within approximately 1 cm in x, y and z coordinates following processing and correction. Water samples were collected to determine their pH, temperature, electrical conductivity, and chemical properties, i.e., their nitrate, phosphate, BOD, and dissolved oxygen contents. Physical parameters were measured using a portable calibrated multiparameter meter and a calibrated turbidity meter for each of the samples taken. The remainder of the parameters was analysed in the laboratory. The samples were transported in 1 ℓ plastic bottles for laboratory analysis (TSS), 250 ml bottles (physical and chemical parameters) and 1 ℓ glass bottles for organic analysis.

The cross-sectional area, depth, and velocity were used to estimate the discharge at various locations along the river. The stream velocity and discharge were established by measuring flow velocity using a current meter, and the cross-sectional area. Discharge, $\mathcal{Q}$, is given by $\mathcal{Q} = \mathcal{A} \times \mathcal{V}$ where $\mathcal{A}$ is the cross-sectional area, and $\mathcal{V}$ is the average velocity at the cross-section.

For the purpose of measuring the quantity of suspended sediment, a depth-integrating sampling technique and grab sampling were used to obtain a sample that accounts for different sediment concentrations throughout the vertical profile of a water body. The deposited sediments were collected with minimum disturbance not to lose the fine material on the sediment surface, also because the vertical distribution of the sediment components is important in the event that there is a need to establish historical records or depositional rates (Natus, 2017).

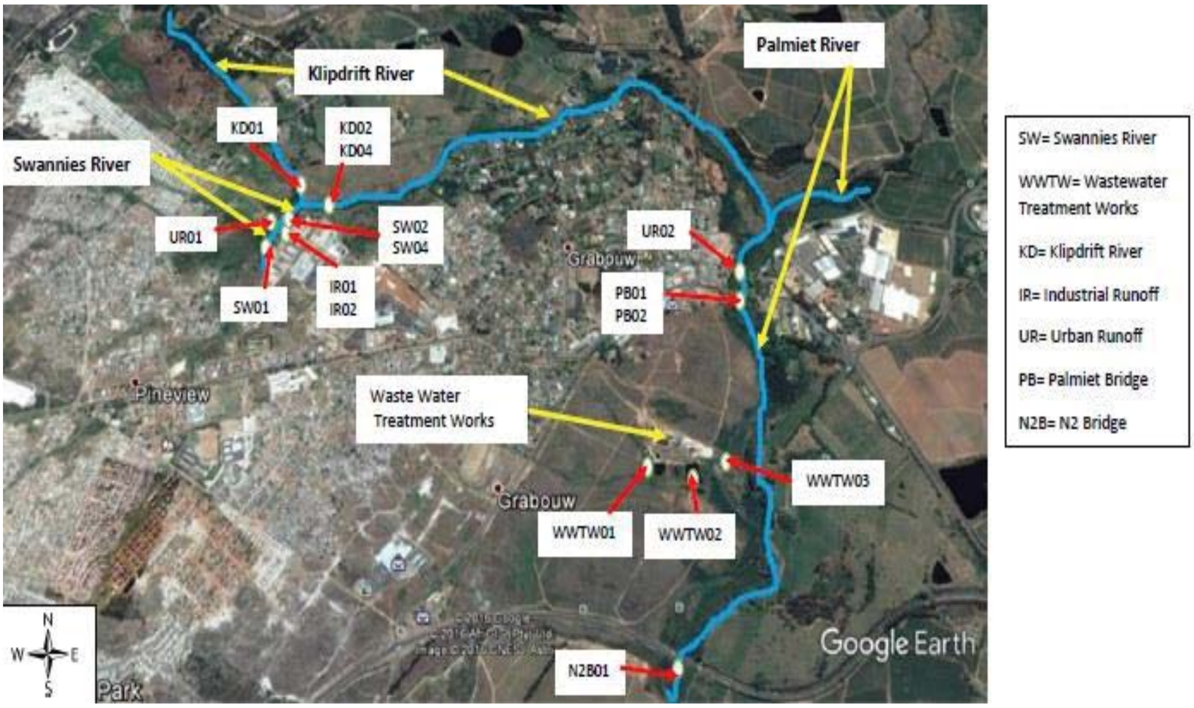

Figure 28: Sampling points

3.4.1 Physicochemical assessment

Temperature, pH, TDS, electrical conductivity (EC), turbidity, nitrate, phosphates, COD, TSS and microbiological (faecal and total coliforms) analyses of the river water were carried out on samples acquired from 11 sites extending from a point near the source of the river up to a point downstream of the Palmiet River. The sites were carefully chosen to ensure that major point and diffuse sources of pollution were captured. Sampling was carried out monthly over the period of a year (2015) and a few samples taken in the year 2016 in order to capture differences in seasons (Natus, 2017). The results are depicted in the Figure 29 to Figure 33.

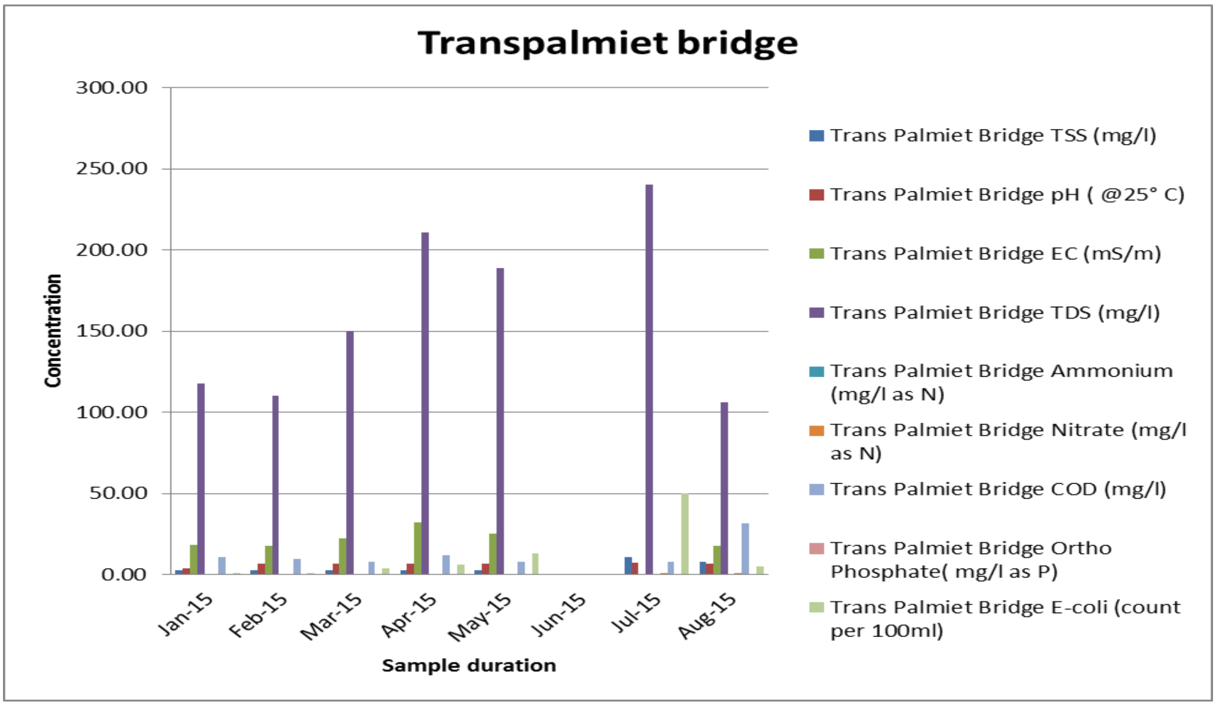

Figure 29: Samples at the Transpalmiet Bridge with influences from nearby farms

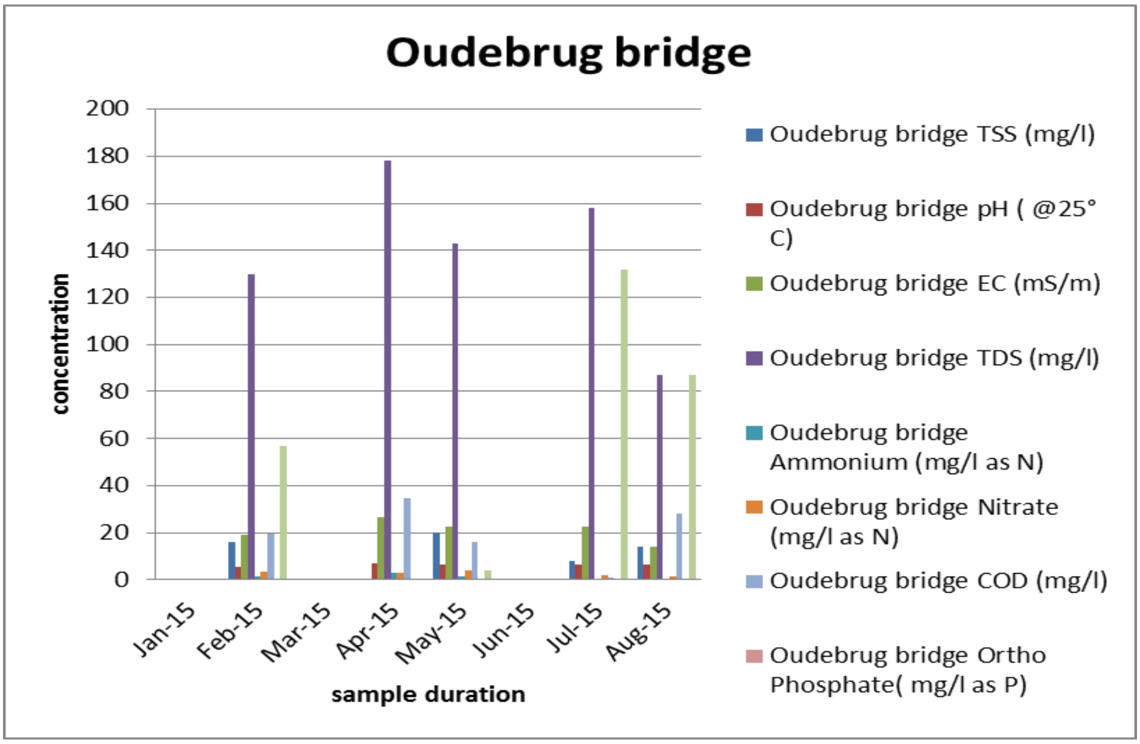

Figure 30: Oudebrug Bridge; samples taken in the town of Grabouw

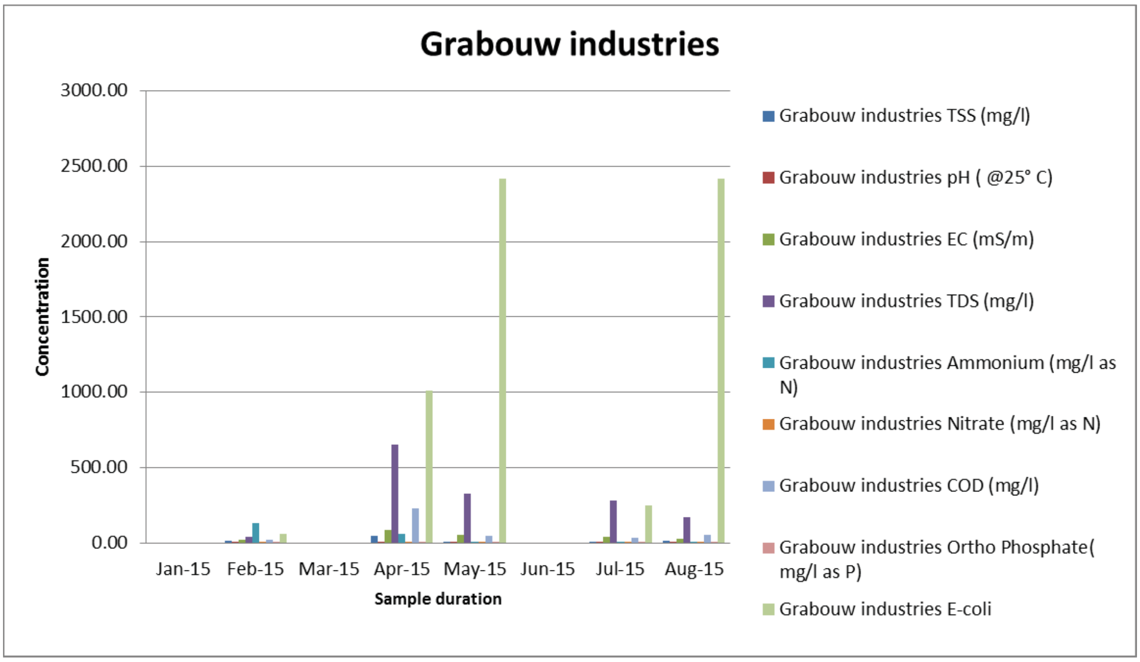

Figure 31: Grabouw industries samples taken with the influence of WWTW

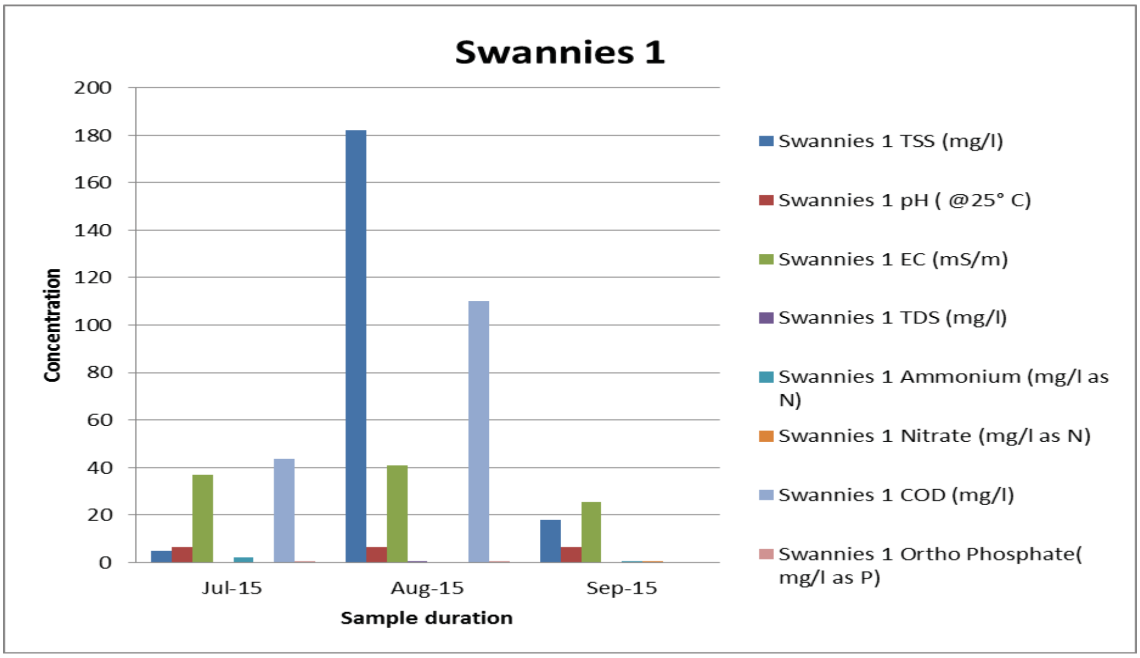

Figure 32: Intersects of the Swannies River 1 influenced by informal settlements and industries

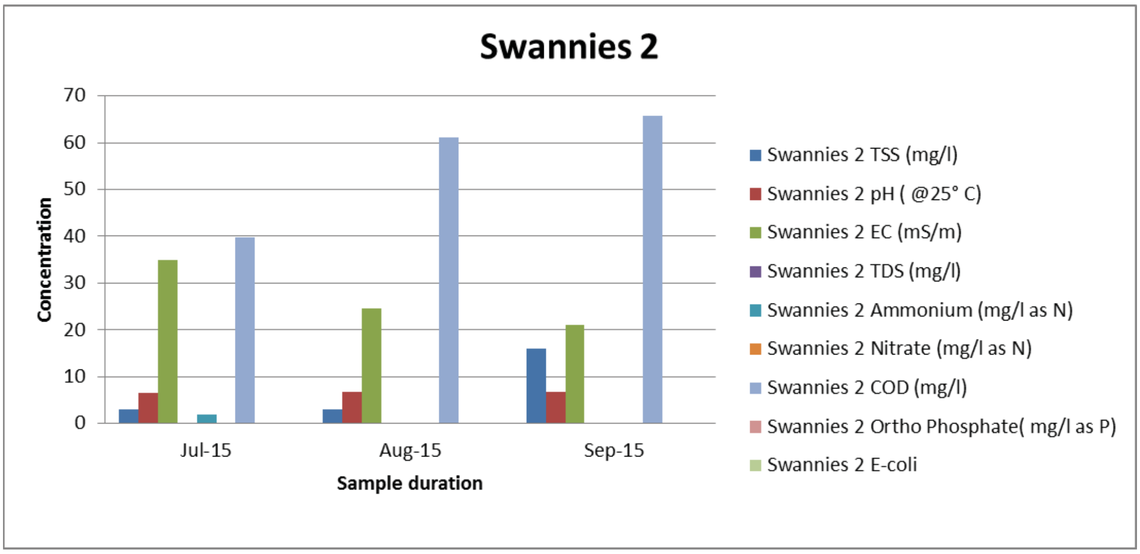

Figure 33: Intersects of the Swannies River 2 influenced by informal settlements and industries

Water quality was determined by the activities in the catchment, the land use and the geology of the area. Water quality analyses indicated that the river water was turbid with high nutrient levels. In general, water quality declined more towards its lower reaches. Concentrations of most contaminants were higher during the summer months, indicating that run-off during this period increased pollution levels in the river.

Dissolved oxygen

The measurements taken ranged from 70%, 82% to 90% and was recorded during winter. The dissolved oxygen concentrations at the inflow were higher during winter season than autumn spring and summer.

pH

The pH units recorded in this study were acceptable for aquatic ecosystems and ranged between 6.82 and 7.4. The pH units in this study might have been affected by elevated levels of TDS and sulphate.

Turbidity

The high turbidity value of 12.52 NTU found at Swannies River indicates that there is some chance of transmitting diseases by microorganisms associated with particulate matter, particularly for agents with low infectious doses such as viruses and protozoan parasites. This coincides with the other parameters (EC, TDS and TSS) exceeding the water quality guidelines for South Africa.

The effects of high turbidity values include severe aesthetic effects such as appearance, taste and odour; and significant effects on the microbiological quality of the water (DWAF, 1996). These high turbidity values could lead to poor visibility and reduced feeding rates for fish living in the system. These also prevent sunlight from reaching plants below the surface, which can reduce the rate of photosynthesis, so less oxygen is produced by plants. Sediment often tops the list of substances or pollutants causing turbidity. However, any watershed has multiple sources of the pollutants or physical features that can affect water clarity. These can be divided into natural or background, and human-induced sources (industrial, mine discharges, sewage discharge) and can contribute significantly to the high or low turbidity levels at a specific site.

COD

COD analysis is the standard method for indirect measurement of the amount of pollution (which cannot be oxidised biologically) in a sample of water. The recorded measurements for this analysis are high for the Swannies intersects during the months of July to September. The COD test procedure is based on the chemical decomposition of organic and inorganic contaminants, dissolved or suspended in water. The result of a COD test indicates the amount of water-dissolved oxygen (expressed as parts per million or milligrams per litre of water) consumed by the contaminants during two hours of decomposition from a solution of boiling potassium dichromate.

TDS

The TDS concentrations ranged from 178 mg/ℓ to 240 mg/ℓ to 652 mg/ℓ. The highest values were recorded at Grabouw industries and the lowest values were recorded at Oudebrug Bridge. Seasonally, the highest TDS concentrations were recorded during autumn.

3.4.2 Quantitative microbial risk assessment

Microbial parameters for protozoan parasites (*Cryptosporidium* and *Giardia*) and enteric viruses were analysed using Method PMP1 based on the US EPA Method 1623.1, which consists of sample concentration, cyst/oocyst separation using immunomagnetic separation, and microscopic detection using fluorescent antibody and DAPI staining (Natus, 2017).

Most of the samples (except for KD02, which could be attributed to a single event or occurrence) tested negative for protozoa and viruses associated with biological waste related to faecal contamination. It was therefore not necessary to model these microorganisms (Table 10).

Table 10: Protozoa and viruses

Sample	**Results**		
	Cryptosporidium oocyst Count/10 ℓ	**Giardia cyst Count/10 ℓ**	**Enteric virus Count/10 ℓ**
AT01	0	0	0
KD02	1	2	0
MK01	0	0	0/4 ℓ
N2B01	0	0	No sample
PB01	0	0	0
RD01	0	0	0
SW01	0	0	0/6 ℓ
SW02	0	0	0
Ur01	0	0	0
WWTW01	0	0	0
MOF01	0	0	0

However, the monitoring for *Cryptosporidium* should be ongoing as literature suggests that with *Cryptosporidium*, whether an individual is exposed to 1 or 10 000 organisms, if they become infected and ill, the health end points are assumed to be similar in severity (US EPA, 2006). One could conclude that for that specific time, *Giardia* and the enteric virus pose no risk to the Palmiet River and its tributaries. However, the presence of *Escherichia coli* was detected in all samples as indicated in Table 11 and Figure 34. This creates the assumption that exposure is limited to a pathogen specific context.

Table 11: *E. coli* concentrations

Escherichia coli (cfu/100 ml): Period June–October 2015					
	June	**July**	**August**	**September**	**October**
Swannies Upper	2 300	360	380	1 200	3 001
Storm water outlet behind Theewaterskloof Municipality	1 200	7000	500	30 001	670
Worcester street bridge	800	150	180	900	1 200
Water drainage pump	7				
Downstream of Agri organics	90	4 500	150	9	80
Swannies 1	1 100	240	310	320	270
Swannies 2	2 200	2000	11 200	0	3 001
Elgin Dew storm water	0		0		
Sump at Elgin fruit juices	6 700	0	3 300		3 001
Opposite CHEP	10 000	2 700	3 200	2 500	3 001
Rooi Dakke	17	2 500	1 880	1 800	900
End of Loop Street	36	2 400	760	1 700	3 001
Bos and Van Eck Street	2 400	450	10 000	2 600	3 001
Upper Klipdrift		7	4	6	5

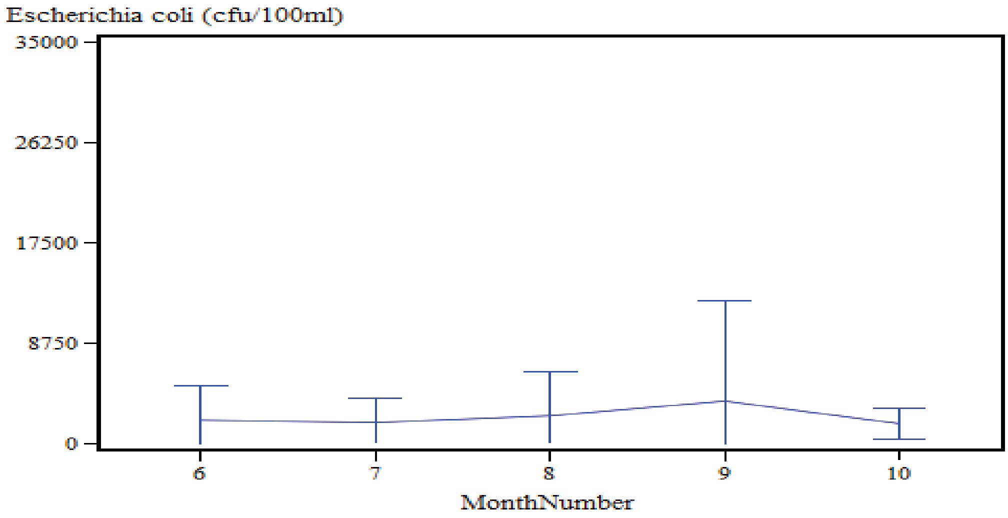

Figure 34: ***E. coli*** **concentrations**

Table 12: Spread of ***E. coli*** **concentrations**

Table: Spread of *E. coli* concentrations Month 2015	**Mean of *E. coli* (cfu/ 100 ml)**	**Std. Dev. of *E. coli* (cfu/ 100 ml)**	**Std. Error of *E. coli* (cfu/ 100 ml)**	**Variance of *E. coli* (cfu/ 100 ml)**	**No. of missing values for *E. coli* (cfu/ 100 ml)**	**Minimum *E. coli* (cfu/ 100 ml)**	**Maximum *E. coli* (cfu/ 100 ml)**
	2 347	4 379	560.7	19 175 410.30	9	0	30 001
June	2 065	3 009	834.5	9 052 013.09	1	0	10 000
July	1 859	2 164	624.6	4 681 399.54	2	0	7000
August	2 451	3 798	1053	14 427 191.74	1	0	11 200
September	3 731	8 766	2 643	76 846 585.47	3	0	30 001
November	1 761	1 335	385.4	1 782 209.17	2	5	3 001

Given the descriptive data in Table 12, we determined the risks by making inference by means of a one-way analysis of variance (ANOVA) to test for the differences between the concentrations of *E. coli* and the month of the year (Table 13). The F value of 0.36 and p value of 0.83 support the hypothesis that the *E. coli* concentrations are spread equally over the given months. One could conclude that *E. coli* will be present throughout the year. The F statistic is simply a ratio of two variances. Variances are a measure of dispersion, or how far the data are scattered from the mean. Larger values represent greater dispersion.

Table 13: One-way ANOVA process

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	4	29 208 609	7 302 152	0.36	0.8327
Error	56	1 121 316 009	20 023 500		
Corrected Total	**60**	**1 150 524 618**			

Table 14:

R Square	**Coefficient Variance**	**Root Mean Square Error**	***E. coli* (cfu/100 ml) Mean**
0.025387	190.6309	4 474.763	2 347.344

Table 15:

Source	**DF**	**ANOVA SS**	**Mean Square**	**F Value**	**Pr > F**
Month	4	29 208 609.21	7 302 152.30	0.36	0.8327

The data in Table 16 indicates p values greater than 0.05 ($p < 0.05$ = statistical significant correlation), meaning that there is no statistical significant difference.

A correlation analysis was conducted to test for statistical significant difference between the relationship of the variables concentrations, site and month (Table 16 and Table 17).

Table 16: Correlation for sampling sites

Spearman Correlation Coefficients Prob > |r| under H0: Rho = 0 Number of Observations							
	Elgin Dew storm water	**Sump at Elgin fruit juices**	**Opposite CHEP**	**Rooi Dakke**	**End of Loop Street**	**Bos and Van Eck Street**	**Upper Klipdrift**
Swannies Upper	. . 2	0.40000 0.6000 4	0.30000 0.6238 5	-0.90000 0.0374 5	0.10 000 0.8729 5	0.30000 0.6238 5	-0.40000 0.6000 4
Storm water outlet behind Theewaterskloof municipal storm water outlet behind Theewaterskloof Municipality	. . 2	-0.40000 0.6000 4	-0.70000 0.1881 5	0.10 000 0.8729 5	0.10 000 0.8729 5	-0.70000 0.1881 5	0.80000 0.2000 4
Worcester street bridge	. . 2	0.40000 0.6000 4	-0.10 000 0.8729 5	-0.70000 0.1881 5	0.30000 0.6238 5	0.40000 0.5046 5	-0.40000 0.6000 4
Water drainage pump	. . 1	. . 1	. . 1	. . 1	. . 1	. . 1	. . 0
Downstream of Agri organics	. . 2	-0.40000 0.6000 4	0.30000 0.6238 5	0.60000 0.2848 5	-0.10 000 0.8729 5	-0.30000 0.6238 5	0.20000 0.8000 4
Swannies 1	. . 2	1.00000 <.0001 4	0.40000 0.5046 5	-0.70000 0.1881 5	-0.80000 0.1041 5	0.10 000 0.8729 5	-0.40000 0.6000 4
Swannies 2	. . 2	0.40000 0.6000 4	0.70000 0.1881 5	-0.10 000 0.8729 5	-0.10 000 0.8729 5	0.70000 0.1881 5	-0.80000 0.2000 4

Spearman Correlation Coefficients
Prob > |r| under H0: Rho = 0
Number of Observations

	Elgin Dew storm water	Sump at Elgin fruit juices	Opposite CHEP	Rooi Dakke	End of Loop Street	Bos and Van Eck Street	Upper Klipdrift
Elgin Dew storm water	. . 2	. . 2	. . 2	. . 2	. . 2	. . 2	. . 1
Sump at Elgin fruit juices	. . 2	1.00000 4	1.00000 <.0001 4	-0.80000 0.2000 4	-0.80000 0.2000 4	0.40000 0.6000 4	-1.00000 <.0001 3
Opposite CHEP	. . 2	1.00000 <.0001 4	1.00000 5	-0.50000 0.3910 5	-0.60000 0.2848 5	0.20000 0.7471 5	-0.80000 0.2000 4
Rooi Dakke	. . 2	-0.80000 0.2000 4	-0.50000 0.3910 5	1.00000 5	0.30000 0.6238 5	-0.10 000 0.8729 5	0.40000 0.6000 4
End of Loop Street	. . 2	-0.80000 0.2000 4	-0.60000 0.2848 5	0.30000 0.6238 5	1.00000 5	0.00000 1.0000 5	0.40000 0.6000 4
Bos and Van Eck Street	. . 2	0.40000 0.6000 4	0.20000 0.7471 5	-0.10 000 0.8729 5	0.00000 1.0000 5	1.00000 5	-1.00000 <.0001 4
Upper Klipdrift	. . 1	-1.00000 <.0001 3	-0.80000 0.2000 4	0.40000 0.6000 4	0.40000 0.6000 4	-1.00000 <.0001 4	1.00000 4

Table 17: Correlation by month

Spearman Correlation Coefficients
Prob > |r| under H0: Rho=0
Number of Observations

	June	July	August	September	October
June	1.00000 13	-0.24545 0.4669 11	0.62238 0.0307 12	0.26061 0.4671 10	0.57995 0.0615 11
July	-0.24545 0.4669 11	1.00000 12	0.11888 0.7129 12	0.48182 0.1334 11	-0.06345 0.8447 12
August	0.62238 0.0307 12	0.11888 0.7129 12	1.00000 13	0.40000 0.2229 11	0.78379 0.0026 12
September	0.26061 0.4671 10	0.48182 0.1334 11	0.40000 0.2229 11	1.00000 11	0.33371 0.3159 11
October	0.57995 0.0615 11	-0.06345 0.8447 12	0.78379 0.0026 12	0.33371 0.3159 11	1.00000 12

Logistic regression was used as an appropriate predictive analysis to describe the data (Table 18–Table 20) and to explain the relationship between one dependent binary variable (a set standard) and one or more nominal, ordinal, interval or ratio-level independent variables. The binary variable was determined as 126 based on the WHO (2003) recommendation that concentrations of *E. coli* not exceed 126 cfu/100 ml in freshwaters.

Table 18: Model information

Model Information	
Data Set	WORK.SORTTEMPTABLESORTED
Response Variable	Above126
Number of Response Levels	2
Model	Binary logit
Optimisation Technique	Fisher's scoring

Table 19: Analysis effect

Type 3 Analysis of Effects			
Effect	DF	Wald Chi Square	Pr > ChiSq
Site	13	3.0721	0.9977
Months	4	2.7281	0.6043

Table 20: Analysis of maximum likelihood estimates

Analysis of Maximum Likelihood Estimates						
Parameter		**DF**	**Estimate**	**Standard Error**	**Wald Chi Square**	**Pr > Chi Square**
Intercept		1	3.2336	28.0572	0.0133	0.9082
Site	Bos and Van Eck Street	1	9.3057	81.2771	0.0131	0.9088
Site	Downstream of Agri organics	1	-2.7510	28.6949	0.0092	0.9236
Site	Elgin Dew storm water	1	-20.8244	156.7	0.0177	0.8943
Site	End of Loop Street	1	-0.00529	28.6941	0.0000	0.9999
Site	Opposite CHEP	1	9.3057	81.2771	0.0131	0.9088
Site	Rooi Dakke	1	-0.00529	28.6941	0.0000	0.9999
Site	Storm water outlet behind Theewaterskloof Municipality	1	9.3057	81.2771	0.0131	0.9088
Site	Sump at Elgin fruit juices	1	-0.8132	28.7023	0.0008	0.9774
Site	Swannies 1	1	9.3057	81.2771	0.0131	0.9088
Site	Swannies 2	1	-0.00529	28.6941	0.0000	0.9999
Site	Swannies Upper	1	9.3057	81.2771	0.0131	0.9088
Site	Upper Klipdrift	1	-20.0835	113.5	0.0313	0.8596
Site	Water drainage pump	1	-11.3460	253.6	0.0020	0.9643
Month Number	6	1	-3.1005	9.0747	0.1167	0.7326
Month Number	7	1	-0.8215	9.0882	0.0082	0.9280
Month Number	8	1	7.4249	36.0889	0.0423	0.8370
Month Number	9	1	-2.6815	9.0889	0.0870	0.7680

The above data illustrates p values (Pr > ChiSq) in excess of 0.05, which is an indication of no statistical significant difference. This means that the likelihood of *E. coli* concentrations exceeding the limit of 126 cannot be predicted. It has been suggested that the data set obtained is too small to infer the likelihood of exceeding the limit or that the outcome data could be attributed to a one-off event such as a spillage. It is a well-known fact that during the rainy months (June to September) the sewer systems in Grabouw reaches its capacity to handle inflow and blockages, which results in overflow.

3.4.3 Quantitative trace elements risk assessment

Trace metals were analysed on an Agilent 7900 ICP-MS, using the standard configuration of quartz spray chamber and torch, and Ni-plated sampling and skimmer cones. A 0.4 ml/min micromist nebulizer was used to aspirate the sample. The instrument was optimised for sensitivity and oxide formation before calibration. Instrument parameters were set as follows:

Table 21: Agilent 7900 ICP-MS parameters

	Value
RF power (W)	1600
Plasma mode	HMI
Sample depth (mm)	10
Carrier gas (L/min)	0.68
Dilution gas (L/min)	0.27
Make-up gas (L/min)	0
Robustness (% CeO/Ce)	< 1

Cell gas parameters		**Elements**
He flow (ml/min)	4.8	All except Se
H_2 flow (ml/min)	6	Se

Acquisition parameters

Peak mode	1 point
Replicates	3
Integration time (sec)	0.3–1

US EPA Methods 6020 A and 200.8 guidelines were followed for instrument calibration and data verification protocols. The instrument was calibrated using NIST traceable standards purchased from Inorganic Ventures, and the accuracy of the calibration validated by a separate standard from Merck. A drift monitor standard was analysed after every 12 samples, with internal standard elements added online to correct for drift and matrix differences between samples and standards (Natus, 2017).

The trace elements with concentration measured in mg/ℓ are depicted in Table 22.

Table 22: Trace element concentrations mg/ℓ

Sampling Points	SW01	IR01	UR01	KD01	KD02	UR02 W	PB01	WWTW01	N2B01 W
Distance (m)	0	12	17	34	257	4 657	4 688	4 824	6 388
Ba	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.005	0.01
Ca	16.91	22.66	14.10	2.71	6.66	18.02	3.45	30.97	3.95
K	2.67	1.88	3.06	1.64	1.92	2.48	1.03	10.64	1.12
Mg	2.12	2.56	2.15	1.18	1.42	2.15	2.01	3.40	2.07
Na	13.67	12.45	14.29	7.54	9.22	12.88	8.14	36.26	8.91
P	0.20	0.24	0.50	0.04	0.08	0.10	0.02	2.75	0.06
S	3.60	2.06	3.10	0.65	1.38	3.28	1.33	11.08	1.62
Si	2.46	1.20	2.42	0.75	1.19	2.41	1.28	3.35	1.33
Sr	0.11	0.16	0.09	0.02	0.04	0.12	0.02	0.16	0.03
Li	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Be	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
B	16.70	16.18	14.22	9.25	10.31	14.78	12.66	20.86	11.17
Al	509.84	106.80	615.52	586.39	589.54	492.21	462.18	51.42	418.62
V	1.04	0.44	1.12	0.73	0.84	1.03	0.54	0.83	0.52
Cr	0.98	0.65	1.10	0.53	0.69	0.90	0.48	0.59	0.45
Mn	2.40	14.93	14.97	2.51	1.87	1.56	11.23	23.54	9.92
Fe	559.70	840.49	660.47	370.96	453.59	519.36	453.45	82.05	393.04
Co	0.07	0.20	0.13	0.05	0.05	0.07	0.07	0.27	0.07
Ni	0.77	1.08	0.86	0.25	0.37	0.69	0.34	1.12	0.42
Cu	1.96	6.57	1.98	0.27	0.77	1.83	0.60	1.64	0.55
Zn	16.04	56.76	17.32	3.31	5.01	13.69	4.20	9.69	5.08
As	2.76	0.90	3.11	0.44	1.13	2.46	0.48	3.93	0.51
Se	0.36	0.24	0.43	0.38	0.33	0.36	0.28	0.28	0.13
Mo	0.17	0.15	0.21	0.04	0.11	0.15	0.03	1.02	0.03
Cd	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Sb	0.26	0.31	0.20	0.03	0.09	0.25	0.03	0.41	0.04
Hg	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Pb	0.50	6.62	0.41	0.31	0.36	0.54	0.20	0.08	0.19

3.4.4 Quantitative chemical risk assessment

The content of the chemical parameters list was determined by GC-MSMS using the multiple reaction monitoring mode. Quantitation was by external standard calibration.

Method of test

- 5 g of sample was homogenised, weighed, and prepared following the QuEChERS method. Undiluted samples were used for the analysis.
- Calibration standards were prepared by diluting the stock solution with solvent to cover the expected range of sample concentrations. Once linearity was established, samples were injected.
- To quantify the chemicals, a linear regression of the response ratio for the sample peak was performed by the instrument control and data acquisition software.

- The calibration curve was accepted only if the correlation coefficient was equal or greater than 0.995 ($R2 \geq 0.995$).

The initial sampling point was taken midway down the Swannies River at the point SW01. This point is also regarded as the inflow point of the river system. Run-off from the urban settlements and industrial area enter the river system at this point. When the sewer system overflows, its contents are also deposited into the system at this point.

The initial analysis in Table 23 shows the concentration levels of nine chemical residues taken at SW01. The cumulative concentration level of all nine elements at the different sampling points is also presented.

Table 23: Sampling data of pesticide chemical residues obtained from the Swannies River to the waste water treatment close to the Palmiet River

Sampling Points	SW01	IR01	UR01	SW02	KD01	KD02	PB01	WWTW01
Distance (m)	0	12	17	22	34	257	4 428	4804
Acetamiprid	0.106	0.108	0.106	0.146	0.119	0.105	0.083	0.095
Captan	0.958	0.969	0.84	1.127	1.046	0.996	0.784	0.997
Chlorpyrifos	0	0	0	1.029	0	0	0	2.732
Deltamethrin	0	0	0.073	0	0.048	0.044	0	0.02
Difenoconazole	0.024	0.002	0	0	0.014	0.007	0.002	0.008
Indoxacarb	0	0	0	0	0	0	0	0
Thiacloprid	0.163	0	0.365	0	0	0	0	0.16
Trifloxystrobin	0.941	0.685	0.749	1.041	1.045	1.407	0.54	0.969
Cumulative	2.192	1.764	2.133	3.343	2.272	2.559	1.409	4.981

Five of the nine chemical residues were present at SW01 with captan and trifloxystrobin having the highest levels of 0.958 mg/kg and 0.941 mg/kg respectively. Thiacloprid and acetamiprid were also present at lower concentrations of 0.163 mg/kg and 0.106 mg/kg. Table 24 depicts the high and low levels of concentration.

Table 24: Concentration levels

Acetamiprid Level (mg/kg)	Concentration (mg/kg)
High: 0.8	0.8049
Low: 0.3	0.2799
Captan Level	**Concentration (mg/kg)**
High: 0.8	0.7915
Low: 0.3	0.2908
Chlorpyrifos Level	**Concentration (mg/kg)**
High: 0.8	0.9514
Low: 0.3	0.3662
Deltamethrin Level	**Concentration (mg/kg)**
High: 0.8	0.9806
Low: 0.3	0.3433

Acetamiprid Level (mg/kg)	Concentration (mg/kg)
Indoxacarb Level	**Concentration (mg/kg)**
High: 0.8	0.8258
Low: 0.3	0.2943
Thiacloprid Level	**Concentration (mg/kg)**
High: 0.8	0.7938
Low: 0.3	0.2971
Trifloxystrobin Level	**Concentration (mg/kg)**
High: 0.8	0.7751
Low: 0.3	0.3019
Difenoconazole Level	**Concentration (mg/kg)**
High: 0.8	0.8457
Low: 0.3	0.3189

3.5 Predictive Assessment

An effective method of controlling and predicting water pollution is using information systems consisting of two main components: mathematical models and software that are generated by numerical models (Găgescu et al., 2011). A mathematical model provides the ability to predict the contaminant concentration levels of a river. When assessing the quality of water in a river, there are many factors to be considered: the level of dissolved oxygen; the presence of nitrates, chlorides, phosphates; the level of suspended solids; environmental hormones; COD such as heavy metals; and the presence of bacteria (Pimpunchat et al., 2009).

The transport characteristics of a pollutant differ from type to type and medium to medium. Transport models predict spread in all directions, not just horizontally. Its main objective is to predict (if water flow is at a certain speed and depth) if pollutants are released at point $\mathcal{X}$. The model will then indicate the predicted percentage at point $\mathcal{Y}$ and how long it will take. Thus, the model output will have an equation: concentration in time over a certain distance.

3.5.1 Trace elements

The initial sampling point was taken midway down the Swannies River at point SW01. This point is also regarded as the inflow point of the river system. The input analysis shows the concentration levels of nine trace elements measured in mg/ℓ and 19 trace elements measured in µg/ℓ taken at SW01. The cumulative concentration level of all elements at the different sampling points are presented in Figure 35. At the reference testing station SW01, the trace elements Ca and Sr have the highest concentration levels of 16.91 mg/ℓ and 13.7 mg/ℓ in water. The other elements have insignificantly low levels. The concentrations trends over the first 35 m show a decrease in concentrations, except Ca that increases significantly to 22.66 mg/ℓ at IR01 before decreasing.

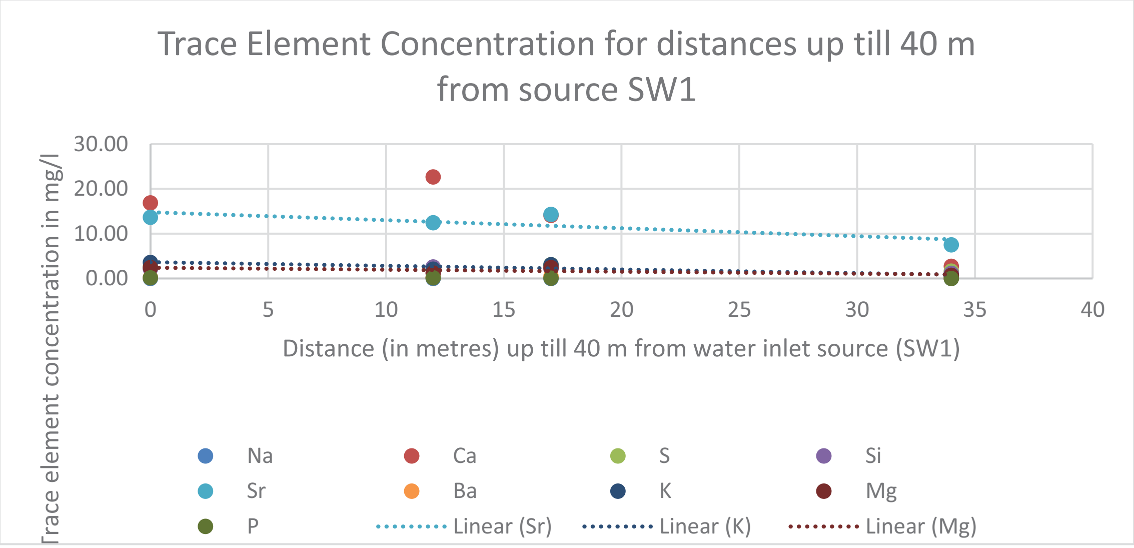

Figure 35: Trace element concentration up to 40 m from source SW1

The concentration of this group of trace elements is dominated by the concentrations of Fe and Al with concentrations of 559.7 µg/ℓ and 509.84 µg/ℓ. The trend of Fe concentration shows a nett decrease over the first 35 m, while that of Al shows a slight increase over the same distance. The concentrations of all other elements remain relatively constant at low concentration levels. See Figure 36.

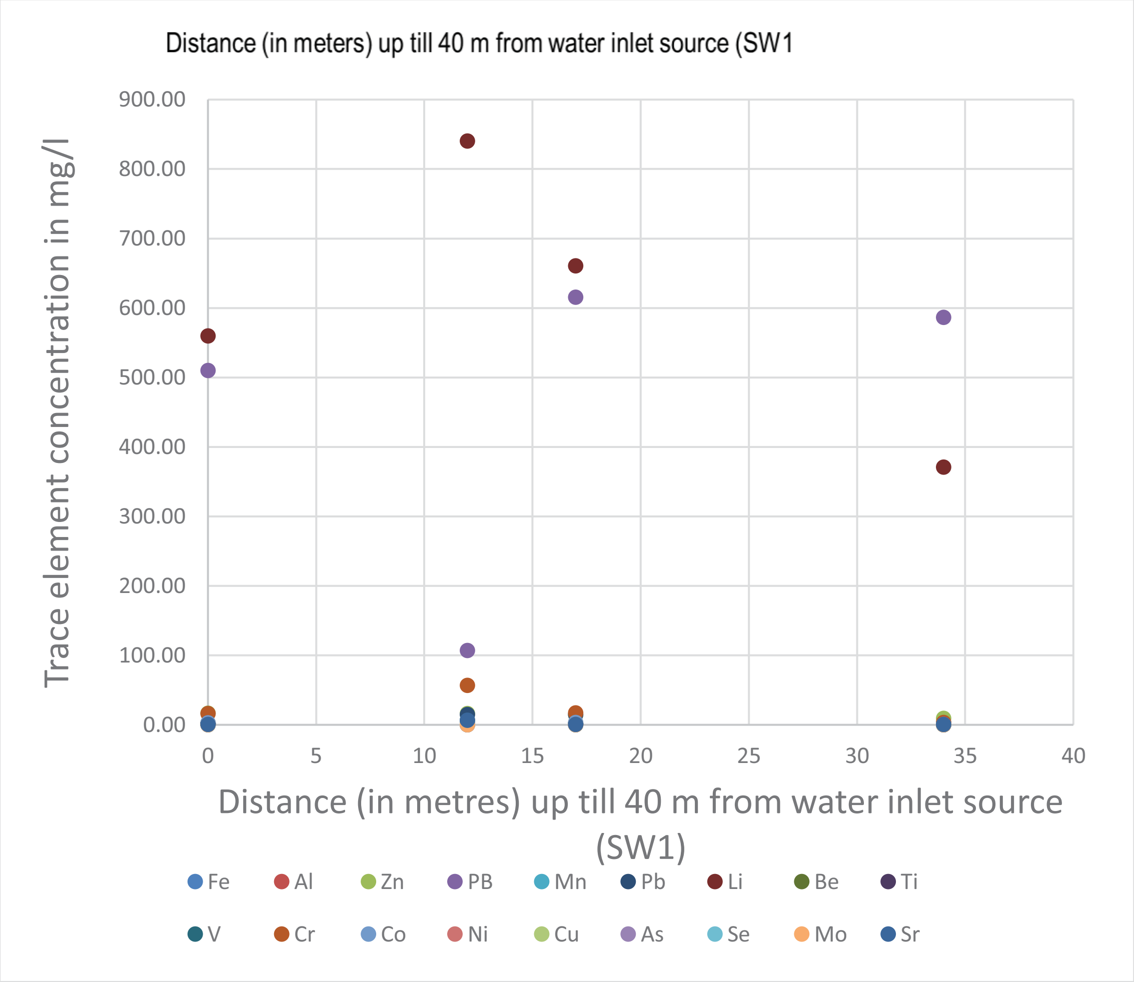

Figure 36: Trace element concentration between 40 m and 7000 m from source SW1

The concentration levels of all the trace elements stayed relatively constant from the levels at KB01 to N2B01 (35 m to 6500 m), except at testing station UR02, PB01 and WWTW where we noticed a significant increase in the concentrations of Sr and Ca, especially at PB01, with Ba and K showing slight increases. See Figure 37.

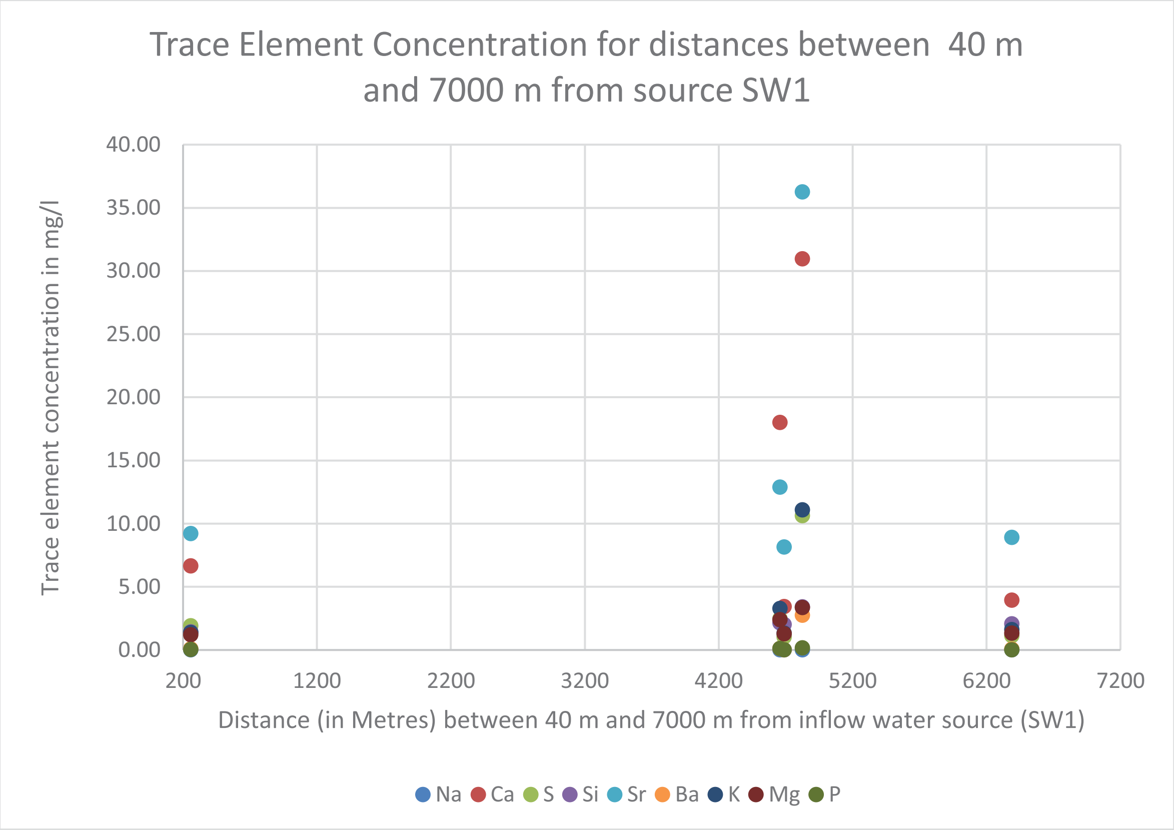

Figure 37: Trace element concentration between 40 m and 7000 m from source SW1

- The concentration of this group of trace elements is dominated by the concentrations of Fe and Al with concentrations of 559.7 µg/ℓ and 509.84 µg/ℓ.
- The trend of Fe concentration shows a nett decrease over the first 35 m, while that of Al shows a slight increase over the same distance.
- The concentrations of all other elements remain relatively constant at low concentration levels. See Figure 37.

3.5.2 Chemical residue

Sample analysis

The initial sampling point was taken midway down the Swannies River at point SW01. This point is also regarded as the inflow point of the river system. The initial analysis shows the concentration levels of nine chemical residues taken at SW01. Five of the nine chemical residues are present at SW01 with captan and trifloxystrobin having the highest levels of 0.958 mg/kg and 0.941 mg/kg respectively.

Thiacloprid and acetamiprid are also present at lower concentrations of 0.163 mg/kg and 0.106 mg/kg. The trend of both captan and trifloxystrobin indicates an increase in concentration levels, while that of thiacloprid and acetamiprid show a decrease in concentration levels as the river migrate downstream up till 35 m. However, at testing station UR01, capstan shows a significant decrease, while thiacloprid shows a significant increase in concentrations. However, at station SW02, capstan is the only chemical with a significant increase.

Modelling

The results of the sample analysis were verified against a revised mathematical transport model that was developed and updated since 1998 (Ghosh & McBean, 1998; Park & Lee, 2002; Salvai & Bezdan, 2008; Sardinha et al., 2008; Zhang et al., 2012).

The river channel is divided into control volumes of length Δx, describing causes in concentration of water quality variables, and the transport mechanism represented by the advection, diffusion and dispersion of pollution elements in the river system.

The simplified mass balance equation is presented below. We assumed one-dimensional flow and the concentration of variables remain constant across each flow section. The resulting partial differential equation is:

$$\frac{\partial C}{\partial t} = -\frac{1}{A}\frac{\partial (QC)}{\partial x} + \frac{1}{A}\frac{\partial}{\partial x}\left(D_L\, A\,\frac{\partial C}{\partial x}\right) \pm \frac{S}{V} + \frac{W}{V}$$

- Where, *C* is the concentration of a variable in mg/ℓ.
- *X* is the distance in the flow direction in m.
- *A* is the cross-sectional area of a measuring point in m^2.
- D_L is the longitudinal dispersion coefficient in ℓ/°C.
- *V* is the water volume in m^3.
- *S* and *W* are sink or source terms representing input pollution and water sources.

No data sampling was done on *S* and *W* and the last two terms of the equation thus fell away. The method of finite differences was used for spatial discretisation of the equations. Time-partial differentiations were discretised using the fourth order Runge–Kutta method.

The resulting discretised equation is given as:

$$\frac{\partial C}{\partial t} = -\frac{1}{A}\,\frac{Q_i^k - Q_{i-1}^k}{\Delta x} + \frac{1}{A}\,\frac{D_{L\,A}}{\Delta x}\,\frac{C_{1+1}^{K} - 2\,C_i^k + C_{i-1}^k}{\Delta x}$$

Where i denote position and k time variables. Numerical results that correspond to the sampling station distances are indicated with the sample data in Table 25.

Table 25: Sampling data of chemical residues obtained from the Swannies River to the waste water treatment close to the Palmiet River

Sampling Points	Distance (m)	Acetamiprid		Captan		Difenoconazole		Thiacloprid		Trifloxystrobin	
		Sample	Model	Sample	Model	Sample	Model	Sample	Model	Sample	Model
SW01	0	0.106	0.106	0.958	0.958	0.024	0.024	0.163	0.163	0.941	0.941
IR01	12	0.108	0.095	0.969	0.921	0.002	0.016	0	0.160	0.685	0.914
UR01	17	0.106	0.085	0.840	0.885	0	0.011	0.365	0.157	0.749	0.888
SW02	22	0.146	0.076	1.127	0.850	0	0.007	0	0.154	1.041	0.862
KD01	34	0.119	0.068	1.046	0.817	0.014	0.005	0	0.152	1.045	0.837
KD02	257	0.105	0.061	0.996	0.785	0.007	0.003	0	0.149	1.407	0.813
PB01	4 428	0.083	0.055	0.784	0.755	0.002	0.002	0	0.146	0.540	0.790
WWTW01	4 804	0.095	0.049	0.997	0.725	0.008	0.001	0.16	0.144	0.969	0.767

Figure 39 to Figure 47 are based on the output of both the chemical samples and the mathematical transport model data. The mathematical transport model is based on the principle of diffusion and assumes that the chemicals will continue to decrease as it moves downstream.

In Figure 38 we observe that the acetamiprid concentrations decrease up to a distance of 17 m and then shows a steady increase. This could be attributed to the fact that the urban run-off enters the Swannies River at this point.

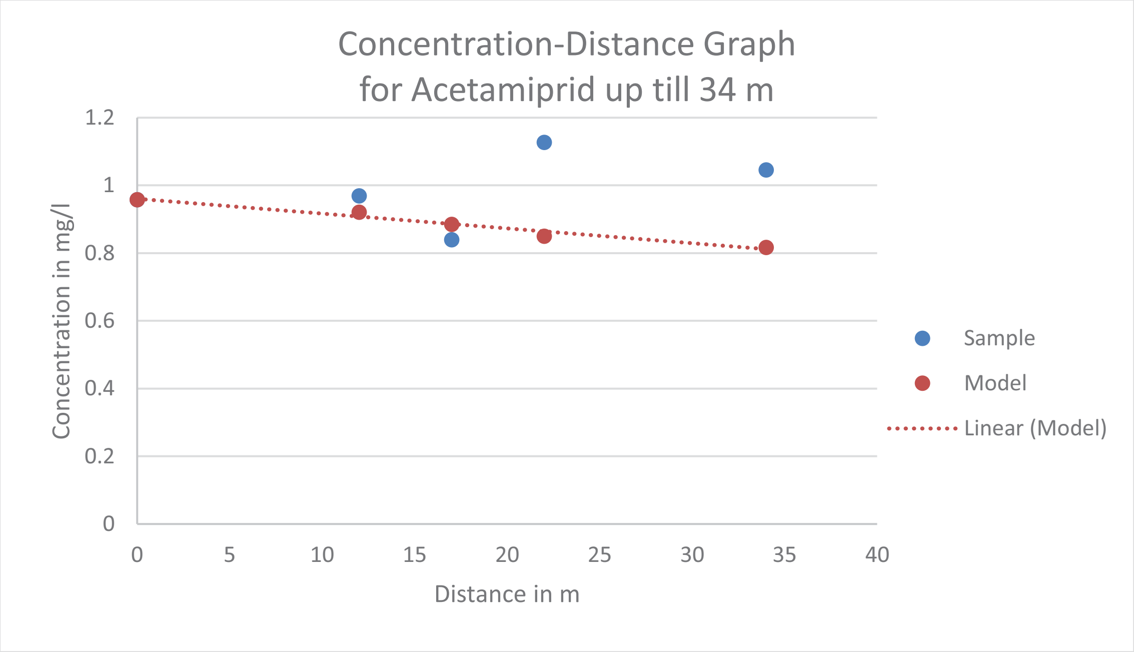

Figure 38: Acetamiprid concentrations up to 34 m

The concentrations then decrease and then increase again (Figure 39). The decrease is because the sample was taken before Klipdrift River meets up with the Swannies River. The increase at 4804 m is because at this sampling point, the treated waste water has not entered the settling ponds of the WWTW.

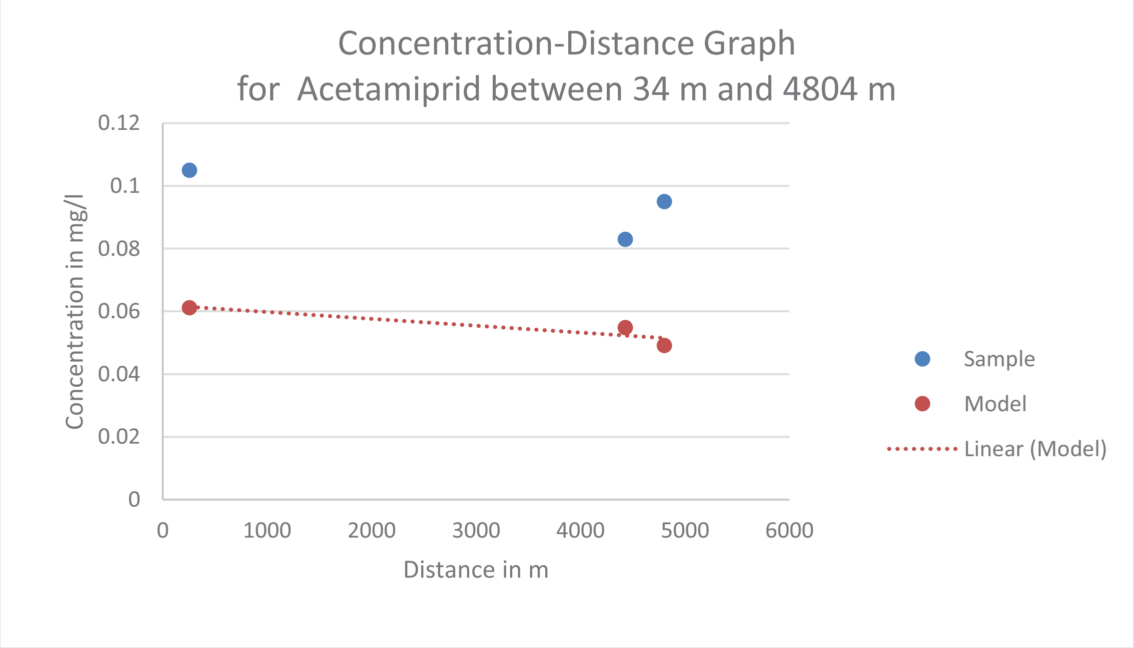

Figure 39: Acetamiprid concentrations between 34 m and 4804 m

The captan concentrations decrease but then at 22 m shows an increase (Figure 40). The increase is explained by the fact that the urban and industrial runoffs enter the Swannies River.

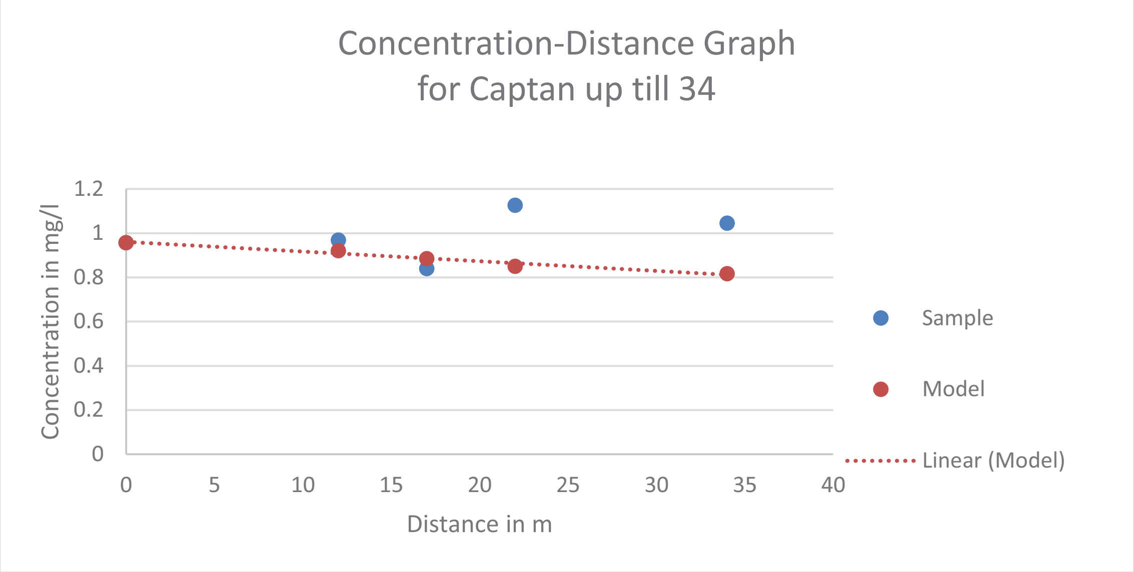

Figure 40: Captan concentrations up to 34 m

The increase in captan concentrations (Figure 41) is also because the treated waste water has not entered the settling ponds of the WWTW.

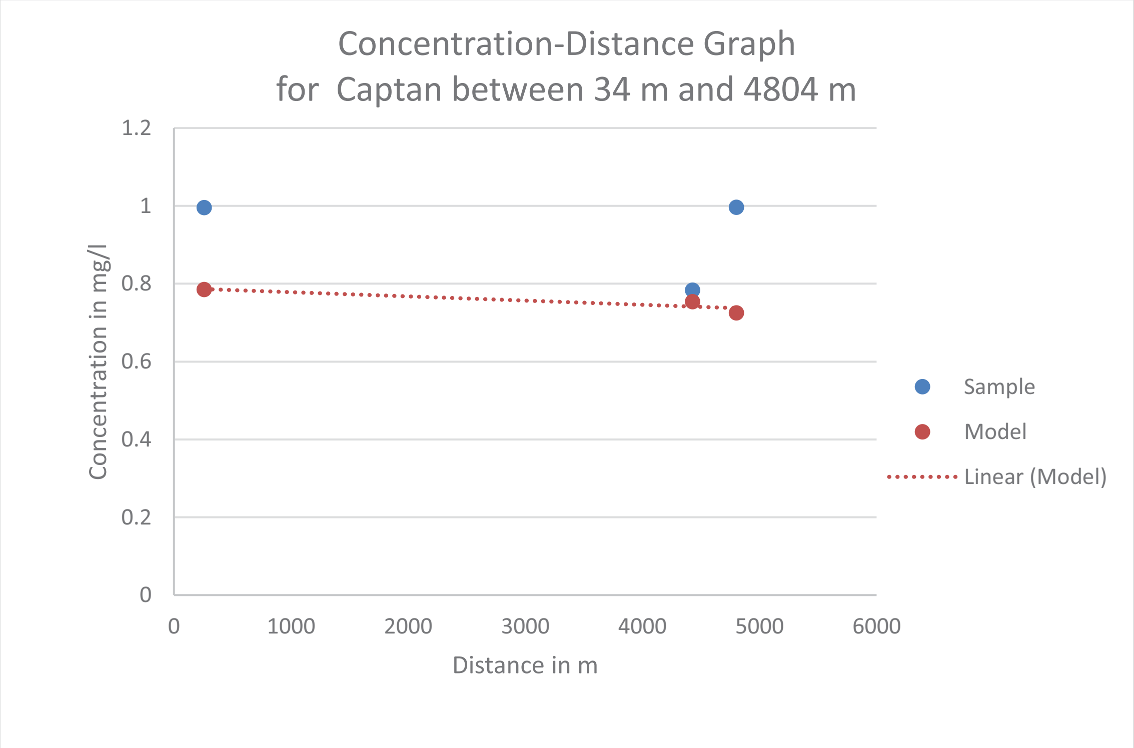

Figure 41: Captan concentrations between 34 m and 4804 m

Figure 42 shows that concentrations of difenoconazole decrease significantly and then rises sharply at 34 m. This is explained as the farm run-off that could have entered the Klipdrift River.

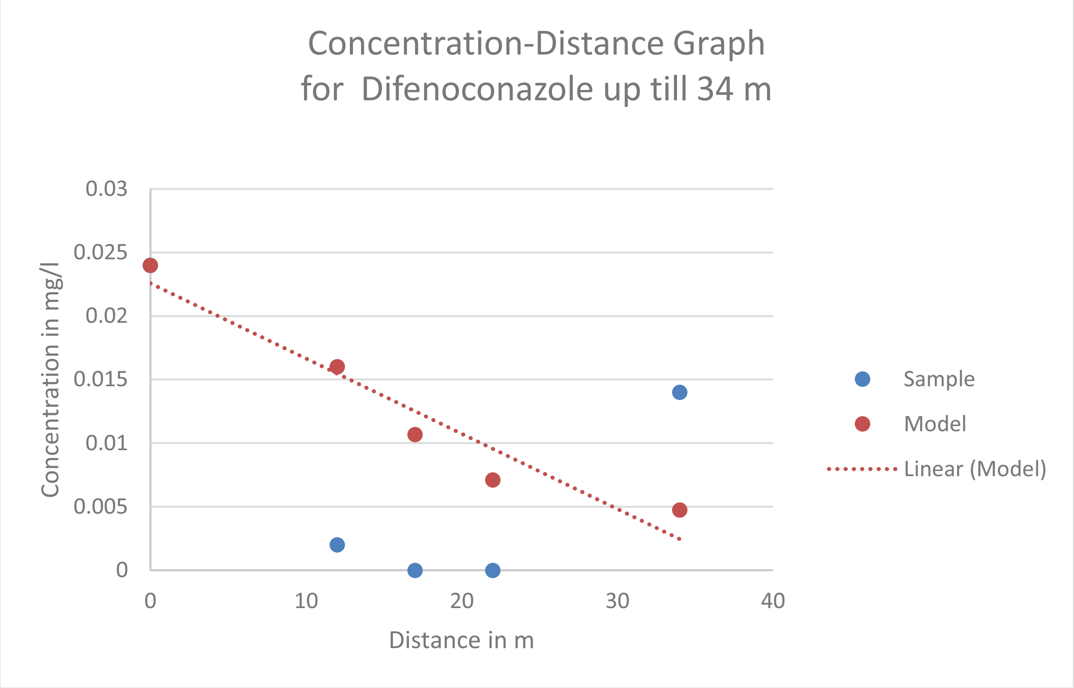

Figure 42: Difenoconazole concentrations up to 34 m

The difenoconazole concentrations (Figure 43) decrease and the rise. The decrease is probably due to the fact of the convergence of the Klipdrift and Palmiet Rivers creating a diluting effect.

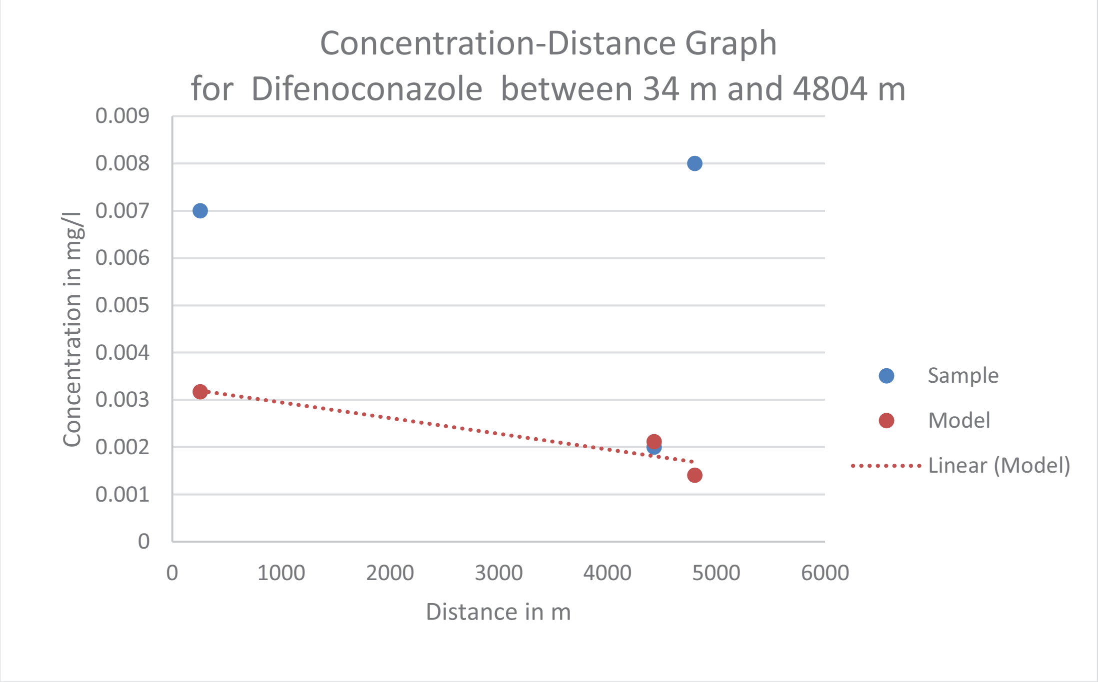

Figure 43: Difenoconazole concentrations between 34 m and 4804 m

The triacloprid concentrations (Figure 44) increase as the urban run-off enters the Swannies River but then decrease as the river continues.

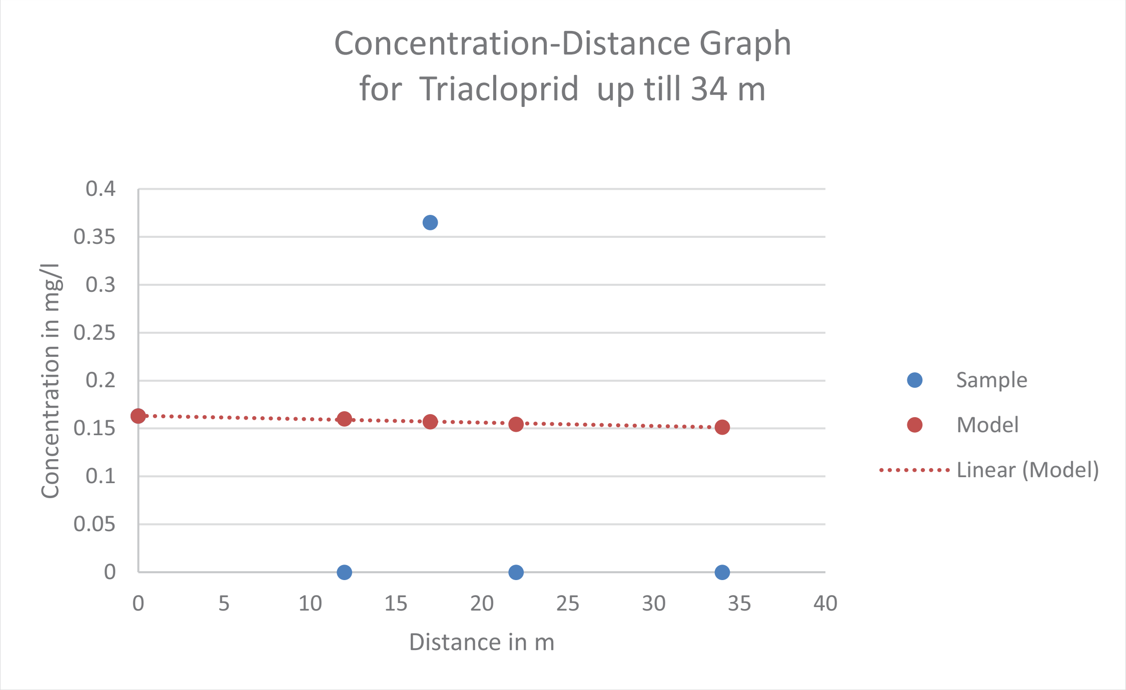

Figure 44: Triacloprid concentrations up to 34 m

The decrease of triacloprid concentrations continues (Figure 45) and then shows an increase at the point before the treated waste water enters the settling ponds.

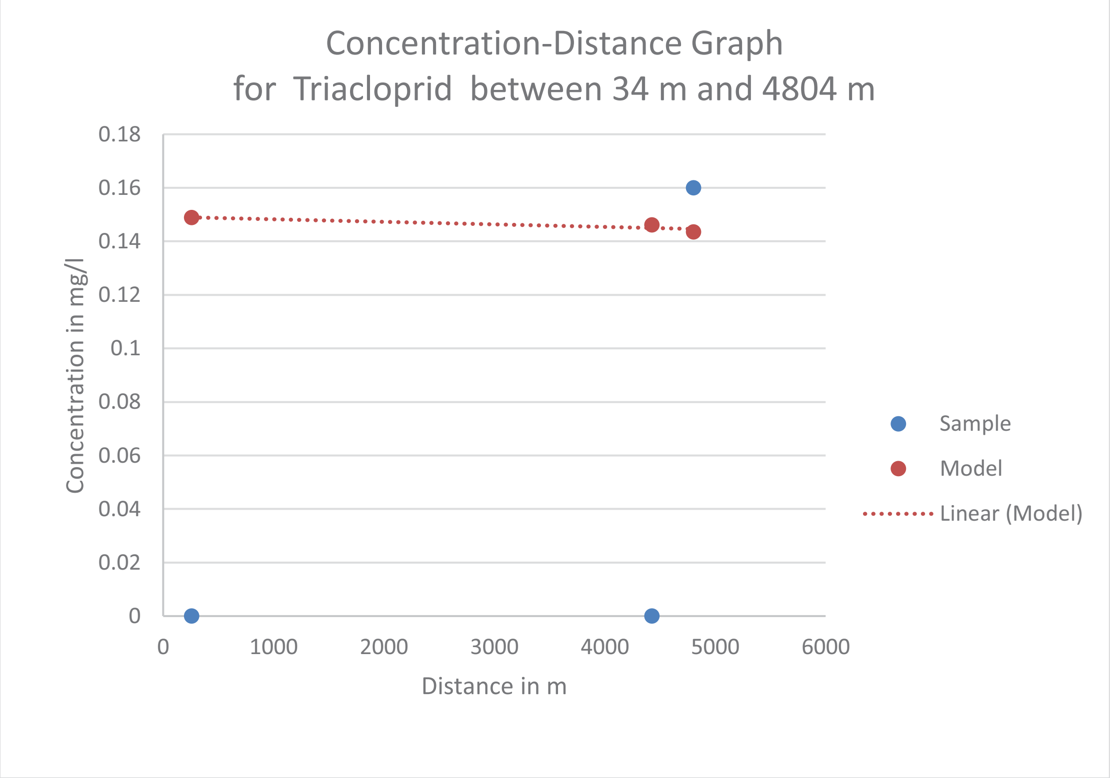

Figure 45: Triacloprid concentrations between 34 m and 4804 m

The trifloxystrobin concentrations increase (Figure 46) and then plateaus. This could be attributed to a possible load entering the system.

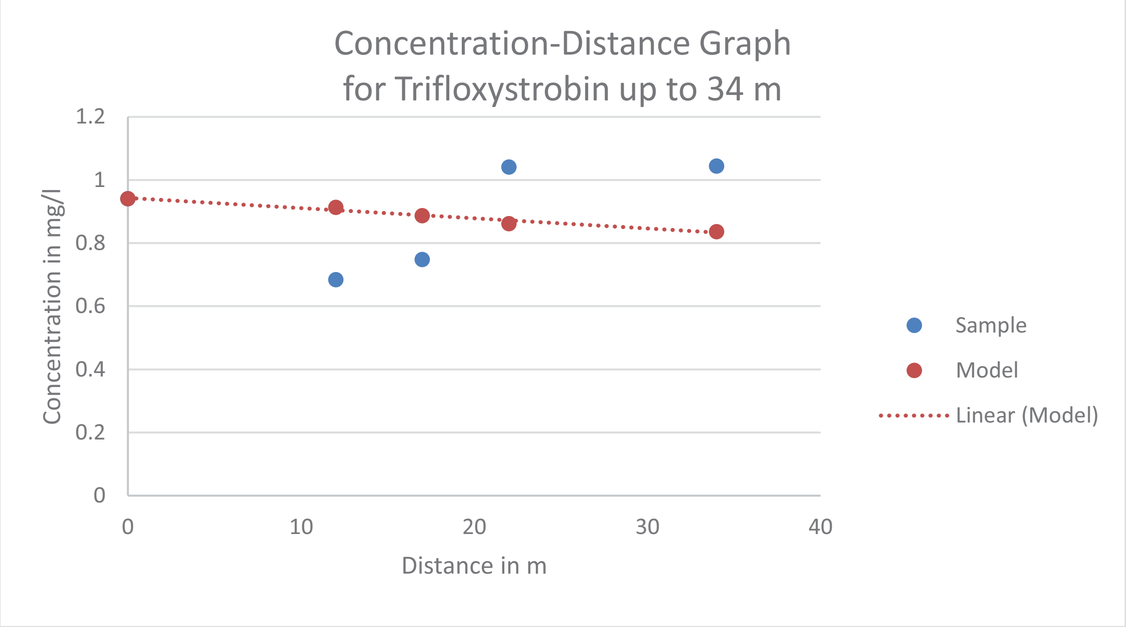

Figure 46: Trifloxystrobin concentrations up to 34 m

Trifloxystrobin concentrations then decrease (Figure 47) as the Klipdrift River converges with the Palmiet River causing the diluting effect.

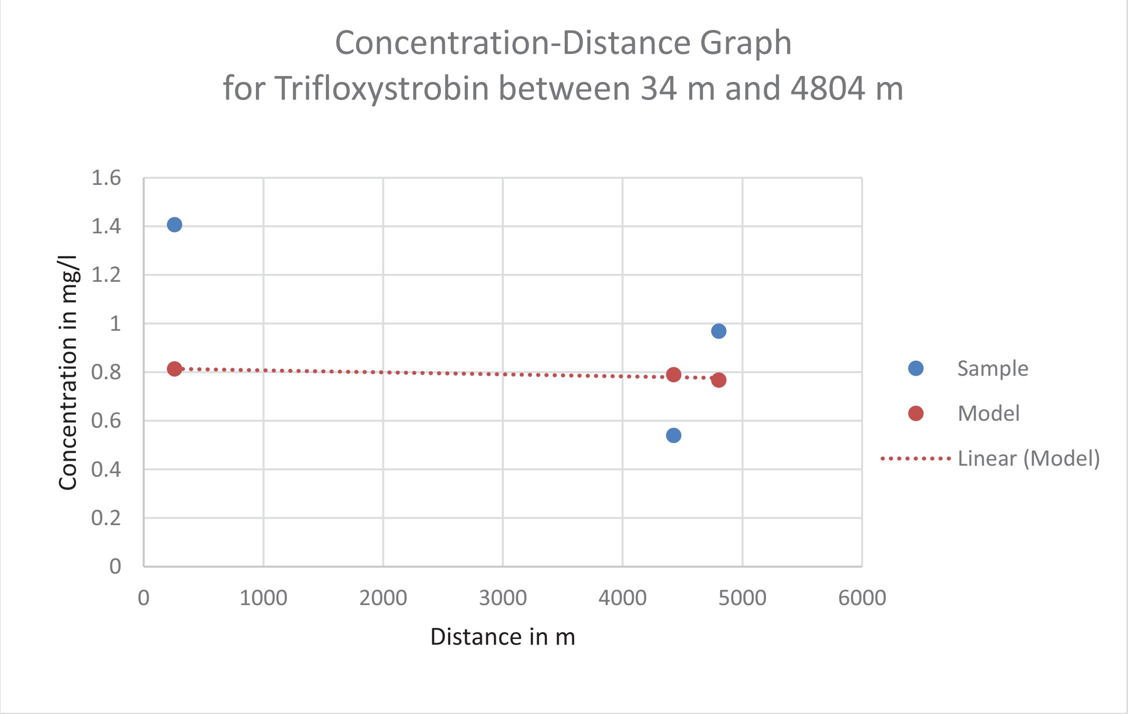

Figure 47: Trifloxystrobin concentrations between 34 m and 4804 m

3.6 Outcome Assessment

The above graphs all follow the model where concentrations eventually decrease but an increase is observed at the waste water treatment. This could be explained that the chemicals enter the waste water treatment system from other points of entry and not necessarily through the point that flows through the town of Grabouw.

Standardised methods are often used to assess the likelihood of effects from exposure to a specified hazard, which inform opinions and decisions about risk management and communication. Understanding and simulating how such pathogens get into, travel through, and eventually affect humans and the environment is a challenging problem that involves many different aspects. Integrated environmental modelling recognises this and has been developing solutions by representing and linking modelling tools in various ways to provide comprehensive and flexible solutions to these complex environmental problems (Whelan et al., 2014).

Applying integrated of system-based models, which address interactions within risk processes on different levels, is an important evolutionary step in advancing the scientific development of ERA as a useful environmental management tool and therefore highly recommended for environmental decision-making (Chen et al., 2013). We therefore need to be cognisant of the fact that some modelling practices have led to problems including (Black et al*.,* 2014):

- Modellers having difficulty demonstrating to stakeholders that the models are credible in the way they are implemented, and that they function and are fit for purpose.
- Stakeholders having difficulty understanding and trusting results.
- Inconsistencies of approach between different implementations and applications of the same modelling platform making comparison of results difficult and, where it is subsequently found to be necessary to connect them, making this impossible.

Modelling can deliver integrated simulations of fate and effects, and scenarios or simulate assumptions can be tested. Coupled fate-and-effect modelling allows extrapolation to different exposure or climate conditions thereby exploring the effects of mitigation measures and moving a step closer to risk management (Focks et al*.,* 2014).

The action taken by authorities is regular monitoring but only for the standard parameters as required by legislation. Regular clean-up of blocked drains and spilled sewage involves opening up the run-off channels and allowing the sewage to enter the river system with the perception of the diluting effect.

The analysis of the samples indicates the presence of unacceptable levels of certain physical, biological and chemical pollutants.

4 CONCLUSION AND RECOMMENDATIONS

Humans, through their activities, increasingly modify ecosystems by means of habitat destruction and pollution. The major hazardous sources in Grabouw are agriculture, manufacturing, motor industry, transport and urbanisation. These sources produce a wide range of biological and chemical pollutants, which then in turn have a devastating effect on aquatic life as highlighted in the hazard characterisation process. The conceptual models (to display environmental pathways) linked and showed the relationships between the emission of the pollutant and the receiving water bodies.

The literature revealed that an integrated risk assessment could assist in addressing issues as a result of the effects of urbanisation, industrialisation and population growth. However, the application of an integrated risk assessment requires the use of predictive models. Once the pollutant enters a water body, an effective mathematical model is needed to predict the pollutant concentration levels and how the pollutant is distributed and spread over various distances.

This research implemented an adaptive version of a predictive model. An assessment was carried out on biological (faecal coli forms, *E. coli*, *Giardia*, *Cryptosporidium* and enteric viruses) and chemical parameters (BOD, DO, NH_4, pH, and various pesticides) within the Swannies, Klipdrift and Palmiet Rivers. Statistical results were produced indicating concentrations levels. The concentration levels were used as input into a practical mathematical transport model to predict direction and spread over a distance of approximately 7 km. In applying the practical model for fate and transport, we concluded that pollutant concentrations do have a tendency to increase initially and then decrease. Although this model tends to be useful for small river systems, the model needs to be expanded to predict how pollutants are transported over large distances.

Risk assessment is widely used (through a hazard analysis and critical control point system) when determining the safety of drinking water. However, this approach is seldom considered when determining the quality of rivers and streams. In determining water resource quality, the process often concludes when the pollutant concentrations are known. The following are therefore recommended:

Policy

- Local authorities must be compelled to include a risk assessment strategy for water resources in their compulsory environmental management plans. This will then encourage the authorities to develop action plans to protect the water sources.
- Instead of just routine monitoring, local authorities and catchment management agencies must develop surveillance systems to establish exposure risk relations and estimate impact.
- Resource water quality objectives must be set for anthropogenic specific parameters. In other words, authorities need to submit a list of all anthropogenic activities and associated pollutants within a specific geographic radius of a water resource. They will then report regularly on the concentration levels of these pollutants and take action when the levels exceed legislated levels of acceptance.

Future research

- This practical model was applied to a small-scale river system (main focus was on Grabouw and not the entire catchment) and more research is needed on large-scale rivers to determine how variability affects the outputs of the model.
- Research is also needed to determine the impact of the identified pollutants on the aquatic life in the Swannies, Klipdrift and Palmiet Rivers.

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