Public knowledge and stormwater quality in Cape Town, South Africa: a case study of the Liesbeek River

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ABSTRACT

It is widely recognized that stormwater is one of the main contributing factors to the deterioration of water quality in urban rivers. The problem is partly caused by the design of conventional stormwater infrastructure, which is intended to remove runoff as quickly and efficiently as possible. In many developing countries urban rivers are already highly degraded and efforts to safeguard these waterways from further deterioration are often a low-level priority for local authorities that are already struggling with basic service delivery challenges. However the condition of an urban waterway cannot be understood simply as a cause and effect relationship, but rather as the result of dynamic interactions between people, drainage infrastructure and ecological systems. In South Africa, and worldwide, there is a paucity of studies that focus on understanding the nexus of these interacting systems. The objectives of this study are twofold: to examine the spatial distribution and variation in stormwater quality; and to examine the extent of residents' knowledge and understanding of urban stormwater systems. The study focuses on two residential areas adjacent to the Liesbeek River, Cape Town, one of the oldest urban rivers in the country. The quality of stormwater flowing into the drainage system is examined based on data captured in 25 roadside catchpits over five months during the winter rainfall period. A combination of field observations and interviews with local residents was conducted to explore the interactions and perceptions of stormwater systems. The findings are used to develop a conceptual framework for understanding urban stormwater and inform efforts to achieve sustainable urban drainage by accounting for the social-ecological processes that connect these systems. The results show that although management interventions are likely to be context-specific, public engagement and ways of effecting behavioural change are critically important in the transition to sustainable urban drainage systems.

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AIC	Aikaike's Information Criteria
BIC	Bayesian Information Criteria
CSRM	Catchment, Stormwater, and River Management Branch
DWAF	Department of Water Affairs and Forestry
EC	Electrical Conductivity
FoL	Friends of the Liesbeek
LID	Low-Impact Design
NWA	National Water Act
OBSID	Observatory Improvement District
PCA	Principal Component Analysis
SUDS	Sustainable Urban Drainage Systems
TDS	Total Dissolved Solids
WSUD	Water Sensitive Urban Design

CHAPTER 1: INTRODUCTION

1.1 Overview

Urban aquatic ecosystems are persistently degraded as a result of complex changes in biophysical processes and human influences that accompany urban development. It has become increasingly clear that sustainable development and sustainable management of urban ecosystems requires simultaneously addressing the well being of the environmental resources as well as human needs and societal progress (Burns & Weaver, 2008). The interactions of these urban stressors within an urban ecosystem must be acknowledged if policy-makers, planners, engineers, and civil society are to ensure that development transitions toward an environmentally and socially sustainable city (Walsh et al., 2005a). The ecological challenges arising in many urban areas necessitate a new approach to development and management that is capable of embracing the dynamic nature of both the environment and people interacting in an urban system.

It is now recognised that urban stormwater is a key contributor to the degradation of urban aquatic ecosystems and that conventional management of urban drainage systems is unsustainable (Paul & Meyer, 2001; Konrad & Booth, 2005). Historically, urban stormwater has been perceived as a hazard, rather than as a useful resource or as adding to the amenity of an urban landscape (Brown et al., 2009). Conventional stormwater management was designed to address flooding and public safety risks by removing runoff as quickly and efficiently as possible (Butler & Davies, 2011; Burns et al., 2012). This approach has largely overlooked environmental concerns and the conservation of ecological systems, leading to poor water quality and degraded urban rivers (Walsh et al., 2005a, 2005b; Butler & Davies, 2011; Burns et al., 2012). Diffuse pollution, such as from urban storm runoff, may present a greater environmental risk than point discharges for rivers, lakes, and groundwater because of the difficulty in monitoring and managing runoff over large areas (Butler & Davies, 2011), and is one of the obstacles that must be overcome to progress towards sustainable urban water management.

Conventional urban drainage techniques interrupt the hydrological processes associated with storm runoff in an urban landscape. This, in turn, limits the potential for ecosystem services, such as improved water quality from infiltration and absorption. With recognition of the catchment-wide scale of the hydrological processes that effect persistent urban aquatic degradation, questions are increasingly being directed to the planning and design criteria underpinning conventional urban stormwater management (Wong, 2006).

Conventional drainage infrastructure is largely hidden, which reinforces the conventional notion that stormwater is not a useful resource and perpetuates a general 'out of sight, out of mind' perspective (Wong & Eadie, 2000). The public, then, is also inclined to disregard the value and significance of urban stormwater because the way in which a water resource is presented influences the public perception of these water systems (Berghoefer et al., 2010; Selman et al., 2010). Conventional infrastructure therefore creates structural and cognitive barriers between people and water systems, and contributes to the increasing dissociation between people and urban aquatic ecosystems (Stokman, 2008; Selman et al., 2010).

The condition of an urban waterway is not the result of simplistic cause and effect relationships, but is the manifestation of complex interactions between people, technology, and the environment (Paul & Meyer, 2001; Allan, 2004; Konrad & Booth, 2005). Multiple dynamic processes interact to produce and sustain the various ecological and biophysical conditions in aquatic ecosystems. In an urban context, aquatic ecosystems face additional influences, with impacts from people and technology contributing to interactions among hydro-geological and biological processes (Poff et al., 1997; Paul & Meyer, 2001; Allan, 2004). With the growing knowledge of the complex influences on urban aquatic ecosystems, there is worldwide effort to conceptualize and manage stormwater drainage more holistically (Wong, 2006; Roy et al., 2008).

The international dialogue on sustainable urban drainage systems represents a cognitive shift toward a systems approach to urban sustainability. Collins et al. (2011) propose that the resilience of a city is directly related to its ability to simultaneously maintain ecosystem and societal functions. Progress toward sustainable urban water management requires an integrated, holistic approach not only to the urban water systems and watershed characteristics, but also to the human impacts and societal[1] processes involved in water systems management (Wong & Eadie, 2000). A systems approach to drainage includes an examination of the built and natural environment, as well as local human activities and perspectives, management strategies, and relevant governing policies and regulations. Although flood management and public safety is a critical service, the conventional stormwater approach is outdated in its exclusion of integrated, catchment-wide environmental and societal considerations.

1.2 Recent Developments

Sustainable drainage systems were synonymous with best management practices, but the approach has evolved to encompass both structural (technical) and non-structural (societal) mechanisms. Used in combination, sustainable drainage techniques aim to manage stormwater at its source, rather than using conventional end-of-pipe solutions, and by working at the interface between the public, drainage technology, and the environment (Rauch et al., 2005).

Advances in sustainable stormwater systems reveal its potential role as a resource, not only as a supplemental water supply, but also as a tool to reduce negative impacts on urban waterways and to add amenity value to the urban environment (Wong & Eadie, 2000). The benefits of these approaches are described by Wong (2013):

> “There is increasing evidence that green infrastructure can deliver a net positive economic benefit to urban communities. Our cities can provide ecosystem services through protecting and improving ecological values of urban environments and adjoining waterways by

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[1] The term ‘societal’ is used more frequently throughout this dissertation than of the term ‘social’ in reference to human influences. Although the terms are arguably interchangeable, the former is used to imply a relation to the complex forces within human populations.

> improving the quality of stormwater runoff; and this improved quality enables stormwater to be a significant additional source of supply, particularly for non-potable uses."

In addition to restoring natural hydrological processes and ecosystem services, sustainable systems stimulate additional benefits associated with aesthetically pleasing urban green spaces, natural habitat, and recreational space.

The international shift in focus toward sustainable urban drainage has resulted in a plethora of research on various tools and techniques (e.g. Konrad & Burges, 2001; Charlesworth et al., 2003; Rauch et al., 2005; Mitchell, 2006; Dietz & Clausen, 2008; Burns et al., 2012). Sustainable systems have been implemented in urban areas of many developed countries, such as Australia, the USA, and Sweden. In some cases, they have been embraced by cities that champion the approach, implemented as demonstration projects, or endorsed by municipal and national agencies. However, the majority of new stormwater systems remain aligned with the conventional approach, delaying the shift to sustainable urban water management (Brown, 2005; Roy et al., 2008; Wong & Brown, 2008).

While much progress has been made in sustainable urban drainage, successful implementation faces many challenges. After evaluating the evolution of stormwater drainage in the USA and Australia, Roy et al. (2008) identified seven major impediments to the implementation of sustainable systems. These include: (1) uncertainties in performance and cost, (2) insufficient engineering standards and guidelines, (3) fragmented responsibilities, (4) lack of institutional capacity, (5) lack of legislative mandate, (6) lack of funding and effective market incentives, and (7) resistance to change. These are fundamentally social issues, but will require an adaptive, integrated approach that encourages partnership and communication among researchers, policy-makers, stakeholders, managers, and the public (Pahl-Wostl et al., 2007). In addition, the majority of the literature is focused on new developments and does not address the widespread impacts generated by existing conventional systems. Furthermore, it has become clear that implementation is highly context-specific, which generates the need to understand the current conditions (e.g. ecological, societal, political, etc.) of a locale before sustainable drainage can be successfully considered and applied.

In developing countries, formal implementation of sustainable urban drainage lags behind other countries because attention is focused on the supply of sanitation and management of wastewater, thus leaving drainage and surface water quality as a lower priority (Reed, 2004). While low-income countries experience similar impediments to developed countries, these are compounded by, *inter alia*, a lack of sufficient resources for research and development, unique contextual issues (e.g. water-related diseases), and a lack of motivation for- or understanding of- integrated water management (Reed, 2004).

In South Africa, policies that mandate sustainable urban drainage management have not yet produced the intended results. As Haskins (2012) points out, the drivers of sustainable municipal stormwater strategies must be manifested in the form of goods and services, and management decisions must incorporate technical information (e.g. discharge, water quality, ecological conditions) that is balanced with considerations of socio-economic factors, and local needs and values.

Research in urban water management has focused largely on technological solutions, with little focus on the integration of societal interactions with technology and ecological systems (Wong & Eadie, 2000; Wong, 2006; Pahl-Wostl et al., 2007). The transition to sustainable drainage systems requires that people are not only connected with the technology, but also with policy, planning, current available knowledge and the decision-making processes (Brown, 2005; Rauch et al., 2005; Pahl-Wostl et al., 2007; Wagner, 2008; Wong & Brown, 2008). One way to deal with the problems of conventional drainage and the difficulties of implementing sustainable techniques is to improve knowledge and understanding of how people and ecological systems interact through the use of conventional drainage infrastructure.

1.3 Problem Statement, Aims and Objectives

The aim of this study is to examine the nexus of stormwater drainage systems, runoff quality, and resident knowledge and experience in a high-density urban setting. The study seeks to understand the potential to conceptually link actions on the land with existing drainage technology that is directly connected to a river ecosystem.

The research provides insight into the environmental and societal influences on conventional urban drainage by focusing on two sites in Cape Town, South Africa, where conventional stormwater drainage is utilized alongside policy that mandates sustainable management of stormwater and urban river systems. The study focuses on the quality of storm runoff generated in these areas, and the relationship between local residents and urban drainage. The objectives of this study are:

1. To determine the spatial and temporal variation of runoff quality in specific urban areas;
2. To critically understand local resident knowledge, experience, and activity in relation to stormwater drainage; and,
3. To develop a conceptual framework describing the nexus of drainage infrastructure, stormwater quality, and resident knowledge and experience.

These aims and objectives were selected as they seek to examine interacting components of the urban stormwater drainage system, and were applicable to a conceptual approach set forth by the Urban Ecology framework. Figure 1.1 depicts one example of an Urban Ecology model, in which a city is considered a functional ecosystem where ecological and societal conditions are fundamentally linked through interacting patterns and processes (Collins et al., 2011; Grimm et al., 2000; Pickett et al., 2001). In accordance with an Urban Ecology approach, urban ecosystem complexities can only be understood by including physical and societal components. Objective 1 informs the “Ecological patterns and processes” occurring in the context of urban stormwater drainage. Objective 2 seeks to understand “human perceptions and attitudes” or changes therein, in relation to the land use, ecological patterns and processes, and/or changes in ecological conditions. Objective 3 aims to use knowledge gained from Objectives 1 and 2 to develop a contextualised framework rooted in the Urban Ecology model presented in Figure 1.1. Applying these insights to an integrated conceptual framework enables an examination of the dynamic linkages between the environmental and societal contexts. The Urban Ecology approach and the model depicted in Figure 1.1 are discussed further in Chapter 2.2.

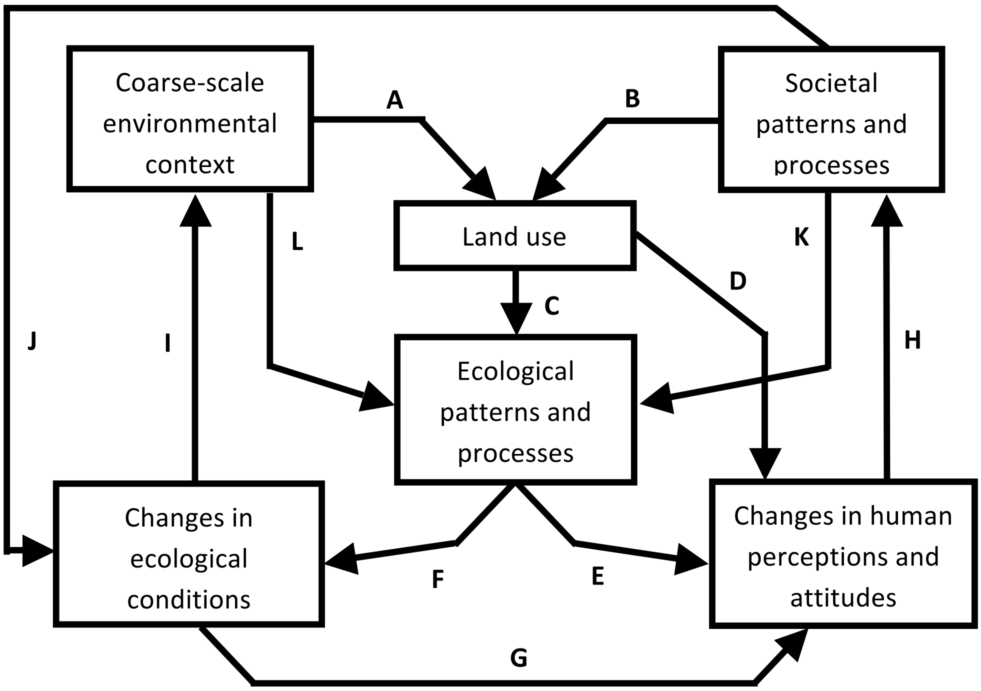

Figure 1.1: The Urban Ecology model showing the integration of societal and ecological processes influencing the urban landscape (Grimm et al., 2000).

1.4 Overview of Research Methods and Study Design

The focus of this study is to identify and explain the interactions and connections between stormwater drainage, runoff quality, and societal perspectives and behaviours. This project combines qualitative and quantitative methods to describe a complex relationship in an exploratory process (Shah & Corley, 2006; Burns & Weaver, 2008). The research design comprises two distinct research activities to examine environmental and societal components of urban stormwater drainage: water quality analysis and resident surveys. Stormwater quality was determined by collecting water samples from stormwater drainage inlets in selected study areas. Multiple water quality parameters were analysed to determine the quality of stormwater entering drainage catchpits during storm events of varying rainfall. Resident surveys were used to examine the knowledge and experiences of local residents with stormwater drainage and urban rivers. The data were compiled to understand stormwater quality, resident knowledge, and perspectives of urban drainage and water quality impacts, as well as the successes and/or failures of the local stormwater system.

1.5 Assumptions and Limitations

This study uses an Urban Ecology model to understand the interaction between people and the environment through conventional urban drainage. It is important to note that each variable (box) in the model (Figure 1.1) is the product of multiple interacting processes. This study does not seek to develop a complete conceptual model for urban drainage in the context of Cape Town, South Africa, which would require an in-depth examination of each variable, including its inherent dynamic systems and feedbacks, and its relationship to all other variables and linkages. In this limited application of the Urban Ecology model, it important to recognise that other social or environmental patterns and processes might be influencing the research results, and should be considered in their interpretation and application.

Researchers focusing on complex human-environment interactions must attempt to identify key system components, linkages and feedbacks. While there may be some simple causal relationships observable in such a system, much of the causality in the underlying processes are too complex to describe succinctly (Rauch et al., 2005). It is therefore not feasible within the scope of this project to examine the breadth of environmental and societal components interacting in stormwater drainage and management. This study has a relatively narrow scope of examining water quality inputs to the Liesbeek River and resident actors interacting with the drainage system, but excludes a comprehensive examination of the historical and current institutional and management approach.

This study focuses on stormwater that is *entering* the drainage system, rather than examining in-stream conditions. In order to conceptually link stormwater to the river as part of a social-ecological system, discussion will rely on the extensive literature available that deals with the relationships between water quality, contaminants and aquatic ecosystem conditions and processes. Certain water quality parameters have been identified as key indicators for stormwater in residential areas. Other quality parameters, although important for waterway conditions, have been excluded based on feasibility and relevance to the current project.

Results will be compared with guidelines for aquatic ecosystems and wastewater effluent, as South Africa lacks a set of guidelines for stormwater quality. While these guidelines discuss limits for soluble reactive phosphorous and total inorganic nitrogen, this study is limited to orthophosphate, and nitrate and nitrite measurements.

The study focuses on two formal residential areas that differ in demography, but do not span the broad range of variation in development (i.e. formal and informal settlements), land use, and service delivery that exists in the region. Although urban design and land-use patterns within a catchment can strongly influence stormwater quality and the condition of urban waterways (Allan, 2004), this study is limited in its inclusion of land-use types, and focuses only on residential areas. This narrow focus eliminates variation that arises from differences in commercial, industrial and residential influences on stormwater.

Interviews with residents are aimed at understanding individual and household practices and awareness of stormwater issues. This component does not include values, incentives or motivations as these are complicated by culture, history, and other considerations, which are outside of the scope of this project. The intention is to understand *what* knowledge and practices exist, rather than *why* they exist.

1.6 Structure of the Report

Chapter Two of this report provides the literature review for the study. The literature review is focused on conventional stormwater management using an Urban Ecology perspective, which views societal and ecological patterns and processes in the urban landscape as inherently linked. The chapter introduces the South African context and South Africa’s water policy. It then provides a detailed discussion of the ecological and societal linkages that influence urban stormwater management and associated impacts on urban waterways. Furthermore, an overview is given on the current shifts occurring in the international dialogue regarding sustainable approaches to urban stormwater management. Chapter Three provides a detailed discussion of the research methodologies used in this study, including descriptions of the study areas, sampling and survey methods, and analytical techniques. Chapter Four presents and discusses the results in the context of previous research. Chapter Five concludes the report, and presents a conceptual framework depicting the interconnections between people, stormwater technology, and ecological conditions, and implications for the City of Cape Town’s approach to stormwater management.

CHAPTER 2: LITERATURE REVIEW

2.1 Overview

Cities are functional ecosystems governed by interacting social and ecological patterns and processes (Grimm et al., 2000; Pickett et al., 2001). Yet urban development largely disconnects residents from natural processes and obscures the inherent relationships between societal and ecological conditions (Kong et al., 1999; Wong & Eadie, 2000; Stokman, 2008; Selman et al, 2010). It is not surprising therefore that ecological degradation and a limited diversity of species is pervasive in urban rivers and wetlands (Walsh et al., 2005a). Apart from the impact of poorly treated wastewater being discharged into urban river systems – an extensive problem in South Africa - it is now widely acknowledged that stormwater significantly contributes to the deterioration of surface water quality (Glazewski, 2005; Konrad & Booth, 2005; Walsh et al., 2005a).

The condition of an urban waterway cannot be understood simply as a cause and effect relationship, but rather as resulting from interactions between people, technology, and ecological systems (Paul & Meyer, 2001; Allan, 2004; Konrad & Booth, 2005; Walsh et al., 2005a). These interactions are poorly understood largely because research in urban water management has focused on technological solutions, and rarely on the integration of societal patterns and processes that interact with both technology and ecological systems (Wong & Eadie, 2000; Wong, 2006; Pahl-Wostl et al., 2007). While South Africa has progressive water policies, stormwater management continues to use conventional techniques and infrastructure. However, management strategies and policies that ignore interactions between ecology and society are insufficient to produce sustainable outcomes (Pickett et al., 1997; Alberti et al., 2008).

A new approach is required that seeks to integrate the dynamic nature of biophysical and societal components in a cityscape, and understand how they interact as part of an urban system. One such example is the Urban Ecology model, which views societal and ecological patterns and processes as inherently linked (i.e. Pickett et al., 1997; Grimm et al., 2000; Collins et al., 2011). The

Urban Ecology model presents a conceptual framework with which to consider these interconnections and for exploring the potential of sustainable management approaches.

2.2 The Urban Ecology Framework

Ecosystems are open, dynamic systems with multiple potential states of equilibria, a high level of unpredictability, and are subject to frequent external disturbance (Alberti et al., 2008). People directly or indirectly influence all ecosystems on earth (Vitousek et al., 1997), but urban ecosystems are arguably the most intensely and fundamentally altered (Grimm et al., 2000). Current urban conditions are the product of multiple dynamic interactions, feedbacks, and linkages between biophysical variables (e.g. climate, geologic context, and natural cycles) and the individual decisions of various human actors (e.g. government, planners, businesses, and households) (Collins et al., 2011). These interactions are observed in different patterns of development, management, and infrastructure, and ultimately influence the integrity of ecosystems through resource use, land alteration, and the generation and management of waste materials (Collins et al., 2011).

The ongoing degradation of urban aquatic ecosystems results from a myriad of human influences, including (*inter alia*): conventional water management practices and services infrastructure; residential, commercial and industrial development; and transportation infrastructure (Paul & Meyer, 2001; Walsh et al., 2005a). Thus, societal processes and activities are integral determinants of the quality of urban aquatic ecosystems (Pickett et al., 1997; Grimm et al., 2000; Collins et al., 2001). It is therefore evident that ecological and societal linkages must be examined in, and are fundamental to, understanding and managing urban ecological systems (Vitousek et al., 1997; Alberti et al., 2008). It follows that more integrated and “realistic models” (Grimm et al., 2000, p. 571) have been developed to examine interactions among societal and biophysical stressors. These models are likely to facilitate progress towards the development of sustainable solutions to environmental and societal problems associated with urban aquatic systems and the deterioration of waterways in particular (Grimm et al., 2000; Walsh et al., 2005a).

Within the Urban Ecology model, a city is considered a functional ecosystem where ecological and societal conditions are fundamentally linked through interacting patterns and processes (Collins et al., 2011; Grimm et al., 2000; Pickett et al., 2001). An example of such a framework is shown in Figure 1.1, in which variables are shown in boxes, with interactions and feedbacks represented as arrows. According to the model, the environmental and societal patterns and processes are the outcome of inherent fundamental drivers: the environmental context is the result of (current and historical) climate, geology, and biogeography, while the societal context is generated by (current and historical) socioeconomic systems, culture, demography and social institutions (Grimm et al., 2000). This conceptual framework illustrates how environmental contexts (e.g. climate and watershed dynamics) and societal processes (e.g. policy or management approaches) inform and constrain land use and land use change: labelled as processes 'A' and 'B' in Figure 1.1 (Grimm et al., 2000). Land use change may be the result of development, urban renewal, changes in land ownership or management, or infrastructure development (*ibid*.). The model suggests that environmental patterns and processes are enhanced or impaired due to feedbacks from land use or management decisions (through processes 'C', 'F', and 'I'). The current state of an ecological system, land use, or changes therein, can influence the perceptions of individuals towards that ecosystem or its management (through processes 'D', 'E', and 'G'), with the potential to feedback by influencing societal patterns and processes ('H'). In addition, society can respond directly to undesirable changes in ecological conditions ('J') or can respond to the mechanisms causing those changes ('K'). Thus, societal aspirations broadly influence the social context and the adaptation to changing conditions, needs, and values in particular.

The interactions shown in Figure 1.1 reflect temporal steps, where 'Land Use' and 'Ecological Patterns and Processes' are a snapshot of a single point in time. When a change occurs in these conditions, or when environmental problems arise, a sequence of interactions and feedbacks are carried out to incorporate solutions or adjustments in management decisions. However, human interaction with, and perception of, the biophysical environment is influenced by a range of societal patterns and processes (e.g. culture, socioeconomic status), as well as understanding of ecological concepts (Berghoefer et al., 2010). According to Collins et al. (2011), valuable ecosystem services, such as nutrient filtration, flood attenuation, and water purification, are the primary linkage between societal and ecological capital. The continuous cycle of human decision-making affects the environmental context, and the resulting changes in ecological services can influence or alter human behaviour and societal contexts (Collins et al., 2011). In the transition to more sustainable urban water management, process 'H' represents a potentially valuable tool, whereby changes in the perceptions or attitudes towards a land use, ecological patterns, or altered ecological conditions, can effect change in human behaviour or the societal processes generating water management approaches.

In the urban ecosystem, ecological complexity is compounded by societal complexity. Human systems have unique characteristics, such as the ability to make forward-thinking decisions, generate and respond to abstract concepts, create interactions that act on multiple spatial and temporal scales, and develop technologies with far-reaching consequences (Burns & Weaver, 2008; Collins et al., 2011). As Pickett et al. (1997) point out, changes in societal structures are driven by the ability of humans and their institutions to perceive changes in the built and natural environment, the fact that they attach value to such changes, and, as a result, attempt to change the environment. Fully integrated social-environmental models must then consider the range of societal system components, including: social institutions (e.g. health, justice, faith, commerce, education, leisure, government), social order (e.g. age, gender, class, norms, wealth, power, status, knowledge, territory), social dynamics (e.g. physiological, individual, organisational, institutional, environmental), and social resources (e.g. economic, cultural) (Pickett et al., 1997).

The conceptual model in Figure 1.1 and its application to urban stormwater is explained further in the literature review. It presents a conceptual basis for considering the decline of urban river systems and poor stormwater quality. However, biophysical and societal systems exhibit considerable variation, which necessarily reinforces the importance of developing context-specific solutions for individual locations.

2.3 The South African Context

South Africa is a water-scarce country facing increasing pressures from population growth and urbanization. It has a population of over 51.7 million people, with a population growth of 15.5% since the 2001 census (City of Cape Town, Strategic Development Information & GIS Department, Statistics South Africa, 2012). Populations in the urban areas of the Western Cape and Gauteng provinces are growing significantly faster than their rural counterparts of the Eastern Cape, Free State and Limpopo provinces, where populations are declining (City of Cape Town, Strategic Development Information & GIS Department, Statistics South Africa, 2012).

South Africa often experiences water shortages, which is likely to be exacerbated by climate change. Average annual surface runoff is a little over 49 billion cubic meters: less than half of the Zambezi River's annual flow (Republic of South Africa, Department of Water Affairs and Forestry, 2004). Under increasingly hot, dry conditions, South Africa could expect a decrease in runoff of up to 10% in the western parts of the country by 2015 (Republic of South Africa, Department of Water Affairs and Forestry, 2004). Severe floods often occur after periods of drought, and can lead to serious impacts on infrastructure and public safety.

Rising population and urbanization negatively affect South Africa's aquatic environments (Driver et al., 2012). The majority (57%) of river ecosystems in South Africa are threatened: 23% critically endangered, 19% endangered, and 13% vulnerable (Figure 2.1). If tributaries are excluded from this calculation then the statistic rises to an alarming 65% of river ecosystems classified as threatened (Driver et al., 2012). A greater proportion of threatened river ecosystems exist in lowland areas, where gradual pollution accumulation is compounded by intensive agriculture and urban development practices. Surface water pollution is a serious and growing problem, exacerbated by the loss of natural riparian vegetation (*ibid*). Degradation of South Africa's rivers is primarily driven by over-abstraction, altered discharge hydrographs, and declining water quality (*ibid*). Changes in urban surface hydrology and deteriorating water quality are fundamentally linked to stormwater runoff from urban areas (Glazewski, 2005; River Health Programme, 2005; Walsh et al., 2005a, 2005b; City of Cape Town, Catchment, Stormwater, & River Management Branch, 2010; Driver et al., 2012).

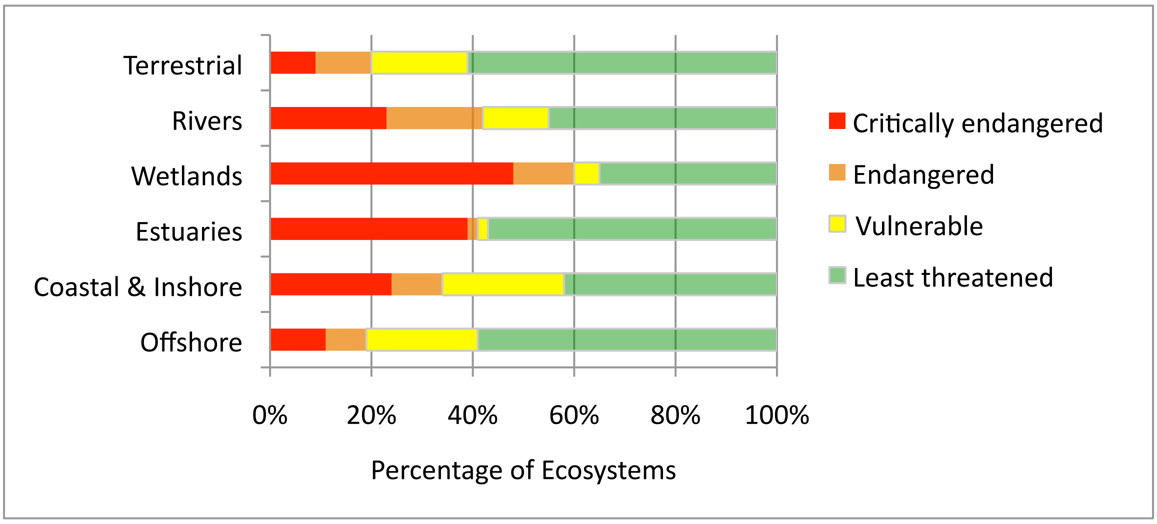

Figure 2.1: Status of ecosystems in South Africa (Driver et al., 2012)

As is the case in many developed and developing countries, wetlands are the most threatened ecosystem category in South Africa. Currently, over 50% of all wetland areas have been lost to development and agriculture. Of those that remain, 65% are threatened: 48% critically endangered, 12% endangered, and 5% vulnerable (Driver et al., 2012). As development encroaches on these systems, floodplain wetlands are most likely to become critically endangered. Such vast wetland degradation seriously impairs valuable ecosystems services, including capacities for runoff storage, flood attenuation, and water purification, thereby intensifying the catchment-wide pressures on water quality decline and altered flow regime (*ibid*).

Rapid urbanization and population growth place increasing stress, not only on South Africa’s scarce water resources and ecological systems, but also on the nation’s ability to provide water services to the entire public.

2.3.1 National Water Policy

South Africa's water law changed drastically with the abolishment of apartheid and adoption of a democratic government. The new constitution was the basis for the nation's progressive environmental legislation. The National Environmental Management Act of 1998, for example, introduced a mandatory commitment to the protection of environmental systems and the remediation of damage, explicitly encompassing water resources and pollution (Glazewski, 2005).

South Africa revolutionized water law by adopting a national legislation that transforms society by integrating social and environmental needs. Under the National Water Act of 1998 (NWA), water resource management must meet basic human needs and environmental sustainability, both of which are guaranteed as a right (Republic of South Africa, Department of Water Affairs and Forestry, 2004). The NWA allocates a portion of the nation's water resources for sustaining environmental needs and processes (Haskins, 2012). In addition, the national government became responsible for ensuring that water resources are protected, used, conserved, and managed in a sustainable and equitable manner for the benefit of all persons (Glazewski, 2005).

The Department of Water Affairs and Forestry (DWAF) identified three major problems associated with water quality, and viability and maintenance of aquatic ecosystems, which include (Glazewski, 2005):

- Increasing salinization of water resources due to irrigation;
- Excessive concentrations of nutrients introduced to water resources from fertilizers; and
- Introduction of toxic chemicals to water resources from industrial and mining processes, and agricultural and urban runoff.

Not surprisingly, these three problems typically result from conventional urban and agricultural development, management practices, and the resulting surface water runoff.

Water quality and pollution control measures permeate the entire NWA. It stipulates that all water use requires a license, unless explicitly excluded within the policy. Regulated water use includes (*inter alia*): water storage; discharge of waste or water through a conduit; alteration of the bank, bed, course, or characteristic of a watercourse; and activities on land that may impact a water resource. This broad definition of water use reflects an integrated and holistic approach to water legislation and protection, and recognizes the complexities of the hydrological cycle (Glazewski, 2005).

2.3.2 National Stormwater Policy

Although South Africa has a sophisticated legislative system in place to protect its scare water resources, aquatic ecosystems continue to be degraded (Davies & Day, 1998; Brown & Magoba, 2009; Driver et al., 2012). Pollution from urban runoff has been identified as one of the three main problems for national water resources (Glazewski, 2005). While the NWA requires a license for any activity that will discharge water or waste into a water resource, some activities are excluded. No license is required to discharge runoff water, including stormwater, from a residential, recreational, commercial, or industrial site into a canal, sea outfall or other conduit that is controlled by another person (e.g. the municipality) who is responsible for the treatment or purification of that water, granted that approval from that controlling body has been given (Glazewski, 2005). These residential, recreational, commercial, and industrial sites are not permitted to release contaminants onto land that may impact a water system, but monitoring and enforcement of this mandate is impractical (Haskins, 2012; Schreiner, 2013). While runoff from these sites is recognized as a major water quality problem (Bannerman et al., 1993; Paul & Meyer, 2001; Glazewski, 2005), responsibility for its treatment falls to the municipality. South Africa's stormwater reticulation system, however, does not incorporate constructed treatment facilities and simply discharges via local rivers to the sea.

The Constitution requires that municipalities provide and administer stormwater management systems in built up areas (Act 108 of 1996). Municipal stormwater management requirements primarily focus on the engineering and maintenance goals of efficient water conveyance through gutters, pipes, culverts, and canals in order to prevent flooding in developed areas (Haskins, 2012). Thus, South African cities are dominated by a conventional version of stormwater reticulation infrastructure. Some local authorities, such as the City of Cape Town, have generated by-laws to deal specifically with stormwater-related sustainability issues.

2.4 Applying Urban Ecology to Conventional Stormwater

Conventional stormwater reticulation systems comprise extensive networks of drains, canals, and pipes that collect runoff and direct the flow in either ‘separate’ or ‘combined’ systems. In a separate drainage system, runoff is collected in curb-side drainage channels and catchpits and then flows directly into a waterway via networks of pipelines and culverts. In a combined system, stormwater is drained along with sewage to a treatment plant before being discharged except when a storm overwhelms the system and it flows as untreated effluent into a watercourse. In both cases, the majority of the reticulation system is found underground and consists of hard infrastructure technologies, such as lined pipes, concrete culverts, etc. The remainder of this thesis focuses on the separate stormwater drainage scheme, which is utilized in South Africa’s formally developed urban areas.

The Urban Ecology model, introduced in Chapter 1.3, is used in this study to develop a new perspective on conventional urban stormwater, as shown in Figure 2.2. The urban environmental context, including conditions such as rainfall, rates of infiltration and evaporation, catchment imperviousness and drainage routes, influence land use options and associated ecological patterns. These influences are represented as processes labelled ‘A’ and ‘L’ in Figure 2.2. These conditions are modified by the societal patterns and processes that, among other factors, use stormwater infrastructure designed to reduce risk to public safety by removing runoff as quickly and efficiently as possible (Brown et al., 2009), shown as process ‘B’. There is little or no attenuation for the receiving waterways (process ‘C’). Meanwhile, the efficient removal of stormwater risks is acknowledged as an important public service (Brown et al., 2009): process ‘D’. Large volumes of runoff and contaminants are discharged to urban waterways along these reticulation systems and upon entering urban waterways, directly influence biophysical patterns and processes in freshwater systems (process 'F'). The interconnections between societal and ecological patterns and processes, and their cumulative impacts on the ecological conditions of urban rivers, generally go unrecognized by the public (Ball, 1999; Stokman, 2008). Therefore, processes 'E' and 'G' are arguably weak interactions. Thus, urban society(ies) are increasingly disconnected from adjacent aquatic ecological systems, resulting in increasingly unproductive and ecological degraded urban river systems (Kong et al., 1999; Stokman, 2008). The application of this complex conceptual framework is described further in the sections below.

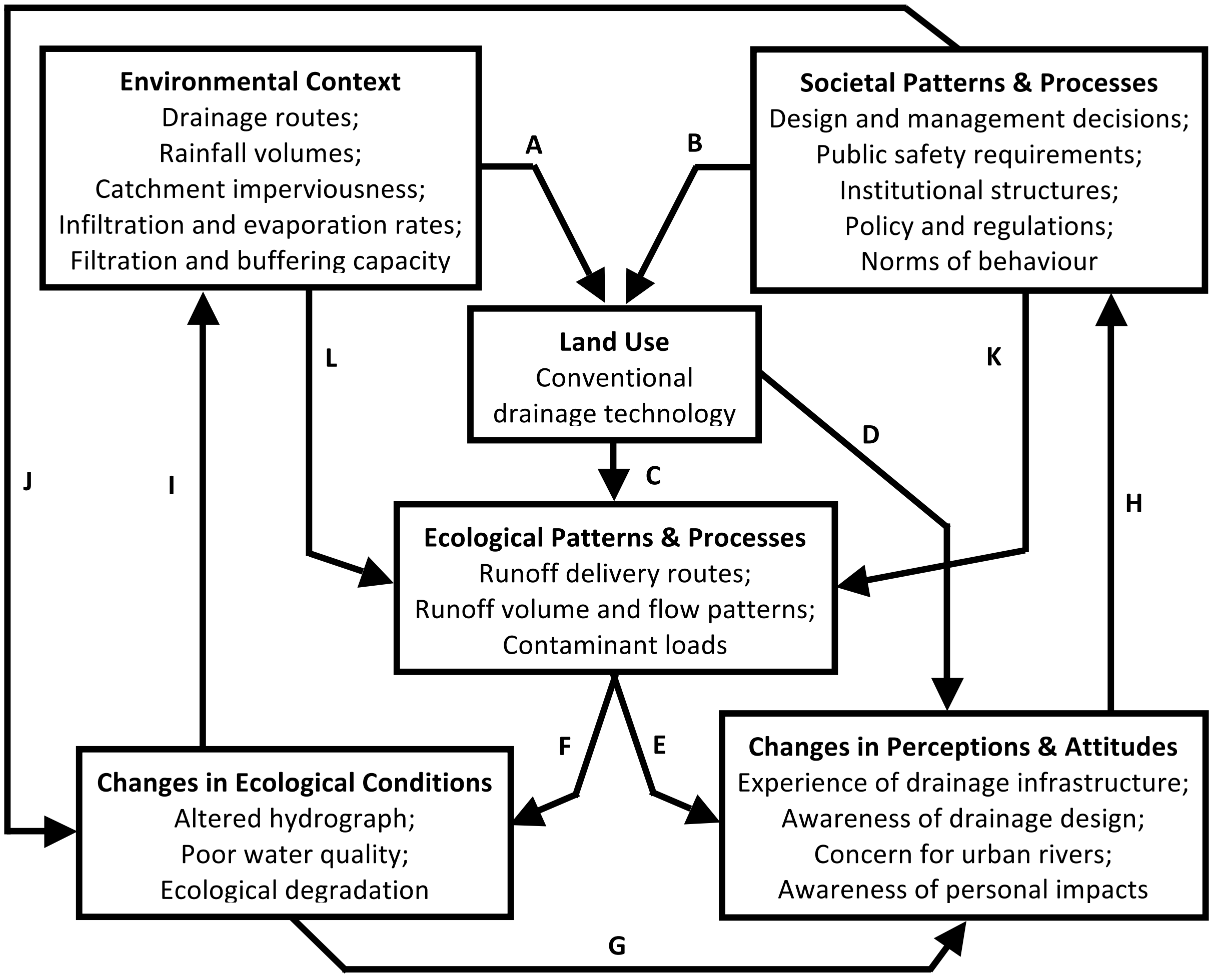

Figure 2.2: Application of the Urban Ecology model to conventional stormwater in South Africa (adapted from Grimm et al., 2000)

2.4.1 Ecological Linkages

Conventional stormwater drainage has generated interrelated, cascading effects on urban aquatic ecosystems (Booth, 1991; Paul & Meyer, 2001). The resulting characteristics of rivers and wetlands are observed in altered discharge patterns, erosion and sedimentation rates, stream channel morphology, and water quality. In the urban context, rivers are typically characterized by elevated concentrations of nutrients and contaminants, an erratic hydrograph, altered channel morphology, increases in water temperature, reduced channel and habitat structure, and decreased biotic richness with increased dominance of tolerant species (Paul & Meyer, 2001; Allan, 2004; Konrad & Booth, 2005; Walsh et al., 2005a). However, these conditions are not the result of simple causal pathways, but rather a complex web of interactions and feedbacks (Walsh et al., 2005a). Figure 2.3 depicts a simplified diagram of the complexity of mechanisms influencing ecological change in urban waterways. Although there are multiple interacting factors most changes are driven by stormwater runoff from impervious surfaces (*ibid*).

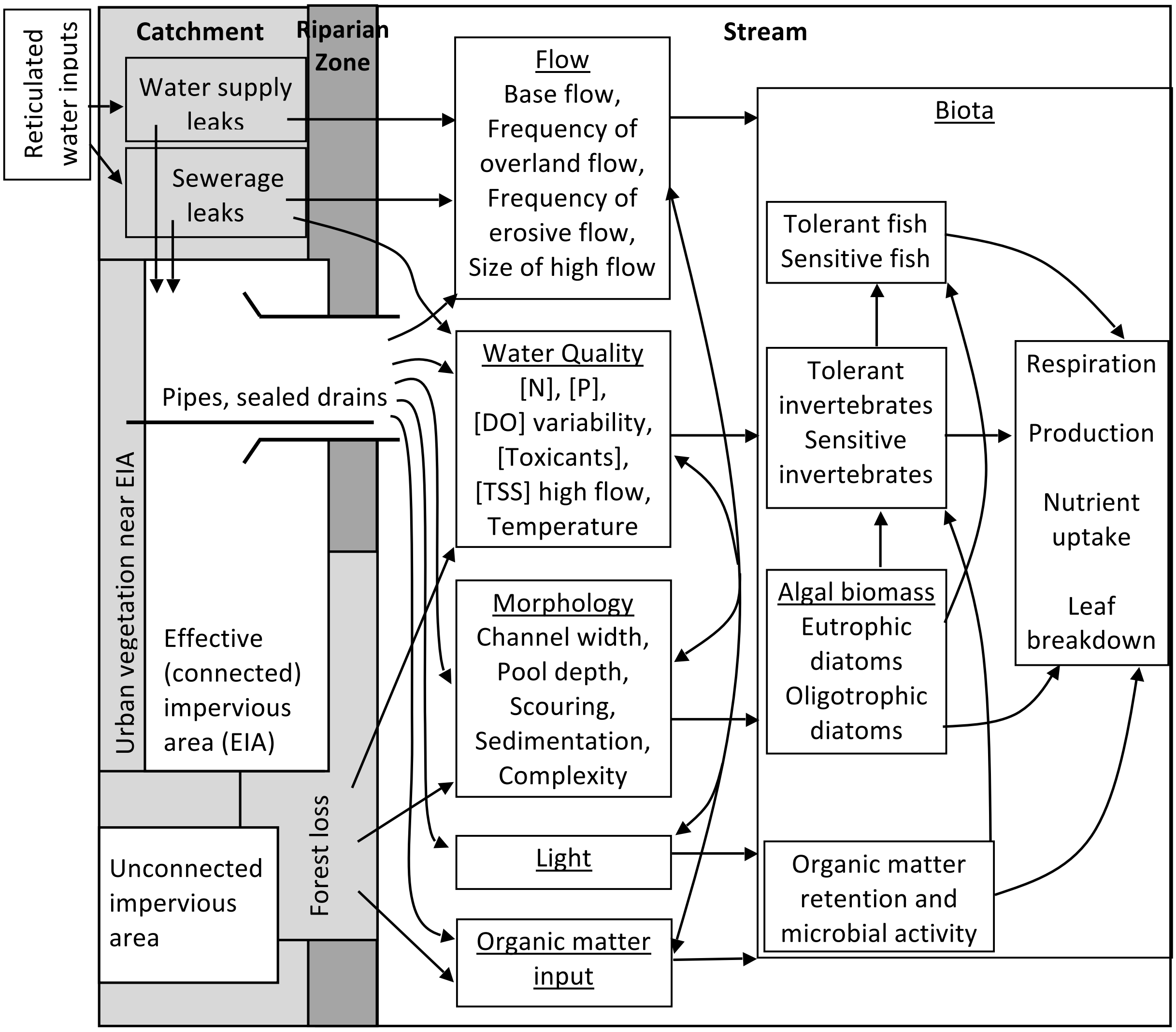

Figure 2.3: Conceptual model of the complex influences on urban waterways (simplified from Walsh et al., 2005a)

As Wong and Eadie (2000, p. 2) state, “denuded, eroded, and lifeless waterways choked with anthropogenic litter and exotic weeds are symptomatic of the unsustainable conditions being imposed on the environment by conventional urban development practices.” As shown in Figure 2.3, the typical degraded state of urban streams is primarily caused by urban stormwater runoff that has been designed and managed for flood control using pipelines to connect impervious areas directly to urban waterways (Paul & Meyer, 2001; Allan, 2004; Konrad & Booth, 2005; Walsh et al., 2005a, 2005b).

Hydrology and Catchment Imperviousness

As urban areas expand, vegetation is removed to make space for development, and catchment imperviousness increases with the compaction of soils and paving of surfaces. These changes significantly reduce infiltration and evapo-transpiration capacities, causing precipitation to accumulate on surfaces (Arnold & Gibbons, 1996): an environmental context that constrains land use and management decisions in process 'A' of Figure 2.2. Conventional stormwater technologies are installed in order to manage the risks to public safety and infrastructure, as represented by process 'B' in Figure 2.2. These changes associated with urban development alter the natural runoff storage and treatment capacities, and the hydrological balance of the urbanizing catchment (Konrad & Booth, 2005). Hydrological processes have direct and indirect effects on stream characteristics (Konrad & Booth, 2005). Thus, any change in a catchment landscape that alters one aspect of the hydrological cycle will, in turn, affect the hydrology of receiving waterways (Arnold & Gibbons, 1996; Allan, 2004): process 'C' in Figure 2.2.

Major hydraulic changes in urbanized catchments stem from the efficiency with which impervious surfaces are drained via conventional reticulation systems (Mullis et al., 1996; Walsh et al., 2005a). Reduced runoff storage and rapid delivery generates erratic, or 'flashy,' hydrographs that are typical of streams in the urban landscape (Paul & Meyer, 2001). Associated hydrological changes in urban receiving waterways consistently include (Konrad & Booth, 2005; Walsh et al., 2005a):

- Increased frequency of overland flow;
- Increased frequency of erosive flow;
- Increased magnitude and frequency of high flows;
- Decreased lag time to peak flow; and
- A rapid rise and fall of storm hydrographs.

Fundamentally linked to the flow regimes, aquatic ecosystems are significantly degraded by these changes (Walsh et al., 2001; Allan, 2004): process 'F' in Figure 2.2. Discharge patterns influence stream geomorphology, temperature, water chemistry, habitat diversity, and other ecosystem processes that are vital for river health (Resh et al., 1988; Poff et al., 1997). While small precipitation events of only a few millimetres are unlikely to have large hydraulic impacts on streams, frequent occurrence could produce negative effects due to elevated contaminants and temperature changes (Walsh et al., 2005a, 2005b). In addition, the greater proportion of rainfall leaving urban areas as runoff cause reduced groundwater recharge and stream base-flow discharge (Paul & Meyer, 2001; Konrad & Booth, 2005; Walsh et al., 2005a).

The combination of efficient water conveyance and reduced infiltration leads to rapid delivery of large volumes of runoff. Large quantities of water moving quickly through a watercourse cause bank instability, and bed and bank erosion (Booth, 1991). In response, urban rivers are often channelized (enlarged and straightened) or canalized (lined with concrete) to improve stability and transport efficiency. These alterations directly affect the ecological conditions via process 'J' in Figure 2.2. Although these solutions may successfully address convenience and safety concerns rooted in the societal context, they negatively affect aquatic habitat, aesthetic benefits, and recreational opportunities provided by the waterway. Furthermore, these changes have the potential to influence human attitudes and perceptions in the process labelled as 'G' in Figure 2.2 (Berghoefer et al., 2010; Selman et al., 2010).

Imperviousness as an Indicator

Impervious surface coverage reduces infiltration and interception capacity, with corresponding increases in runoff volume and velocity (Arnold & Gibbons, 1996). In some urban areas, as much as 90% of rainfall may be converted to runoff, collected in drains and delivered to waterways (Brown & Magoba, 2009). The proportion of impervious surface cover is also positively associated with increasing pollutant loading in stormwater runoff (Hatt et al., 2004; Walsh et al., 2005b; Dietz & Clausen, 2008). In a study of 27 watersheds, Klein (1979) found that disturbances in aquatic ecology began to appear where watersheds comprised 12% impervious surface cover, and severe degradation occurred when imperviousness reached 30% coverage. Furthermore, the activity that occurs on a paved surface will determine its contribution to deleterious effects. For example, vehicle servicing areas and parking lots contribute high pollutant loads, whereas roof runoff might contribute less (Bannerman et al., 1993; Pitt et al., 1995).

Arnold and Gibbons (1996) argue that two main factors designate imperviousness as a valuable indicator for river health, urban planning, and development. Firstly, imperviousness integrates four major factors: impervious surfaces (1) are critical contributors to urban hydrologic changes that degrade streams, (2) are a major component of pollutant-producing land uses, (3) prevent natural pollutant processing by soil and plant interception, and (4) efficiently convey pollutants into the drainage system and receiving waterway. Secondly, imperviousness is a measurable characteristic, which enhances its utility for research, planning, regulation, and management. Therefore, catchment imperviousness not only informs and constrains opportunities and requirements of stormwater drainage (process ‘A’), but also influences the ecological processes themselves (‘L’). Furthermore, it is a tool with which to understand and formulate management and land use decisions (‘B’), and possible responses to changed ecological conditions (‘K’ and ‘J’), such as through emerging Water Sensitive Urban Design and Sustainable Urban Drainage Systems techniques.

Nutrients and Contaminants

It is well documented that urban surface runoff carries high concentrations of pollutants to receiving waterways (Bannerman et al., 1993; Paul & Meyer, 2001; Allan, 2004; Hatt et al., 2004; Butler & Davies, 2011). A wide range of contaminants may be found in stormwater, including (*inter alia*) litter and debris, nutrients, bacteria and viruses, heavy metals, hydrocarbons, pesticides, and various other toxicants (*ibid*).

During periods of high rainfall conditions, urban areas become a highly significant source of contaminants because of reduced storage, interception, and buffering capacity (Boyacioglu, 2006).

Thus, stormwater pollutants are delivered to receiving waterways more efficiently, more directly, and in greater concentrations than under natural, undeveloped conditions: process ‘C’ in Figure 2.2.

Urban litter is the most easily visible pollutant of urban waterways. While litter and debris are undoubtedly unsightly, their accumulation in the drainage system can cause blockage and flooding. Removal of debris from drainage infrastructure and a receiving waterway is tedious and expensive (Armitage et al., 1998). In developing countries this problem is exacerbated by the dis-proportionality of slow litter collection service development and exponential growth of litter production (Armitage & Rooseboom, 2000). Furthermore, in areas with formal runoff reticulation systems and lacking basic refuse and sanitation services, drainage systems frequently metamorphose to a mechanism for refuse and waste removal (Armitage & Rooseboom, 2000; Winter & Mgese, 2011). While the broad solution to this problem requires societal service delivery development, a smaller-scale solution is the installation of litter traps to prevent it from reaching the waterway: a societal response to one of the processes causing the condition, via process ‘K’ in Figure 2.2. Alternatively, rivers are occasionally dredged for debris: a response to the changed condition itself, represented as process ‘J’.

Not surprisingly, many contaminants delivered to urban waterways have potential to disrupt biological and ecological patterns and processes in-stream (Paul & Meyer, 2001; Allan, 2004; Butler & Davies, 2011): process ‘F’ in Figure 2.2. For example, nutrient enrichment leads to increased autotrophic biomass production and changes assemblage compositions, potentially triggering eutrophication and degradation of the aquatic ecosystem. Increased toxicant loads negatively affect survival and reproduction of aquatic organisms, with potential for bioaccumulation in sediments and tissues (Paul & Meyer, 2001).

The diversity and concentrations of contaminants is dependent on the local context as determined by environmental and societal patterns and processes (Allan, 2004; Butler & Davies, 2011). Runoff contaminants originate from a myriad of sources, which may include, *inter alia*, vehicle emissions, corrosion/erosion of buildings and roads, animal faeces, urban landscaping practices, sewage infrastructure leakage, and atmospheric deposition (Bannerman et al., 1993; Paul & Meyer, 2001; Butler & Davies, 2011). Golf courses, and residential and commercial lawns and gardens are common sources of nutrients and pesticides (Paul & Meyer, 2001). Roof runoff, vehicle service areas, and parking areas produce hydrocarbons and heavy metals (Bannerman et al., 1993; Pitt et al., 1995). In residential, commercial, and industrial land uses, streets are critical sources of heavy metal, hydrocarbon, and nutrient contaminants (Bannerman et al., 1993; Paul & Meyer, 2001). However, the contribution of source areas to the contaminant load is not evenly distributed; one street or garden often contributes significantly more than others in a given area (Bannerman et al., 1993). The proportion of residential, commercial, and industrial development, the extent of the reticulation system, as well as the presence of wastewater treatment plant effluent all influence the manifestation of physical and chemical effects to the receiving waterway (Paul & Meyer, 2001).

One of the primary driving factors influencing runoff contaminant loading is rainfall (Pitt et al., 1995; Mulliss et al., 1996; Bertrand-Krajewski et al., 1998; Lee et al., 2002). According to the 'First Flush' theory, the onset of rainfall is associated with elevated pollutant concentrations and loads decrease over the course of a precipitation event, as the contaminant becomes increasingly diluted and surfaces washed clean (Mulliss et al., 1996; Bertrand-Krajewski et al., 1998; Lee et al., 2002). However, duration of the antecedent dry period and level of storm intensity may also be significant drivers of contaminant concentrations (Pitt et al., 1995; Gupta & Saul, 1996). Other drivers that govern concentrations include duration of the rainfall event, level of surface imperviousness, pollutant availability or distribution due to local activities, and the nature of the contaminant in question (Bannerman et al., 1993; Pitt et al., 1995, Gupta & Saul, 1996; Mulliss et al., 1996; Bertrand-Krajewski et al., 1998; Paul & Meyer, 2001).

The impacts of stormwater drainage on urban rivers are numerous, synergistic, and extensive. As Booth et al. (2004, p. 1352) notes, "stream degradation results from a collection of individual decisions and actions that lead to specific urban landscapes and, in turn, to altered stream conditions." The resulting degradation culminates in reduced recreational, educational, and cultural ecosystem benefits. River restoration projects are often undertaken to address such losses, a process represented by ‘J’ in Figure 2.2, however those that focus only on in-stream and riparian conditions are insufficient for long-term results, because they do not match the scale of environmental and societal drivers (Lewis et al., 1996; Booth et al., 2004; Walsh et al., 2005b; Burns et al., 2012). Further, it requires additional resources to manage poor water quality, stream stability, impaired ecosystem services, and to maintain drainage infrastructure itself (Burns et al., 2012). A catchment-wide perspective of urban rivers paired with an environmentally focused approach to urban drainage, may be able to successfully address these issues.

2.4.2 Societal Linkages

Humans are dominant forces in the urban landscapes and are an inextricable driver of urban ecological change (Vitousek et al., 1997). Human actions associated with the urbanization process have unintended consequences for biophysical conditions. As depicted in Figure 2.4, management decisions and technologies, used to address population growth and resource consumption, ultimately generate direct and indirect effects on urban waterways (Booth et al., 2004). However, urbanization itself does not cause degradation; instead, it is the human approach to urbanization that alters the landscape in ways that produce a cascade of effects (*ibid*).

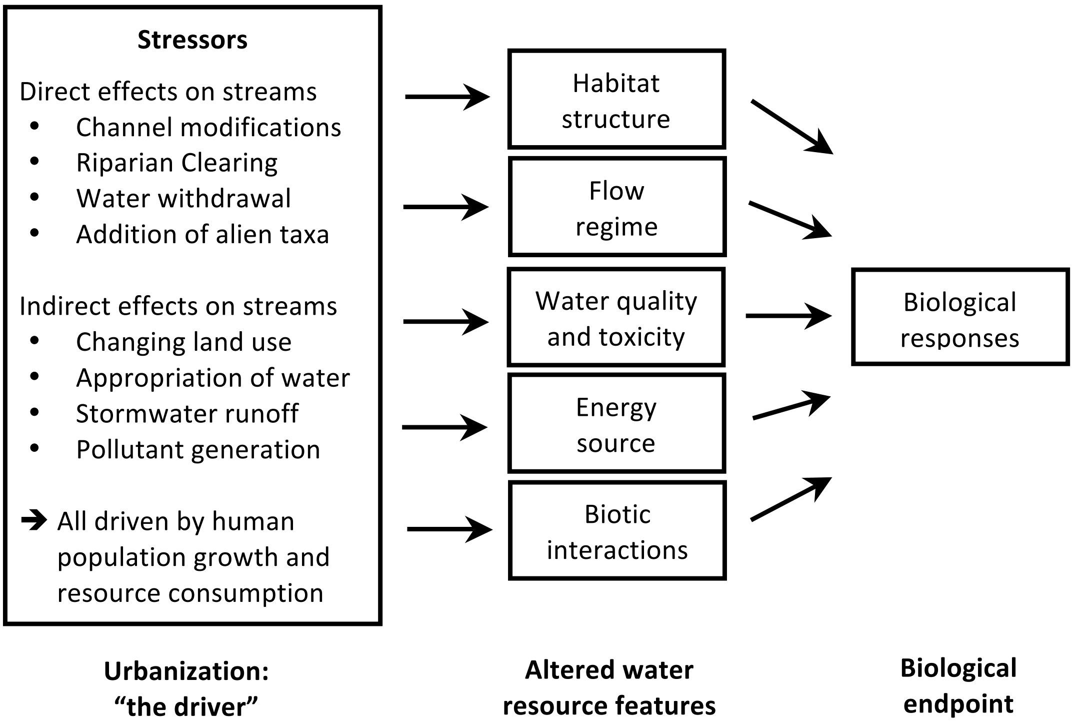

Figure 2.4: Human decision-making as a driver of aquatic ecological change (Booth et al., 2004).

The current state of a city is the result of myriad interactions between the biophysical environment and a range of human actors, including households, businesses, developers and planners, and government institutions (Collins et al., 2011). Human behaviour is inherently linked to stressors on ecological systems, thus, societal patterns and processes must be included in research on urban systems to generate more applicable results and facilitate enhanced sustainability implications (Picket et al., 1997; Walsh et al., 2005a).

According to Grimm et al. (2000), ecological patterns and processes are better studied than their social counterparts in the Urban Ecology model (Figure 1.1). Societal patterns and processes represent the outcome of multiple fundamental social drivers, including the local and regional socioeconomic system, culture, education, demography, and social institutions, all of which influence human interaction with, and perception of, the natural environment (*ibid.*). In the Urban Ecology model, the fundamental drivers of the human components in the urban ecosystem are: (1) the flow on information and knowledge, (2) incorporation of culturally based values and perceptions, and (3) creation and maintenance of institutions and perceptions (Grimm et al., 2000).

Citizens and decision-makers can use the Urban Ecology model as a tool with which to make predictions and generate socially and ecologically sound policies (Grimm et al., 2000). However, a comprehensive approach to understanding how these fundamental social drivers generate current societal patterns and processes requires examination of the demographic pattern, economic system, power hierarchy, land use and management, and the designed environment, each of which is characterised by its own activities, structure, and historic trajectory (Pickett et al., 1997; Grimm et al., 2000). While this scale of inquiry is beyond the scope of this thesis, it will ultimately be required for application of the Urban Ecology model in moving toward a more sustainable urban drainage approach.

The Hydro-Social Contract

The literature identifies a city's approach to water management as its 'hydro-social contract', a term which describes the common values and implicit agreements between the community and government (Lundqvist et al., 2001). Brown et al. (2009) succinctly describe the contract as being shaped by dominant perspectives and historically embedded water values, expressed through institutions and regulations, and physically represented through water systems infrastructure. In turn, each of these social structures influences the development and implementation of water management practices, as well as how the available technology is used (*ibid*). This hydro-social contract sets the stage for the current societal context and its associated patterns and processes, including the constraints on land use, decision-making, and management approaches: process 'B' in Figure 2.2.

Every city develops in its own unique way and at its own pace. However, many cities follow a specific continuum of development with regard to its water resources. According to Brown et al. (2009), there are six transition states in this continuum: the Water Supply City, the Sewered City, the Drained City, the Waterways City, the Water Cycle City, and the Water Sensitive City (Figure 2.5). Progression along the continuum is the result of cumulative societal and environmental transitions that evolve the hydro-social contract. While the stages are distinct, they are not mutually exclusive for different aspects of the urban water cycle, because urban water management consists of multiple components, and a given city may exist in more than one state. Further, each of these states has specific socio-political drivers (normative and regulative dimensions) and service delivery functions (cognitive response), shaping the societal context within which stormwater management decisions are made. Arguably, with its extensive conventional water infrastructure and a progressive set of policies, South African cities exist near the 'Drained City' state while striving to push toward the 'Waterways City' in Figure 2.5.

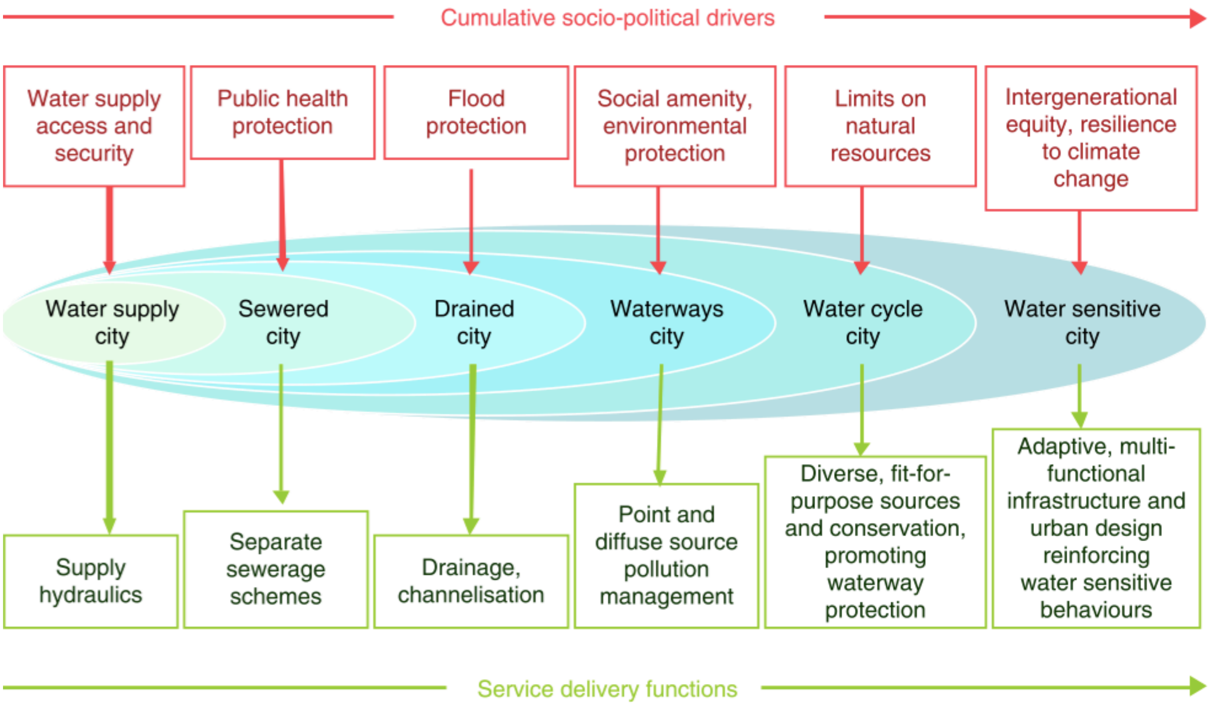

Figure 2.5: Drivers and transition states along the continuum of urban water services delivery (Brown et al., 2009).

Institutional Factors

According to Scott (1995), institutions are comprised of three mutually reinforcing pillars that sculpt societal patterns and processes: (1) normative – community values, needs, and leadership; (2) cognitive – dominant knowledge, thinking, and skills; and (3) regulative –

administration, rules and systems of operation. The current societal context and its institutional influences on stormwater management can be described in terms of how these three components fit together.

In most developed cities worldwide, stormwater has historically been perceived as a hazard and a nuisance that needs to be removed quickly and at low cost (Wong & Eadie, 2000; Brown, 2005; Brown et al., 2009). This early-stage normative context (associated with states up until the 'Drained City') does not account for environmental services and linkages, leading to pollution of water resources, and reflecting a perspective that the environment is a lower priority than economic and public health needs (Brown et al., 2009).

The cognitive faculties used to address these needs were shaped over centuries of engineering practice to inform design and management (Brown et al., 2009), combined with knowledge on the local environmental context such as rainfall and runoff volumes. Conventional technological solutions were engineered to control runoff hazards by simplifying complex systems of catchment hydrology into manageable forms (Brown et al., 2009; Butler & Davies, 2011; Burns et al., 2012): process 'B' in Figure 2.2. In the 'Drained City', communities expect engineers to provide reliable infrastructure to protect against floods, and the municipality to manage and maintain it for continued public safety benefits (Brown et al., 2009): process 'D'. The preoccupation with managing flood risk encourages the use of infrastructure that removes runoff to avoid accumulation, with little or no attenuation for receiving waterways, and allowing stormwater to be largely forgotten once removed from land surfaces (Arnold & Gibbons, 1996; Brown et al., 2009; Burns et al., 2012). It also engenders a situation where disaster management prevails as the community and political regulative priority (Brown et al., 2009).

More progressive normative values, associated with the 'Waterways City', recognize urban waterways as providing valuable ecosystem services and important aesthetic, recreational, and cultural features (Brown et al., 2009). Cognitive measures are then taken to protect these resources and reduce pollution (*ibid*). Researchers and practitioners develop technologies based on available knowledge and skills, such as wetlands, litter traps, and biofiltration systems to protect waterways against stormwater pollution; these actions can be placed as process ‘K’ in Figure 2.2. Use of these tools requires regulative components, such as policies, design guidelines, planning systems, and management approaches, which influence the success or failure of these systems, and their impacts on aquatic ecosystems (Roy et al., 2008; Butler & Davies, 2011): process ‘F’.

In South Africa, the NWA reflects a normative perspective that values environmental resources, more closely aligned with the socio-political drivers of the ‘Waterways City’ (Glazewski, 2005; Brown et al., 2009). Urban runoff is recognized as a major water quality problem (Glazewski, 2005), and the national government is responsible for balancing ecological and societal needs, ensuring that water resources are utilized and managed in a sustainable way. Municipalities are responsible for delivering and maintaining stormwater systems, however, because their regulative framework is focused on engineering standards, with little focus on sustainability (Haskins, 2012), stormwater management continues to function in accordance with the ‘Drained City’ approach.

When stormwater management maintains a conventional cognitive and/or regulative approach, it runs the risk of functioning “as a low-priority, expert-driven and subservient technical activity to road building” (Brown, 2005, p. 464). Figure 2.6 depicts how, under this type of technocratic approach to water management, municipal institutions of Australia have silo structures and are functionally divided (Brown, 2005). Such municipal division is not uncommon and inhibits the trans-disciplinary collaboration necessary for holistic and sustainable environmental management (Brown, 2005; Brown et al., 2009). Executed by engineers operating under the relevant regulatory body, stormwater management is dissociated from the larger urban water cycle, with little opportunity to integrate ecological balances and move toward sustainability. In practice, stormwater continues to be managed as a nuisance and a hazard, rather than a resource adding to the amenity of a landscape, as would be the case in a ‘Waterways City’.

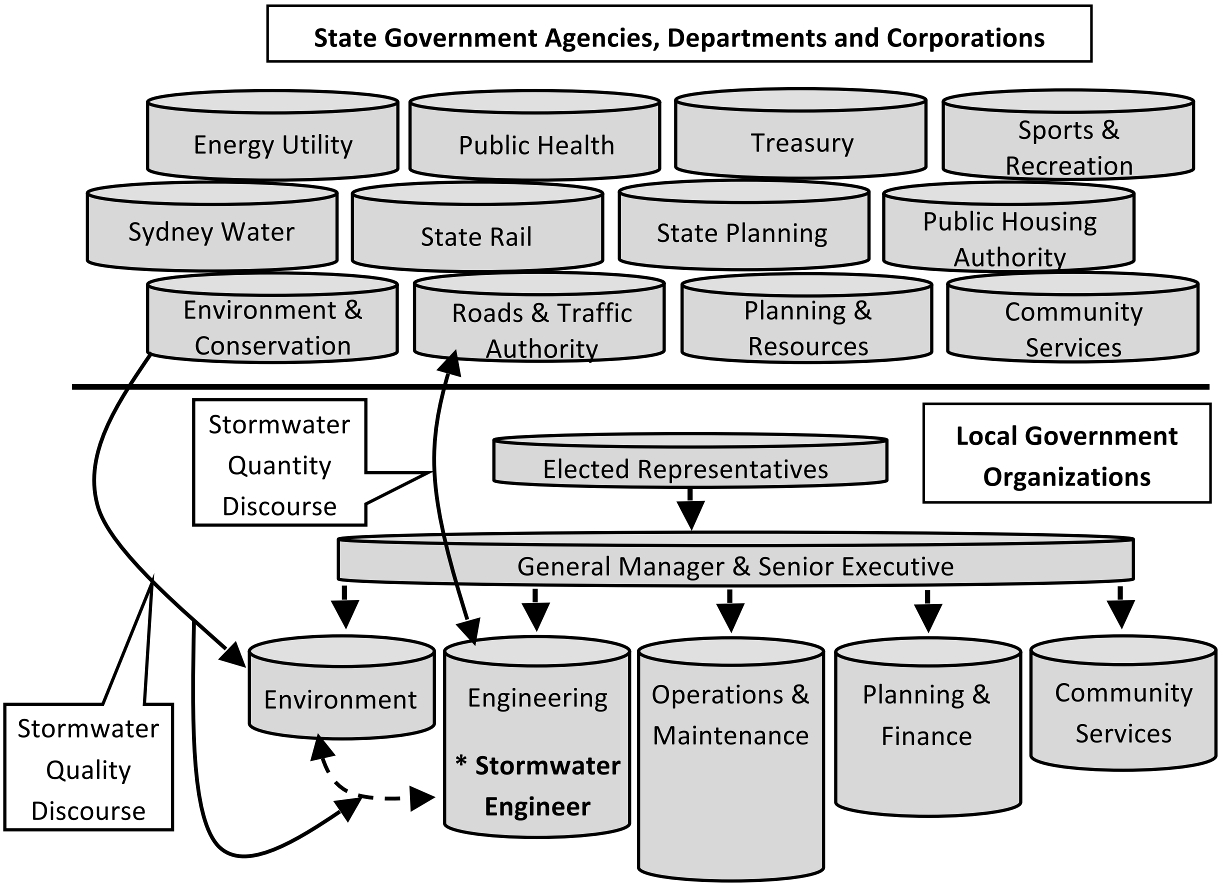

Figure 2.6: A simple representation of typical divisions in municipal functions and relationships to stormwater management (Brown, 2005)

Public Factors

In addition to institutions, culture, the learned patterns of behaviour, is a central component in societal linkages that influence urban ecosystems. Knowledge and resources, and community values, beliefs and needs influence an individual’s activities (Grimm et al., 2000). Thus, norms of behaviour, or culturally acceptable activities, are determined at the merger of normative and cognitive societal components.

Poor stormwater quality and degraded urban waterways result from a collection of individual choices and actions, with cumulative effects on the urban river. While individuals may not have significant control over drainage design, management practices, and pollution policies, their actions are of considerable significance for urban ecological conditions (Morton et al., 1988; Bannerman et al., 1993; Booth et al., 2004).

A multitude of behaviours and decisions impact urban rivers, such as landscaping activities, construction practices, and solid waste and wastewater disposal (i.e. Pitt et al., 1995; Armitage & Rooseboom, 2000; Paul & Meyer, 2001; Booth et al., 2004; Dietz & Clausen, 2008). For example, fertilizers applied in residential gardens are easily transported via runoff and contribute to significantly elevated nutrient loading in streams (Bannerman et al., 1993), especially when coupled with excessive watering (Morton et al., 1988). Research has found that pesticides in urban streams exceed guideline standards, and are even observed at higher concentrations than in agricultural areas (Paul & Meyer, 2001). These societal activities directly influence ecological patterns and processes via linkage 'K' in Figure 2.2. In addition, landscaping decisions influence stormwater infiltration capacity, soil erosion, and garden debris volumes entering the drainage system (Pitt et al., 1995; Armitage & Rooseboom, 2000; Booth et al., 2004), with impacts on the conventional drainage infrastructure, its design, and management (linkage 'B').

Human behaviour exhibits a broad range of variability (Booth et al., 2004), and is unquestionably linked to a web of interacting factors, such as socio-economic conditions, personal values, education, and awareness. For example, economic conditions impact the provision of basic services; insufficient sanitation and waste removal can lead people to use waterways as a substitute, hindering drainage efficiency, and increasing the level of environmental degradation (Armitage & Rooseboom, 2000; Butler & Davies, 2011; Winter & Mgese, 2011). In South Africa, stormwater runoff from dense informal settlements, where basic sanitation and refuse services are lacking, is known for elevated pathogens and pollutants (Jagals, 1997; Davies & Day, 1998; Paulse et al., 2009).

Adding further complexity, there may be many actors with variable influences on a residential drainage system and receiving waterway. Commuters, pedestrians, residential workers, construction crews, and municipal employees (*inter alia*), may visit a location intermittently over space and time. Each actor has their own effects on the drainage system and receiving waterway, depending on their specific behaviours and practices. Unfortunately these public behaviour aspects of societal linkages are rarely a focal topic in research on urban stormwater systems.

Awareness

Urban dwellers often consider nature as existing outside, or separate from, the urban landscape, and lack an understanding or appreciation of urban ecosystems (Kong et al., 1999; Berghoefer et al., 2010). The largely concealed infrastructure of conventional urban development creates tangible and intangible barriers between people and nature, resulting in urban communities that are disconnected from urban aquatic ecosystems and watershed dynamics (Selman et al., 2010; Stokman, 2008). It is therefore to be expected that urban residents will have a limited understanding of their downstream impacts on biophysical processes and water quality (Wong & Eadie, 2000; Stokman, 2008). This obscures the ability of the public to react to undesirable conditions by adapting their attitudes and behaviours. A disassociation with nature predisposes people to prioritizing development goals over conservation needs (Kong et al., 1999). As a result, problems of poor water quality, degraded urban rivers, and clogging and flooding of drainage infrastructure persist.

Similar to the 'flush and forget' problem of conventional sewerage, conventional stormwater technology is hidden underground, reinforcing the conventional (cognitive) belief that stormwater is not a useful resource, and perpetuating a societal context with an 'out of sight, out of mind' perspective (Arnold & Gibbons, 1996; Wong & Eadie, 2000; Butler & Davies, 2011). The public, then, is also inclined to disregard the value and significance of urban stormwater because the way in which a water resource is presented influences the public perception of these water systems (Berghoefer et al., 2010; Selman et al., 2010). Individuals are frequently unaware of the ecological impacts of their own actions, which result from pollutants deposited into the stormwater system (Norris & Burgin, 2009). When urban residents do not fully grasp the connection between actions and impacts, or are not provided with other options, drainage systems and waterways become a convenient conduit for the deliberate or unintentional discharge of polluted urban effluent (Dietz et al., 2004; Brown et al., 2009; Winter & Mgese, 2011).

Stormwater management is described as a 'policy without publics': a situation where community and interest groups have limited interest, leaving the political, technical, and scientific community to regulate the policy agenda (Morison & Brown, 2011). Arguably, community perspectives and values play a pivotal role in developing the hydro-social contract, and these factors can have significant influence on the decision-making process. For example, stormwater quality problems are often more salient in communities which have economic or quality of life interests in the health of local water bodies, such as those near coastlines or rivers with special recreational or economic value (White & Boswell, 2006; Morison & Brown, 2011). Outside of these special circumstances, public awareness of drainage issues may be limited, resulting in minimal community involvement.

Public education can lead to positive behaviour changes and increase community support for environmental improvement initiatives (Dietz et al., 2004; White & Boswell, 2006; Wagner, 2008). Therefore, increasing awareness enables the public to react to changing or undesirable ecological conditions, thereby enabling processes 'E' and 'G' in Figure 2.2, and facilitating societal adaptation and evolution through process 'H' (Pickett et al., 1997; Grimm et al., 2000). However, these connections are poorly understood in the urban stormwater systems of developing countries, such as South Africa. A poor understanding of these interactions and feedbacks will inhibit the ability to adapt to changing conditions and needs (Grimm et al., 2000; Alberti et al., 2008), and South Africa's ability to implement and comply with the sustainability mandates of the Constitution and NWA.

2.5 Current Shifts in Stormwater Management

The international community is gradually shifting towards more holistic management of the urban water cycle, and progress has been made in developing more sustainable drainage approaches (e.g. Wong, 2006; Brown et al., 2009; Butler & Davies, 2011). In contrast to the technical approach of conventional stormwater, these new techniques involve the integration of technical and societal mechanisms influencing drainage management and its ecological implications. Sustainable Urban Drainage Systems (SUDS), Water Sensitive Urban Design (WSUD), and Low-Impact Design (LID) are among a growing list of acronyms, all of which describe a collection of drainage techniques that utilize, enhance, and/or mimic natural hydrologic patterns by using stormwater as a resource to enhance ecosystem services. Fundamentally both a philosophy and technique, these approaches generally involve an assemblage of structural (hard) and non-structural (soft) mechanisms.

Structural SUDS techniques act on the ecological and biophysical linkages interacting in the urban ecosystem. With tools that alter catchment imperviousness and facilitate storage, infiltration, nutrient absorption, and evapo-transpiration, SUDS reduce the quantity and improve the quality of runoff (Wong & Eadie, 2000; Wong, 2006). The array of mechanisms employed in a SUDS project may include (*inter alia*) permeable pavement, rain gardens, vegetated swales and filter strips, infiltration systems, constructed wetlands, bio-retention systems, and enhanced riparian buffers and floodplains (*ibid*). Structural mechanisms are often used in a sequential 'treatment chain', as determined by local conditions (Charlesworth et al., 2003; Butler & Davies, 2011). The small-scale, decentralized nature of SUDS tools means they can effectively be used in residential lots to manage stormwater and its pollutants (Konrad & Burges, 2001; Mongard, 2002; Charlesworth et al., 2003).

Non-structural SUDS mechanisms focus on societal linkages and are incorporated to enhance the success of structural approaches. These 'soft' mechanisms aim to change societal perspectives and activities so as to reduce the generation of runoff and pollutants that would otherwise enter the drainage system (Rauch et al., 2005). In addition, they facilitate an adaptive approach to institutional patterns and processes, and the overall cognitive and regulative framework (Pahl-Wostl et al., 2007). Working at the interface between the public and drainage technology, approaches include public education, adaptive management, and broad integration and trans-disciplinarity of the decision-making processes (Rauch et al., 2005). Public participation and stakeholder engagement are increasingly advocated in the SUDS literature and allow responsibility to shift toward the community and individual, away from end-of-pipe technocratic solutions. These processes also generate awareness and foster change in social expectations and behaviours, often increasing public support for sustainable approaches (Rauch et al., 2005).

While progress has been made in sustainable urban drainage, full realization still faces many challenges (Wong & Eadie, 2000; Wong, 2006). Although SUDS techniques are supported by a breadth of research (e.g. Mongard, 2002; Charlesworth et al., 2003; Wong, 2006), the regulative and cognitive institutional structures are not fully developed (Brown, 2005; Roy et al., 2008). The techniques are highly context-specific and lack detailed standards and guidelines, which generates uncertainty over their ability to provide the services of conventional infrastructure (*ibid*). Other major impediments include a lack of institutional capacity, lack of legislative mandate, fragmented institutional responsibilities, and resistance to change (Roy et al., 2008), all of which are fundamentally social issues. In addition, while some research has been done (e.g. Mongard, 2002), most SUDS literature focuses on green field developments and largely overlooks the difficult, but vitally important, retrofitting of already developed areas (Mitchell, 2005).

Functional challenges aside, the international discussion on drainage infrastructure design, planning, and management points to a necessary cognitive shift towards urban sustainability. In such a revolutionary transition, changes in societal perceptions and values usually must occur before regulations evolve (Scott, 1995; Brown et al., 2009). Technological development and normative evolution engender opportunities for institutional and regulatory transformation (Brown et al., 2009). However, the fact that development of a new hydro-social contract aligned with more sustainable goals (the adapted institutional approach) requires mutually reinforcing shifts (Scott, 1995; Brown et al., 2009), is indicative of the need to understand the nexus between societal and environmental factors interacting in an urban stormwater system. Understanding these linkages will likely facilitate progress along the water management continuum in Figure 2.5, and improve SUDS implementation.

2.5.1 Cape Town's Sustainable Approach to Stormwater

In congruence with the global shift in stormwater management perspectives and South Africa's NWA mandates, the City of Cape Town has evolved its management goals and generated progressive stormwater policies. The Catchment, Stormwater, and River Management Branch (CSRM) expanded on its primary (technology-focused) functions to include a holistic conceptualization of stormwater management. In 2002 the City of Cape Town formalized its new approach using an integrated water management structure striving to balance environmental and societal needs (City of Cape Town, Transport, Roads & Stormwater Directorate, 2002). The CSRM now defines its drainage network as comprising both natural and built components and seeks to protect the range of ecosystem services provided by these systems, including storage, filtration, and buffering, and recreational, cultural and aesthetic benefits.

A by-law created in 2005 regulates activities with potential negative impacts on the development, operation, and maintenance of the holistic stormwater system (City of Cape Town, 2005), and effectively restricts any activities that pollute or alter any aspect of the drainage system without explicit permission from the council.

In 2009, two additional policies were promulgated: the Floodplain and River Corridor Management Policy, and the Management of Urban Stormwater Impacts Policy. Combined, these policies ensure that Cape Town's municipal stormwater services remain consistent with international best management practices. By including SUDS principles and techniques, the policies require that urban development, especially those in close proximity to urban waterways, are developed and managed in sustainable manner (City of Cape Town, Roads & Stormwater Department, 2009a, 2009b).

While the SUDS approach is appealing and logical in a water-stressed region, the tendencies of municipal administration are to perpetuate the conventional stormwater approach (Brown, 2005). Although pollution from urban runoff is one of the main problems for South Africa's water resources (Glazewski, 2005), local authorities are slow to implement change in ecological conditions through means of public education, policy, and regulation because they are largely overwhelmed by efforts to manage conventional stormwater infrastructure (Haskins, 2012). Many of the current challenges to the City of Cape Town are exacerbated by a lack of education and awareness on the importance of good water quality and the necessary societal processes to preserve water resources (PD Naidoo & Associates, 2010). Without reform of the institutional and societal factors that contribute to the management of the urban drainage framework, further financial investment will lead to sub-optimal outcomes and retard progress toward sustainability (PD Naidoo & Associates, 2010).

2.6 Conclusions

Conventional stormwater management is a primary driver of urban river degradation, which has generated significant interest in developing more sustainable approaches. However, progressing towards more sustainable stormwater management requires an understanding of the various environmental and societal influences and linkages that interact in the urban stormwater system. While environmental and technological interactions are relatively well understood, less attention has been given to societal feedbacks in relation to existing conventional stormwater. Societal aspirations are fundamental drivers of institutional contexts, management approaches, and responses to ecological conditions, and also have direct influences through norms of public activity. The slow progress of SUDS in a city that has a legislative mandate indicates a need for research and development in the societal, environmental, and technical nexus of stormwater management. However, the capacity for societal adaptation to changing needs, conditions, and values, hinges on awareness of social-ecological interactions and the ability of new attitudes and expectations to generate an evolved institutional context and management approach. It is argued that improved understanding of the linkages between ecological patterns and processes, or changes therein, and public attitudes and perspectives, will likely inform management decisions and facilitate progress towards sustainable stormwater management.

CHAPTER 3: RESEARCH METHODS

3.1 Study Design

This study aims to identify and explain the extent of the interactions and connections between stormwater quality and societal attitudes and behaviours in selected formal urban areas of Cape Town, South Africa. The study design incorporates two distinct research activities to examine ecological and societal components: water quality analysis and resident surveys. Research activities were conducted in two locations in the Liesbeek catchment, a sub-catchment of the Salt River in the City of Cape Town during the winter rainfall period of 2012.

Water quality analyses were used to describe the 'Ecological patterns and processes' in the Urban Ecology model (Figure 1.1 and its application in Figure 2.2), which focuses attention on the quality of stormwater generated in an urban setting. Multiple water quality parameters were collected and analysed to determine the quality of stormwater entering drainage catchpits during storm events of varying rainfall. The data was compared within and between two selected residential areas in the catchment, and against South African water quality standards. Information on the spatial layout of drainage infrastructure and impervious surfaces was collected from secondary sources in order to place the results within their physical context.

Social field studies were used to understand the 'Human perceptions and attitudes' discussed in the Urban Ecology model, which examines the knowledge and experiences of urban residents with stormwater and urban rivers. This component comprises a survey of local residents and intermittent field observations. The data were compiled to understand how residents perceive their own impacts on urban rivers and water quality, knowledge of stormwater drainage, and the successes and/or failures of the local drainage system infrastructure.

Additional information was collected from secondary sources regarding the condition of the associated urban river, thereby describing the 'Changes in ecological conditions' of the Urban Ecology model. The assumption is that the combination of this information with the data obtained during the two research activities would identify and explain the linkages operating in processes ‘E’ and ‘G’, which connect these variables discussed in Chapter 2 (Figure 2.2).

Pilot studies were conducted to test the logistics and discover any necessary adjustments to the study design.

The rest of this chapter will discuss the detailed methods used to undertake the study. The chapter outlines the project development, study areas, water quality sampling, laboratory analysis, resident surveys, and data analysis.

3.2 Project Development

3.2.1 Study Area Selection

The selected focal drainage study areas are located in the Observatory and Newlands suburbs of the City of Cape Town, Western Cape province. Both of the locations are formal urban areas dominated by residential development and infrastructure. These locations were chosen because of their varied residential development densities and impervious surface coverage, similar socio-economic and education status, the relatively low level of commuter traffic, and the close proximity and drainage connection to the Liesbeek River. Boundaries were set out to delineate the study areas in Newlands and Observatory, and all research activities (catchpit water sampling and resident surveys) were conducted within these respective boundaries.

3.2.2 Sample Catchpit Selection

Multiple individual catchpits in each study area were selected for collection of stormwater runoff samples. In order to be suitable for the study, catchpits had to fulfil certain logistical requirements (see Figure 3.1, Image A). Similarity of structural design was necessary, consisting of a removable grid covering a cavity large enough to insert a sample collection bin. In order to prevent runoff from entering the drainage system prior to reaching the collection bin, there could be no vertical inlet in the curb adjacent to or upslope of the grid and attached collection bin. Catchpits were also chosen to obtain a relatively even distribution over the study area, with approximately 30% of the total number of catchpits utilised as sample collection locations.

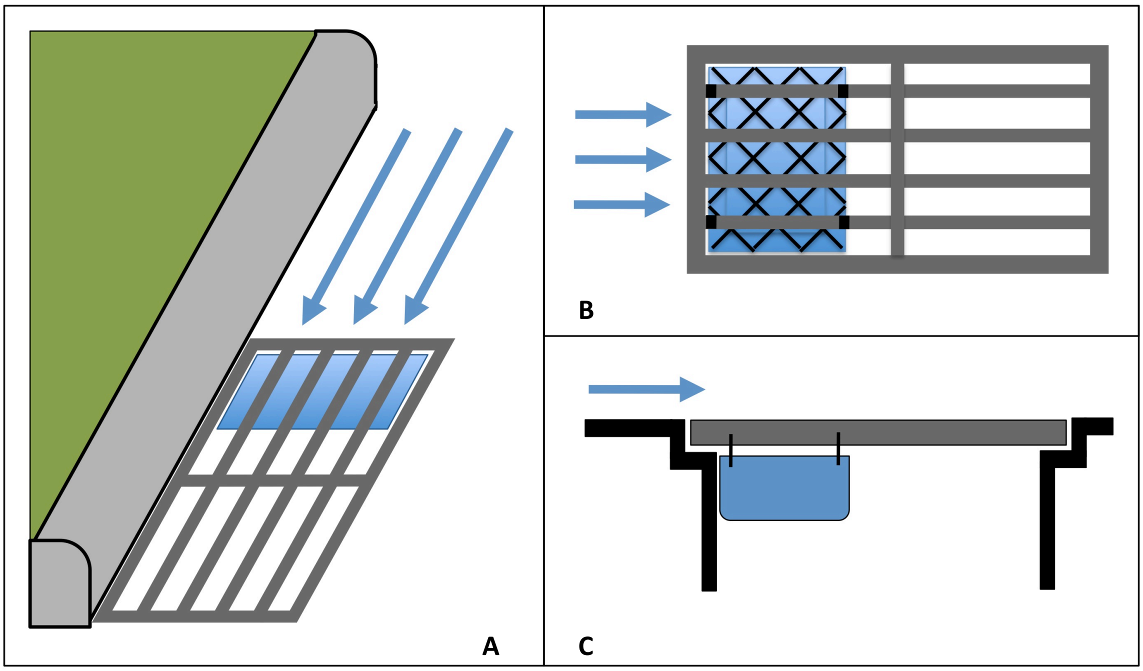

Figure 3.1: Diagram of the required catchpit sampling design. Arrows represent the direction of runoff flow into the sampling collection bin. Image A depicts the stormwater catchpit inlet alongside a typical curb in residential areas of Cape Town, with the sampling bin placed on the upslope side of the inlet. Image B depicts the collection bin, with debris screen, and the approximate size of the bin relative to the inlet grid. Image C illustrates a cross-sectional view of the sampling design, with the bin attached to the removable grid.

3.2.3 Selection of Water Quality Parameters

Water quality parameters measured in this study include: pH, temperature, total dissolved solids (TDS), and electrical conductivity (EC). These variables provided background information on the condition of the stormwater flowing into the catchpits. Although dissolved oxygen was initially included, the meter function and accuracy became impaired shortly into the study and could not be restored, thus it is not included in the results.

Selected nutrients were also examined, including orthophosphate (PO_4^{3-}), ammonia (NH_3^-), nitrate (NO_3^-), and nitrite (NO_2^-). These water quality parameters were chosen because of their relative importance as stormwater contaminants and their significance for biological and ecological processes in aquatic environments (Paul & Meyer, 2001; Cech, 2005; Butler & Davies, 2011). Bacterial indicators, hydrocarbons, and oil contaminants are also important runoff variables, however these were excluded from this thesis to narrow the scope of the study and focus attention on nutrient loading of the river system.

3.2.4 Selection of Survey Design

A survey of local residents in each study area was designed to obtain information regarding their knowledge and experience of the local stormwater drainage system. All households within the boundaries of each study area (Newlands and Observatory) were approached to take part in the survey. The survey began with questions that examined residents' views of the Liesbeek River and sources of pollution in urban waterways. Questions also investigated outdoor activity, such as the use of fertilizers and pesticides, garden irrigation, pet waste management, and car washing. The survey examined knowledge of the stormwater drainage system design and infrastructure, and any issues encountered in its function and use. In addition, questions related to the resident's willingness to play a role in system maintenance were included in order to examine whether residents currently take some responsibility for management.

3.2.5 Area Observation

Field observations were conducted throughout the study duration. This involved time spent walking and driving in the study areas documenting various activities observed, such as street cleaning, construction activities, and municipal and residential workers. These observations supplement data from resident surveys. Observations were later used to provide insight into the water quality and resident survey results.

3.2.6 Pilot Studies

Pilot studies were conducted in June 2012 for both water quality and residential survey sampling methods. Preliminary water quality studies included sample collection and analysis of water quality parameters identified above. The pilot study identified problems prior to the study sampling and improved the design of the collection bins. Piloted resident surveys were used to refine the language, order of questions, and methods of delivery, administration, and collection.

3.3 Study Areas

Two study areas were chosen in Cape Town. These areas exist within the Liesbeek sub-catchment, which falls into the Salt River Catchment. Depicted in Figure 3.2, the study areas comprise small sections of Observatory (GPS co-ordinates 33°56′16″S, 18°28′15″E) and Newlands (GPS co-ordinates 33°58′45″S, 18°27′0″E) suburbs. Both areas are characterized by a conventional drainage system in which separate pipe networks are utilised for stormwater and sewage removal. These locations are in close proximity to the Liesbeek River, where the stormwater reticulation systems discharge runoff. In some locations stormwater ingress into the sewerage system occasionally overwhelms these pipe networks, as evidenced by sewer manholes overflowing onto the street during heavy storms in both suburbs.

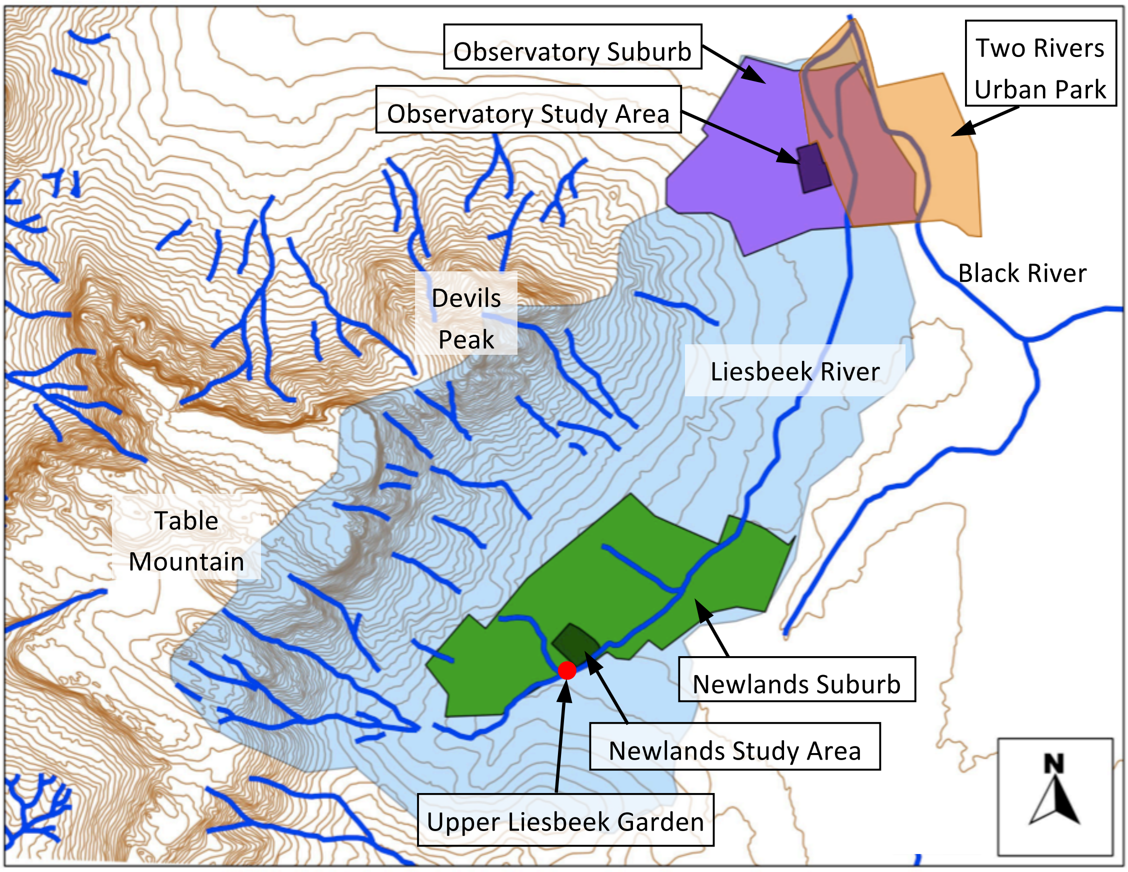

Figure 3.2: A map of Newlands and Observatory suburbs within the Liesbeek Sub-Catchment of Cape Town. The Liesbeek River originates from the tributaries flowing off Table Mountain west of Newlands and runs through Observatory, after which it joins the Black River. The study areas are show within each suburb boundary as a darker polygon.

3.3.1 The City of Cape Town

The Cape Peninsula has a Mediterranean climate with warm dry summers and mild wet winters. Average rainfall is 764 mm per annum with 56 million cubic meters of annual runoff (River Health Programme, 2005). According to a 2011 census, the population of Cape Town has grown by 29% since 2001, and currently has approximately 3.74 million people (City of Cape Town, Strategic Development Information & GIS Department, Statistics South Africa, 2012). In general the number of households is increasing at a faster rate than the population size, which increases service delivery requirements and necessitates rapid service expansion (City of Cape Town, Strategic Development Information & GIS Department, Statistics South Africa, 2012).

Land use in the Greater Cape Town region consists of urban area (17%), irrigated crops (13%), forest plantations (4%), natural vegetation (33%), and dryland crops (29%) (River Health Programme, 2005). The majority of households in urban areas are formal structures (78.4%), while 14% of households comprise informal dwellings located in informal urban settlements (City of Cape Town, Strategic Development Information & GIS Department, Statistics South Africa, 2012). Unlike formalized areas, informal settlements generally do not have formal, closed stormwater drainage systems. There has been a sizable growth of informal households located in formal backyards, estimated at 7%, an increase of 3% since 2001 (City of Cape Town, Strategic Development Information & GIS Department, Statistics South Africa, 2012). By increasing impervious area coverage, the increasing prevalence of these 'backyard dwellings' in formal settlements is placing additional pressure on the already strained stormwater drainage service capacity.

Cape Town's Stormwater Drainage

Cape Town's stormwater drainage system has grown considerably since its inception, striving to cope with an expanding urban footprint and the associated changes in catchment hydrology and runoff volumes. Like all South African cities, Cape Town utilizes the conventional structure of curbs, drainage catchpits, and underground stormwater pipe systems along the majority of paved roads. The city's current stormwater reticulation system comprises 1,500 km of rivers, streams and canals, 5,000 km of underground pipes and culverts, 300 stormwater detention ponds, 300 hectares of wetlands, and 50 hectares of estuarine areas (City of Cape Town, Transport, Roads & Stormwater Directorate, 2002).

Stormwater management falls under the CSRM branch of the City of Cape Town (see Figure 3.3). The CSRM has developed progressive policies that mandate integrated catchment management and utilization of SUDS principles (City of Cape Town, Transport, Roads & Stormwater Directorate, 2002; City of Cape Town, Roads & Stormwater Department, 2009a, 2009b), but this branch of the City falls under the directorate of the Transport, Roads and Stormwater Department and is therefore subordinate to Roads and Transport authorities. The intense institutional focus on service delivery is to the detriment of stormwater policy-making, planning, and enforcement responsibilities of the City (PD Naidoo & Associates, 2010). Thus, the sustainable management of stormwater, in this instance, is unproductive since the mandate involves removing water rapidly from roads rather than managing stormwater sustainably and using it as a resource. In addition, the city has inadequate resources to ensure compliance with stormwater management by-laws and policies, and to provide sufficient drainage services to the entire public (PD Naidoo & Associates, 2010).

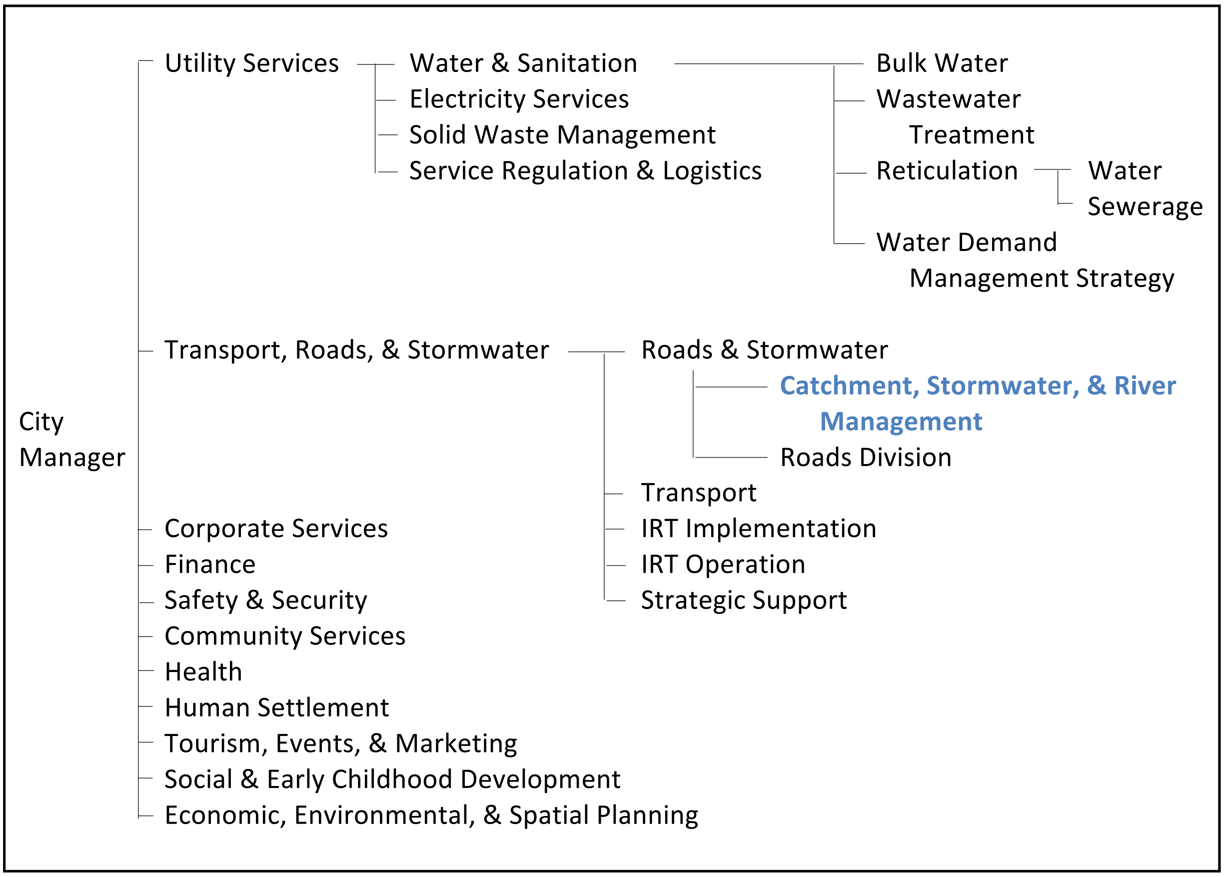

Figure 3.3: Organogram of Cape Town's municipal structure, highlighting fragmentation of water services delivery and environmental planning (City of Cape Town, Transport, Roads & Stormwater Directorate, 2002: 10; City of Cape Town, 2007: 96; City of Cape Town, 2011a: 95).

Stormwater and wastewater infrastructure is overwhelmed, malfunctioning, and poorly maintained in both formal and informal areas of Cape Town (PD Naidoo & Associates, 2010). Whether due to underinvestment or poor planning, the problem is manifesting as increased flooding and intense degradation of waterways (River Health Programme, 2005; Brown & Magoba, 2009; PD Naidoo & Associates, 2010). In response to these problems, the CSRM has adopted the Winter Readiness Programme, which aims to prevent the ingress of litter and other contaminants to the stormwater system. The programme includes proactive measures, such as stormwater pipe clearing, street debris removal, and regular inspection and monitoring of systems in critical catchment areas (Bouchard et al., 2007). A recent report by the CSRM estimated that R587.75 million is required in capital and operational expenditures to manage pollution in the city's stormwater and river systems (PD Naidoo & Associates, 2010).

Urban Rivers of Cape Town

Most of the rivers in the Central Catchment of the Greater Cape Town area transect densely populated urban areas. Consequently, Cape Town's rivers carry water of very poor quality, especially in their middle and lower reaches (River Health Programme, 2005). This is largely due to poor wastewater treatment effluent, the poor quality and high quantity of stormwater runoff, the loss of filtration abilities by reduced riparian vegetation and increased impervious surfaces, and poor litter disposal habits (River Health Programme, 2005; Brown & Magoba, 2009). Local rivers also experience problems associated with eutrophication due to agricultural runoff, residential and commercial garden runoff, septic tank leakage, and untreated human and animal waste (Brown & Magoba, 2009).

Over R20.4 million was spent in 2007 on river and wetland restoration and maintenance by various organizations in Cape Town (Brown & Magoba, 2009). Approximately two-thirds of this was allocated for problems created by urbanization and externalities generated by engineering solutions to water drainage problems (*ibid*). However, this figure is likely a gross underestimate given that funds and efforts from non-governmental organizations, schools, residents, and businesses were not taken into consideration (*ibid*).

During a period of intensive stormwater reticulation engineering, many streams and rivers in Cape Town, including the Liesbeek River, were realigned and largely canalized or piped underground (Haskins, 2012). The Liesbeek River is not entirely canalized and, compared to other local rivers, it retains the most characteristics of a natural river system. Although the water is generally unfit for contact and consumption purposes (Brown & Magoba, 2009), the Liesbeek River and its banks remain a valuable aesthetic, recreational, and educational resource for Cape Town.

3.3.2 Newlands

The Newlands suburb comprises an area of 358 hectares at the foot of Table Mountain in the southern suburbs of Cape Town, as depicted in Figure 3.2. Newlands is characterized by dense urban vegetation, primarily deciduous Poplar trees with relatively large foliage. The street sweeping services and the clearing of drainage catchpits, provided by the City of Cape Town Winter Readiness Programme, are of considerable consequence for effective stormwater management in this area. Without these services, blockage and flooding of the stormwater system may be more severe.

Newlands is a well-established upmarket area with relatively low-density residential development of 5.86 households per hectare (City of Cape Town, Strategic Development Information & GIS Department, Statistics South Africa, 2013). The suburb hosts a population of 5,100 with a density of 14.25 per hectare according to 2011 census data (City of Cape Town, Strategic Development Information & GIS Department, Statistics South Africa, 2013). Most residential development consists of formal dwellings owned by the current occupants. Newlands residents tend to have a relatively high education level and exist in the upper income brackets. (See Appendix 1 for more detailed demographic information.)

The middle segment of the Liesbeek River borders the southern edge of Newlands. As it enters the suburb, the river is un-canalized for approximately 7.3 km and becomes canalized as it flows to the suburb boundary. Water quality of the Liesbeek River in Newlands is highly variable. According to data obtained from the City of Cape Town Department of Scientific Services, between

1988 and 2003 nitrate and nitrite concentrations have generally declined, and ammonia and total phosphorous concentrations have increased (see Figure 3.4). Entering at the southern edge of the Newlands, the Liesbeek River is in very good condition, with relatively negligible modification from human impacts on habitat integrity, water quality, aquatic invertebrate diversity, riparian vegetation, and fish assemblage (River Health Programme, 2005). Further along the river, in the centre and northeast of the Newlands suburb, river health declines moderately. Riparian and in-stream habitat integrity, riparian vegetation, aquatic invertebrate diversity, and water quality in this segment decline from natural to fair condition, in which multiple disturbances are associated with the need for socio-economic development (River Health Programme, 2005). Fish assemblage in this area of the Liesbeek River remains good, with only some human-related disturbance (*ibid*).

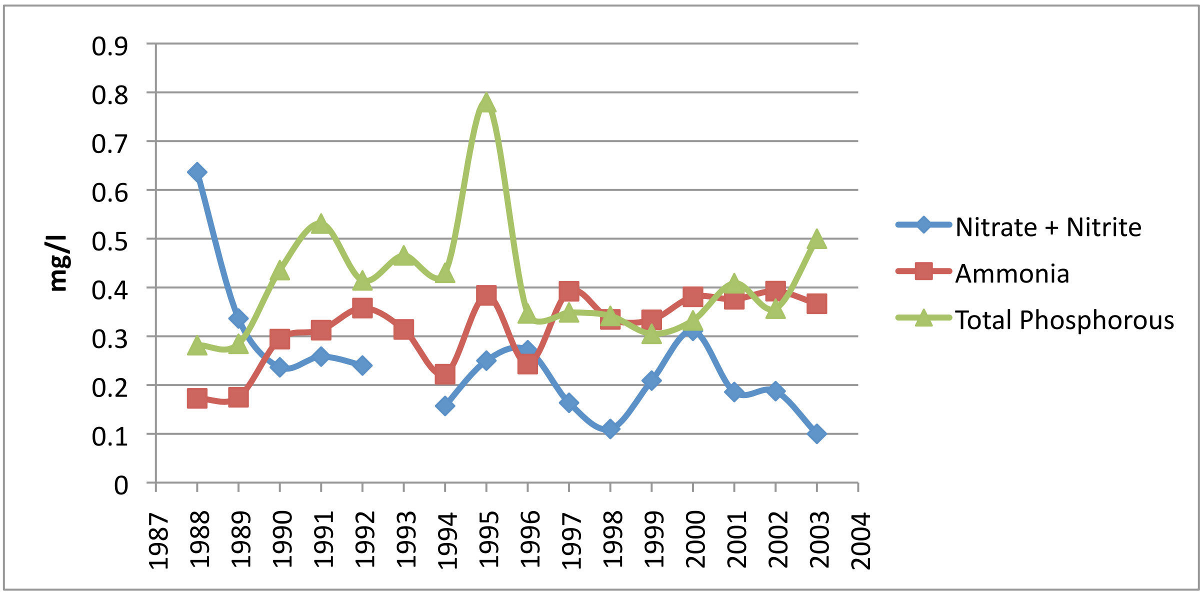

Figure 3.4: Water quality in the Liesbeek River at Paradise Road Bridge in Newlands, Cape Town. Concentrations are yearly averages and do not display seasonal or episodic fluctuations (generated from data obtained from the City of Cape Town Scientific Services Department, 2012).

There is some voluntary community involvement and interest in the Liesbeek River in Newlands. A local non-governmental organization, the Friends of the Liesbeek (FoL), maintains a walking path along this section of the River. The Fernwood Residents Association is an active group of residents in the Newlands area who (*inter alia*) encourage residents to keep the local environment clean and support the work of the FoL along the Newlands riverbanks. In addition, a grassroots initiative has resulted in the Upper Liesbeek River Garden along the Liesbeek riverbank (see Figure 3.2). This park hosts indigenous plant species and provides a recreational and educational green space.

The sub-section of Newlands selected for intensive sampling comprises an area of 10.459 hectares, containing 40 stormwater catchpits and 94 households. Within the boundaries of the study area, 42.50% of the surface area is impervious. Fourteen catchpits were located that adhered to sampling requirements and were selected for water quality sampling. During the study one of these sampling locations was removed due to a resident who was concerned about possible interruption of drainage function.

3.3.3 Observatory

The Observatory suburb comprises an area of 349 hectares at the foot of Devil's Peak, as shown in Figure 3.2. A train line runs north to south through the centre of the suburb with the Observatory Train Station near its mid-point. The suburb contains some commercial properties but is dominated by residential land use.

Observatory is an upper-mid market area with higher residential development than Newlands: 8.77 households per hectare in Observatory versus 5.68 households per hectare in Newlands (City of Cape Town, Strategic Development Information & GIS Department, Statistics South Africa, 2013). Observatory hosts a population of 9,207 with a density of 26.38 per hectare according to 2011 census data. Most residential development consists of formal dwellings and more than half of the housing is used as rental accommodation. Observatory residents tend to have a mid to high level of education and vary from low to upper income levels. (See Appendix 1 for more detailed demographic information.)

The Liesbeek River runs through the eastern section of Observatory as it approaches the confluence with the Black River (see Figure 3.2). The river is canalized throughout this stretch until it joins the larger Black River, which is also canalized. Water quality of the Liesbeek River in Observatory is highly variable. According to data obtained from the City of Cape Town Department of Scientific Services, between 1982 and 2013 nitrate and nitrite concentrations have remained relatively constant, with yearly fluctuations, and ammonia and total phosphorous concentrations have increased (see Figure 3.5). Ecological quality parameters in this stretch of the Liesbeek River vary from fair to poor (River Health Programme, 2005). Water quality, in-stream habitat integrity, and fish assemblage are generally in fair condition, with sensitive species likely lost but tolerant and opportunistic fish species remaining (*ibid*). Riparian habitat, riparian vegetation, and aquatic invertebrate diversity are in poor condition; characterized by a prevalence of alien invasion, disrupted ecosystem dynamics, and predominately tolerant invertebrate species remaining (*ibid*). From a management perspective, this decline can be associated with high human densities and/or extensive resource depletion (River Health Programme, 2005).

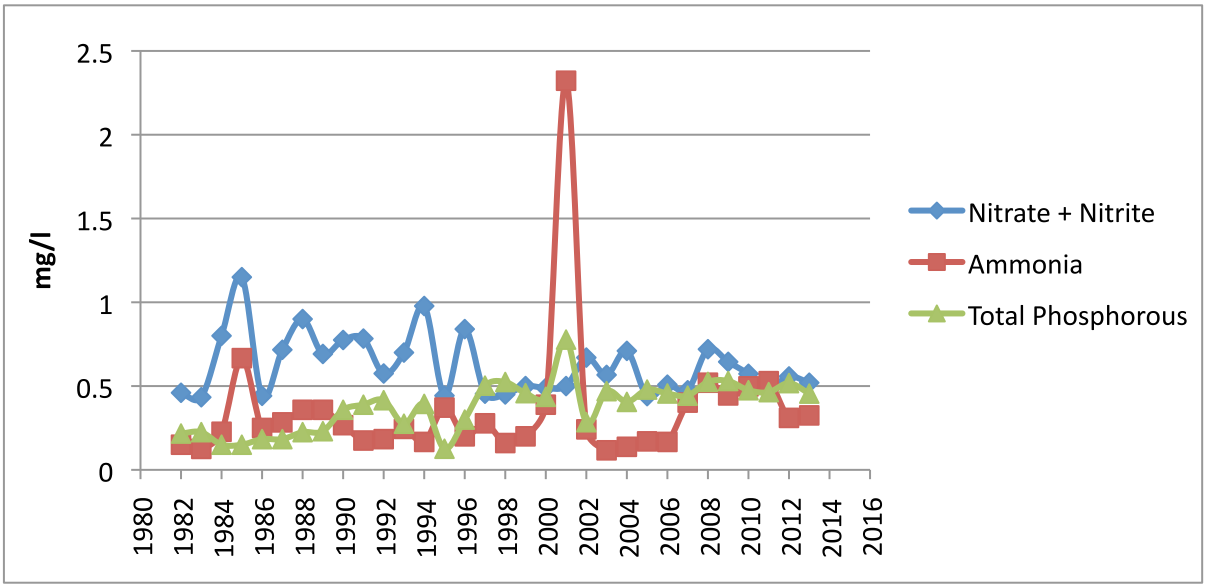

Figure 3.5: Water quality in the Liesbeek River at Hartleyvale Stadium in Observatory, Cape Town. Concentrations are yearly averages and do not display seasonal or episodic fluctuations (generated from data obtained from the City of Cape Town Scientific Services Department, 2012).

Similar to Newlands, there are community resources and investments in the Liesbeek River area of Observatory. The Two Rivers Urban Park is located at the confluence of the Liesbeek and

Black Rivers and provides green spaces and walking paths (see Figure 3.2). Within this area, the Raapenberg Bird Sanctuary protects 10 hectares of land along the Liesbeek River and adjacent to the Black River. The FoL is currently organizing an initiative to improve and maintain the quality of the river and its banks in the stretch of the Liesbeek that flows through Observatory. In addition, by choice of the residents, Observatory is labelled a Special Rating Area whereby it collects an extra monthly levy from property owners to supplement city council services. To this effect, the Observatory Improvement District (OBSID) provides services to (*inter alia*) improve street cleaning, promote public safety, and emphasize urban greening.

The sub-section of Observatory selected for intensive sampling comprised an area of 10.544 hectares, containing 38 stormwater catchpits and 272 households. Within the boundaries of the study area, 69.64% of the surface area is impervious. Twelve catchpits were located that adhered to sampling requirements and were selected for water quality sampling.

3.4 Water Quality Methods

3.4.1 Water Quality Sampling

Water quality sampling was conducted from July to October of 2012 for storm events that resulted in greater than four (> 4.0) mm of rainfall. Smaller rainfall events did not produce enough runoff for sample collection. Open sampling bins (2000 ml in volume) were installed on the upslope side of stormwater catchpits (see Figure 3.1). Water quality samples were taken from multiple catchpit inlets, rather than the more commonly used drainage outfalls where water is discharged into the river. This allowed any observed phenomenon to be connected with activities or conditions in very specific areas that drain to particular system inlet(s). This study did not examine the effects of a first flush phenomenon, and therefore did not take samples at the onset of a storm event, or incrementally throughout each storm event. Sample collection bins were allowed to overflow and flush out, with stormwater samples taken at the end of each rainfall event. The study examined a total of 25 catchpit locations in Newlands (13) and Observatory (12) over 24 storm events. Figure 3.6 shows the distribution of the selected drainage catchpits within each study area.

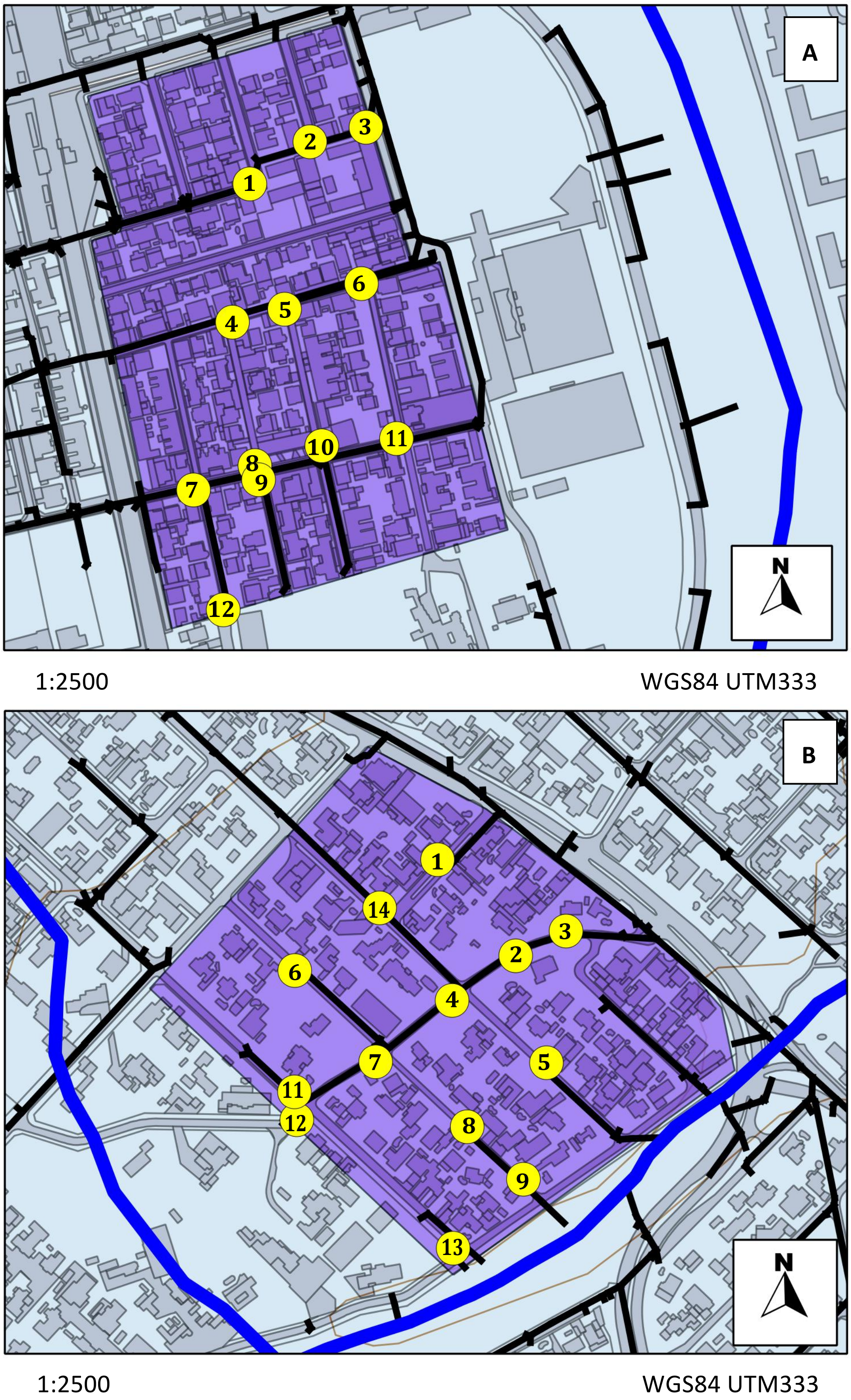

Figure 3.6: Map of the selected study areas within the Observatory (A) and Newlands (B) suburbs of Cape Town. Stormwater drainage pipes are shown as black lines and selected drainage catchpits are indicated as circles with the catchpit identification number. The Liesbeek River is shown as a thick

blue line to the east of the Observatory study area, and southeast of the Newlands study area. Image B also depicts one of the tributaries to the Liesbeek River, located west of the Newlands study area, flowing south into the Liesbeek River.

Precipitation data was collected from two locations in each study area, and was verified with weather station data from the South African Weather Service. On-site measurements of temperature (°C), pH, TDS (ppm), and EC (µS) were performed using a Martini Instruments handheld pH meter and an Eco Tester EC High hand-held meter. These variables were measured and recorded at each catchpit site. Analysis of the remaining variables was conducted at the Water Analysis Laboratory of the University of Cape Town. Samples were collected and kept in cool in a refrigerator prior to laboratory testing.

3.4.2 Laboratory Analysis

Laboratory analysis was conducted to determine concentrations of orthophosphate (PO_4^{3-}), ammonia (NH_3^-), nitrate (NO_3^-), and nitrite (NO_2^-). A DR 2700 portable spectrophotometer with pre-installed programs was used, which automatically adjusts the wavelength for individual tests upon selection. The methods for each of these processes are described below:

Orthophosphate (PO_4^{3-})

Analysis to determine orthophosphate concentrations was conducted following the PhosVer® 3 (Ascorbic Acid) Method (Hach Method 8048). The orthophosphate test (Hach Program: 535 P) was selected on the DR 2700 portable spectrophotometer, which automatically adjusted the wavelength to 880 nm.

A sample vial was filled with 10 ml of the stormwater sample and the contents of a PhosVer® 3 Reagent Powder Pillow were added. The vial was immediately stoppered and the mixture was shaken vigorously for 30 seconds, followed by a reaction time of two minutes. According to this Hach Method, orthophosphate reacted with molybdate in an acid medium to produce a mixed phosphate/molybdate complex. Ascorbic acid then reduced the complex, and the presence of orthophosphate was indicated by a blue colour developing in the mixture.

Prior to measuring each sample, the spectrophotometer was calibrated by preparing a blank control using 10 ml of the sample and excluding the PhosVer® 3 Reagent. Following the allowed reaction time, the sample was then inserted into the spectrophotometer and the concentration recorded. The resulting concentrations of orthophosphate were provided in mg/l.

Ammonia (NH_3-N)

Analysis to determine ammonia concentrations was conducted following the Nessler Method (Hach Method 8038). The Ammonia Nessler test (Hach Program: 2400 N) was selected on the DR 2700 portable spectrophotometer, which automatically adjusted the wavelength to 425 nm.

A 50 ml mixing graduated cylinder was filled with 25 ml of sample and another mixing graduated cylinder was filled with 25 ml of de-ionized water, the latter was used as the blank control for calibration. Three drops of Mineral Stabilizer were added to each cylinder, which were stoppered and inverted to mix. Three drops of Polyvinyl Alcohol Dispersing Agent were then added to each cylinder, which were stoppered and inverted to mix. Next, 1.0 ml of the Nessler Reagent was pipetted into each cylinder, which were stoppered and inverted to mix. According to this Hach Method, the Mineral Stabilizer complexes hardness in the sample. The Polyvinyl Alcohol Dispersing Agent aids with colour formation in the reaction of Nessler Reagent with ammonia ions. In the presence of ammonia, a yellow colour appears in relative proportion to the ammonia concentration.

Following the addition of the Nessler Reagent, a one-minute reaction time was allowed during which each solution was transferred into 10 ml sample vials. After the allowed minute of reaction time, the blank control was used to calibrate the spectrophotometer. The sample vials were then inserted into the spectrophotometer in quick succession and the concentrations were recorded. The resulting concentrations of ammonia were provided in mg/l.

Nitrate (NO_3^-)

Analysis to determine nitrate concentrations was conducted following the Cadmium Reduction Method (Hach Method 8039). The nitrate test (Hach Program: 355 N) was selected on the DR 2700 portable spectrophotometer, which automatically adjusted the wavelength to 500 nm.

A sample vial was filled with 10 ml of the stormwater sample and the contents of a NitriVer® 5 Reagent Powder Pillow were added. The vial was immediately stoppered and the mixture vigorously shaken for one minute, followed by a reaction time of five minutes. According to this Hach Method, cadmium metal reduced nitrates in the sample to nitrite. The nitrite ions then reacted in an acidic medium with sulfanilic acid and formed an intermediate diazonium salt. The salt coupled with gentisic acid and the presence of nitrate was indicated by an amber colour developing in the mixture.

Prior to measuring each sample, the spectrophotometer was calibrated by preparing a blank control using 10 ml of the sample and excluding the NitriVer® 5 Reagent. After the allowed reaction time, the sample was then inserted into the spectrophotometer and the concentration recorded. The resulting concentrations of nitrate were provided in mg/l.

Nitrite (NO_2^-)

Analysis to determine nitrite concentrations was conducted following the Diazotization Method (Hach Method 8507). The nitrite test (Hach Program: 371 N) was selected on the DR 2700 portable spectrophotometer, which automatically adjusted the wavelength to 507 nm.

A sample vial was filled with 10 ml of the stormwater sample and the contents of a NitriVer® 3 Reagent Powder Pillow were added. The vial was immediately stoppered and the mixture was swirled to dissolve the reagent in the sample. A reaction time of 20 minutes was allowed. According to the Hach Method, during this time the nitrite reacted with sulfanilic acid to form an intermediate diazonium salt. This salt then coupled with chromotropic acid and produced a pink colour directly proportional to the concentration of nitrite present

Prior to measuring each sample, the spectrophotometer was calibrated by preparing a blank control using 10 ml of the sample and excluding the NitriVer® 3 Reagent. The sample was then inserted into the spectrophotometer and the concentration recorded. The resulting concentrations of nitrite were provided in mg/l.

3.5 Resident Survey Methods

In July 2012 a letter was delivered to residents of both study areas (Appendix 2a,b). The intent of this letter was to explain the purpose of the research project and related activities that would follow, as well as provide an opportunity for residents to communicate their concerns. The letter informed interested residents of multiple scheduled survey dates, allowing them either to be available for these or to schedule an alternative time with the researcher.

Resident surveys began in late August 2012 and continued until early February 2013. When presented with the survey and agreeing to participate, residents were required to sign a consent form. The consent form (Appendix 2c) described the details of the research project, reiterated the researcher’s contact information given in the initial letter, and included measures to protect their privacy.

The survey (Appendix 2d) was designed for oral administration by the researcher in order to encourage a dialogue between the resident and researcher. When this was not possible, surveys were left with the resident and collected upon completion by the researcher.

3.6 Data Analysis

Multiple statistical analyses were conducted. Water quality data was examined using mixed effect regression analyses and principal component analyses. Mixed effect regressions were conducted with Stata MP version 12 (StataCorp, 2011). Mixed effect regressions were done to model the relationship of water quality variables to rainfall variables. It could thus be determined whether there was a relationship between water quality parameters and weather variation, and if this differed between the two study areas. Principal component analyses were conducted using R and R Studio version 3.0.1 (R Studio, 2012). These analyses were undertaken to examine any outlier water quality data, which would indicate ‘hot spot’ locations. Resident survey results were compiled and chi-square analyses were performed with R and R studio to examine data obtained from the resident survey. A more detailed discussion of data analyses is given in the following chapter.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Overview

In this study multiple analysis techniques were used to understand stormwater quality and resident knowledge and experience. Water quality analyses were used to describe the 'Ecological patterns and processes' in the Urban Ecology model (Figure 1.1 and its application in Figure 2.2), which focuses attention on the quality of stormwater generated in an urban setting. Mixed effect regression analysis was performed to understand the relationships between water quality variables and explanatory variables. It was expected that water quality parameters would be variably influenced by rainfall volume, duration of the antecedent dry period, location, and season. Water quality results were compared against South African Water Quality Guidelines (Appendix 3).

Principal Component Analysis (PCA) was performed on locations within the study areas to understand the relationship between water quality variables and among all of the observations from individual locations. It was expected that some locations would be depicted as outliers in PCA biplots, indicating an elevated contaminant contribution.

Resident surveys were used to understand the 'Human perceptions and attitudes' discussed in the Urban Ecology model (Figure 1.1 and its application in Figure 2.2), which examines the knowledge and experiences of urban residents with stormwater and urban rivers. Resident survey results were tabulated and chi-square analyses were conducted across questions in order to examine possible correlations between resident responses.

This study uses both quantitative and qualitative research to understand the 'Ecological patterns and processes' and 'Human perceptions and attitudes' described in the Urban Ecology model. Each is used to inform and understand the context of the other, however, they cannot be statistically compared.

4.2 Water Quality

A total of 600 water quality samples (N_T = 600) were collected throughout the sampling period, of which 312 were in the Newlands study area (N_{New} = 312) and 288 were in the Observatory study area (N_{Obs} = 288). Data collected during water quality sampling are presented in Appendix 4. Statistical analysis was used to describe the quality of water entering the drainage system in Newlands and Observatory. Descriptive statistics for the study areas, both combined and separated by area, are presented in Appendix 5.

During the sample period, a nearby resident removed the sampling equipment from one location in the Newlands study area. This resident had experienced many problems with flooding of the drain and was concerned that the sample collection bin might generate increased flooding. Newlands location 14 was added on 16 July 2012 as a replacement, and is therefore missing five of the 24 total sample events. The sample collection bin for Newlands location 5 went missing on 22 September 2012, and is therefore missing six of the 24 total sample events. In addition, equipment malfunction prevented measurement of TDS and EC on 21 July (Observatory only) and 22 July 2012 (Newlands and Observatory).

4.2.1 Mixed Effect Regression Analysis

Mixed effect regression analysis was used to model the relationship between water quality variables and the explanatory variables, including rainfall and antecedent dry weather days. This was done to determine whether these had a significant effect on the concentration of contaminants. The response variable (i.e. the pollutant concentration) was examined to determine whether it was normally distributed. When this was not the case, the data were natural log transformed before proceeding with the analysis. Mixed effect regression analysis of EC was excluded because of the close relationship between EC and TDS; it is assumed that EC follows a similar variation trend to TDS.

Mixed effect regression models were built using all subsets as there were few enough predictors and all were hypothesis led. The preferred model was determined by comparing the adjusted Aikaike's and Bayesian Information Criteria (AIC and BIC, respectively). AIC is a relative measure of the goodness of fit of a statistical model. BIC is a slightly stricter version of AIC, with a harsher penalty function and takes into account both the number of parameters and the number of observations within the data. These were used because Likelihood Ratio Tests are not suitable for mixed effect models. The same procedure was followed for each response variable, with location-specific random effects. Fixed effect variables that were considered for inclusion within the model were: antecedent dry days, rainfall, season (categorical: winter, spring), and area (categorical: Observatory, Newlands). Once the model was selected, the p-value was used to determine whether an explanatory variable was significant at the 5% or 10% level. Table 4.1 presents the variables included in regression models.

Table 4.1: Variables used in mixed effect regression equations

Representation	Variable	Explanation
D	Antecedent dry days	The number of preceding days when rainfall ≤ 4 mm in the 24 hour period
R	Centred average rainfall	Determined with 2 rain gauges per study area (mm), where the mean is 23.3 mm
S	Season	Spring versus winter, where winter is used as the baseline *
A	Area	Newlands versus Observatory, where Observatory is used as the baseline
C_x	Coefficient of variable x	Where x represents D, R, S, or A
I	Intercept	The constant when all explanatory variables are null (D, R, S, A = 0)
u_j	Random effect between locations	Where j represents the individual location: the constant random effect
e_{ij}	Random effect within location	Where i refers to observations within the location: the residual random effect
Example	$\text{Ln(dependent variable)}_{ij} = DC_D + RC_R + SC_S + AC_A + I + u_j + e_{ij}$	
* Season effects are calculated by categorising data samples between July through August as winter, and September through October as spring		

Residual analysis was undertaken to examine how well the models represented the data and whether the underlying model assumptions were met. Residual plots were generated, including histograms of the standardized residuals (used to determine whether the distributions of the standard residuals were sufficiently normal), and a plot of predicted versus standardized residual values. These diagnostic figures are presented in Appendix 6. Outliers that were determined to be influential, using the Cook's D Statistic, were removed and the mixed effect regression models were repeated on the adjusted data set.

pH

Mixed effect regression models were performed to examine the influence of variables D, R, S, and A on pH. The data included a total of 585 observations (N_{New} = 300, N_{Obs} = 285). Three outliers were removed to develop the preferred model, including observations from Newlands site 7 on 16 July, and Observatory sites 2 and 11 on 27 July and 10 September, respectively.

The preferred model is: $pH_{ij} = DC_D + RC_R + SC_S + I + u_j + e_{ij}$

This model best describes the relationship between pH and the explanatory variables, and was obtained by comparing AIC and BIC values. Table 4.2 presents the regression summary for the preferred model.

Table 4.2: Mixed effect regression summary for $pH = DC_D + RC_R + SC_S + I + u_j + e_{ij}$

Variable	Coefficient (C_x)	Std. Err.	Z	P > z	[95% Conf. Interval]	
Antecedent Dry Days (D)	-0.10	0.01	-8.39	0.000	-0.12	-0.07
Centred Average Rainfall (R)	0.01	0.00	6.73	0.000	0.01	0.01
Season (S)	0.26	0.07	3.92	0.000	0.13	0.39
Intercept (I)	8.34	0.06	145.24	0.000	8.23	8.46
AIC = 1368.863 BIC = 1395.092 df = 6						

Table 4.2 shows that:

1. There is a significant negative relationship between pH and antecedent dry weather days (p-value ≤ 0.0001, which is significant at the 5% level). According to the model, an increase of 1 antecedent dry day will result in a corresponding decrease in pH by 0.1 units.
2. There is a significant positive relationship between pH and average rainfall (p-value ≤ 0.0001, which is significant at the 5% level). According to the model, an increase of 1 mm rainfall will result in a corresponding increase in pH level of 0.01 units.
3. pH levels are significantly higher in spring than in winter (p-value ≤ 0.0001, which is significant at the 5% level). During spring months, pH levels are generally 26% higher than during winter months.
4. When all explanatory variables are null (i.e. D = 0 and R = 0), the average pH level in winter is 8.34.

The model diagnostics (residual analysis, Appendix 6a) showed that the assumptions for the preferred model were valid because the distribution of standard residuals is adequately normal. Furthermore, the plot of predicted values versus residual scores indicates a random scatter and thus homogeneity of residuals. An independent covariance structure was assumed for the random effects (Table 4.3), which allows for a distinct variance for each random effect within a random effects equation and assumes that all covariance are equal to zero.

Table 4.3: Random effects, estimates of variability for $pH = DC_D + RC_R + SC_S + I + u_j + e_{ij}$

Random-Effects Parameters	Estimate	Std. Err.	[95% Confidence Interval]	
sd(u_j)	0.17	0.04	0.11	0.28
sd(e_{ij})	0.68	0.02	0.64	0.72

Total Dissolved Solids (TDS)

Mixed effect regression models were performed to examine the influence of variables D, R, S, and A. The data were natural log transformed with a total of 551 observations (N_{New} = 287, N_{Obs} =

264). Two outliers were removed to develop the preferred model, including Observatory sites 2 and 11 on 27 July and 10 September, respectively.

The preferred model is: $\text{Ln(TDS)} = DC_D + RC_R + I + u_j + e_{ij}$

This model best describes the relationship between TDS and the explanatory variables, and was obtained by comparing AIC and BIC values. Table 4.4 presents the regression summary for the preferred model.

Table 4.4: Mixed effect regression summary for $\text{Ln(TDS)} = DC_D + RC_R + I + u_j + e_{ij}$

Variable	**Coefficient (C_x)**	**Exponentiated Coefficient (e^{Cx})**	**Std. Err.**	**Z**	**P > z**	**[95% Conf. Interval]**	
Antecedent Dry Days (D)	0.06	1.0618	0.01	7.46	0.000	0.04	0.08
Centred Average Rainfall (R)	-0.01	0.99	0.00	-5.36	0.000	-0.01	0.00
Intercept (I)	4.00	54.5982	0.06	66.60	0.000	3.88	4.12
AIC = 891.3387 BIC = 912.7873 df = 5							

Table 4.4 shows that:

1. There is a significant positive relationship between TDS and antecedent dry days (p-value ≤ 0.0001, which is significant at the 5% level). According to the model, an increase of 1 antecedent dry weather day will result in a corresponding 6.18% increase in TDS.
2. There is a significant negative relationship between TDS and average rainfall (p-value ≤ 0.0001, which is significant at the 5% level). According to the model, an increase of 1 mm rainfall will result in a 1% decrease in TDS.
3. When all explanatory variables are excluded (i.e. D = 0 and R = 0), the average TDS is 54.5982 ppm in winter.

The model diagnostics (residual analysis, Appendix 6b) showed that the assumptions for the preferred model were valid because the distribution of standard residuals is adequately normal. Furthermore, the plot of predicted values versus residual scores indicates a random scatter and thus homogeneity of residuals. An independent covariance structure was assumed for the random effects (Table 4.5), which allows for a distinct variance for each random effect within a random effects equation and assumes that all covariance are equal to zero.

Table 4.5: Random effects, estimates of variability for Ln(TDS) = $DC_D + RC_R + I + u_j + e_{ij}$

Random-Effects Parameters	Estimate	Std. Err.	[95% Confidence Interval]	
sd(u_j)	0.24	1.2712	0.04	0.18
sd(e_{ij})	0.50	1.6487	0.02	0.47

Orthophosphate (PO_4^{3-})

Mixed effect regression models were performed to examine the influence of variables D, R, S, and A on orthophosphate. The data were natural log transformed with a total of 582 observations (N_{New} = 298, N_{Obs} = 284). No outliers were removed.

The preferred model is: $Ln(PO_4^{3-}) = DC_D + RC_R + SC_S + I + u_j + e_{ij}$

This model best describes the relationship between orthophosphate and the explanatory variables, and was obtained by comparing AIC and BIC values. Table 4.6 presents the regression summary for the preferred model.

Table 4.6: Mixed effect regression summary for $Ln(PO_4^{3-}) = DC_D + RC_R + SC_S + I + u_j + e_{ij}$

Variable	Coefficient (C_x)	Exponentiated Coefficient (e^{Cx})	Std. Err.	Z	P > z	[95% Conf. Interval]	
Antecedent Dry Days (D)	0.08	1.0833	0.02	5.23	0.000	0.05	0.12
Centred Average Rainfall (R)	-0.01	0.99	0.00	-3.61	0.000	-0.01	0.00
Season (S)	0.64	1.8965	0.09	6.88	0.000	0.46	0.82
Intercept (I)	-1.279	0.2783	0.16	-7.97	0.000	-1.59	-0.96
AIC = 1678.248 BIC = 1704.426 df = 6							

Table 4.6 shows that:

1. There is a significant positive relationship between orthophosphate and antecedent dry weather days (p-value ≤ 0.0001, which is significant at the 5% level). According to the model, an increase of 1 antecedent dry day will result in a corresponding 8.33% increase in orthophosphate concentration.

2. There is a significant negative relationship between orthophosphate and average rainfall (p-value ≤ 0.0001, which is significant at the 5% level). According to the model, an increase of 1 mm rainfall is associated with a 1% decrease in orthophosphate concentration
3. Orthophosphate concentrations are significantly higher in spring than in winter (p-value ≤ 0.0001, which is significant at the 5% level). During spring months, orthophosphate levels are 89.65% higher than in winter months.
4. When all other explanatory variables are excluded (i.e. D = 0 and R = 0), the average orthophosphate concentration in winter is 0.2783 mg/l.

The model diagnostics (residual analysis, Appendix 6c) showed that the assumptions for the preferred model were valid because the distribution of standard residuals is adequately normal. Furthermore, the plot of predicted values versus residual scores indicates a random scatter and thus homogeneity of residuals. An independent covariance structure was assumed for random effects (Table 4.7), which allows for a distinct variance for each random effect within a random effects equation and assumes that all covariance are equal to zero.

Table 4.7: Random effects, estimates of variability for $Ln(PO_4^{3-}) = DC_D + RC_R + SC_S + I + u_j + e_{ij}$

Random-Effects Parameters	**Estimate**	**Std. Err.**	**[95% Confidence Interval]**	
Sd(u_j)	0.74	0.11	0.55	0.99
sd(e_{ij})	0.96	0.03	0.91	1.02

Ammonia (NH_3-N)

Mixed effect regression models were performed to examine the influence of variables D, R, S, and A on ammonia concentration. The data were natural log transformed with a total of 582 observations ($N_{New} = 298$, $N_{Obs} = 284$). No outliers were removed.

The preferred model is: $Ln(NH_3\text{-}N) = DC_D + RC_R + SC_S + I + u_j + e_{ij}$

This model best describes the relationship between Ammonia and the explanatory variables, and was obtained by comparing AIC and BIC values. Table 4.8 below presents the regression summary for the preferred model.

Table 4.8: Mixed effect regression summary for $\mathrm{Ln}(NH_3\text{-}N) = DC_D + RC_R + SC_S + I + u_j + e_{ij}$

Variable	Coefficient (C_x)	Exponentiated Coefficient (e^{Cx})	Std. Err.	Z	P > z	[95% Conf. Interval]	
Antecedent Dry Days (D)	0.10	1.1052	0.01	7.22	0.000	0.07	0.13
Centred Average Rainfall (R)	-0.01	0.99	0.00	-4.12	0.000	-0.01	0.00
Season (S)	0.38	1.4623	0.08	4.66	0.000	0.22	0.54
Intercept (I)	-1.424	0.2408	0.11	-13.08	0.000	-1.64	-1.21
AIC = 1525.558 BIC = 1551.756 df = 6							

Table 4.8 shows that:

1. There is a significant positive relationship between ammonia and antecedent dry days (p-value ≤ 0.0001, which is significant at the 5% level). According to the model, an increase of 1 antecedent dry days results in a corresponding 10.52% increase in ammonia concentration.
2. There is a significant negative relationship between ammonia and average rainfall (p-value ≤ 0.0001, which is significant at the 5% level). For an incremental increase in average rainfall, the ammonia concentration decreases by 1%.
3. Ammonia levels are significantly higher in spring than in winter (p-value ≤ 0.0001, which is significant at the 5% level). During spring months, ammonia concentrations are 46.23% higher than in winter months.
4. When all explanatory variables are null (i.e. D = 0 and R = 0), the average ammonia level in winter in 0.2408 mg/l.

The model diagnostics (residual analysis, Appendix 6d) showed that the assumptions for the preferred model were valid because the distribution of standard residuals is adequately normal. Furthermore, the plot of predicted values versus residual scores indicates a random scatter and thus homogeneity of residuals. An independent covariance structure was assumed for random effects (Table 4.9), which allows for a distinct variance for each random effect within a random effects equation and assumes that all covariance are equal to zero.

Table 4.9: Random effects, estimates of variability for $Ln(NH_3\text{-}N) = DC_D + RC_R + SC_S + I + u_j + e_{ij}$

Random-Effects Parameters	**Estimate**	**Std. Err.**	**[95% Confidence Interval]**	
sd(u_j)	0.46	1.5841	0.08	0.34
sd(e_{ij})	0.85	2.3396	0.03	0.80

Nitrate (NO_3^-)

Mixed effect regression models were performed to examine the influence of variables D, R, S, and A on nitrate. The data were natural log transformed with a total of 581 observations (N_{New} = 298, N_{Obs} = 283). No outliers were removed.

The preferred model is: $Ln(NO_3^-) = AC_A + I + u_j + e_{ij}$

This model best describes the relationship between nitrate and the explanatory variables, and was obtained by comparing AIC and BIC values. Table 4.10 below presents the regression summary for the preferred model.

Table 4.10: Mixed effect regression summary for $Ln(NO_3^-) = AC_A + I + u_j + e_{ij}$

Variable	**Coefficient (C_x)**	**Exponentiated Coefficient (e^{Cx})**	**Std. Err.**	**Z**	**P > z**	**[95% Conf. Interval]**	
Area (A)	-0.17	0.8437	0.07	-2.34	0.020	-0.31	-0.03
Intercept (I)	-0.68	0.5066	0.05	-13.22	0.000	-0.79	-0.58
AIC = 1106.241 BIC = 1123.429 df = 4							

Table 4.10 shows that:

1. Nitrate levels are lower in Newlands than in Observatory (p-value = 0.020, which is significant at the 5% level). Nitrate concentrations are 15.63% lower in Newlands than in Observatory.
2. The average nitrate concentration is 0.5066 mg/l.

The model diagnostics (residual analysis, Appendix 6e) showed that the assumptions for the preferred model were valid because the distribution of standard residuals is adequately normal. Furthermore, the plot of predicted values versus residual scores indicates a random scatter and thus homogeneity of residuals. An independent covariance structure was assumed for random effects (Table 4.11), which allows for a distinct variance for each random effect within a random effects equation and assumes that all covariance are equal to zero.

Table 4.11: Random effects, estimates of variability for $(NO_3^-) = AC_A + I + u_j + e_{ij}$

Random-Effects Parameters	**Estimate**	**Std. Err.**	**[95% Confidence Interval]**	
sd(u_j)	0.11	0.04	0.05	0.23
sd(e_{ij})	0.66	0.02	0.62	0.70

Nitrite (NO_2^-)

Mixed effect regression models were performed to examine the influence of variables D, R, S, and A on nitrite. The data were natural log transformed with a total of 581 observations (N_{New} = 298, N_{Obs} = 283). No outliers were removed.

The preferred model is: $Ln(NO_2^-) = DC_D + RC_R + SC_S + I + u_j + e_{ij}$

This model best describes the relationship between nitrite and the explanatory variables, and was obtained by comparing AIC and BIC values. Table 4.12 below presents the regression summary for the preferred model.

Table 4.12: Mixed effect regression summary for $Ln(NO_2^-) = DC_D + RC_R + SC_S + I + u_j + e_{ij}$

Variable	**Coefficient (C_x)**	**Exponentiated Coefficient (e^{Cx})**	**Std. Err.**	**Z**	**P > z**	**[95% Conf. Interval]**	
Antecedent Dry Days (D)	-0.04	0.9608	0.02	-1.80	0.072	-0.07	0.00
Centred Average Rainfall (R)	-0.01	0.99	0.00	-4.37	0.000	-0.02	-0.01
Season (S)	0.32	1.3771	0.11	2.77	0.006	0.09	0.54
Intercept (I)	-4.936	0.0072	0.18	-42.20	0.000	-5.17	-4.71
AIC = 1774.21 BIC = 1800.091 df = 6							

Table 4.12 shows that:

1. There is a negative relationship between nitrite and antecedent dry days (p-value = 0.072, significant at the 10% level but not at the 5% level). According to the model, an increase of 1 antecedent dry day is associated with a corresponding decrease in nitrite concentration of 3.92%.
2. There is a significant negative relationship between nitrite and average rainfall (p-value ≤ 0.0001, significant at the 5% level). According to the model, an increase of 1 mm rainfall is associated with a decrease in nitrite concentration of 1%.
3. Nitrite levels are significantly higher in spring than in winter (p-value = 0.006, significant at the 5% level). Nitrite concentrations are 37.71% higher in spring months than in winter months.
4. When all explanatory variables are excluded (i.e. D = 0 and R = 0), the average nitrite concentration in winter is 0.0072 mg/l.

The model diagnostics (residual analysis, Appendix 6f) showed that the assumptions for the preferred model were valid because the distribution of standard residuals is adequately normal. Furthermore, the plot of predicted values versus residual scores indicates a random scatter and thus homogeneity of residuals. However, the model becomes imprecise for larger values of the response variable, with increasing levels of variability and increasing prevalence of outliers. An independent covariance structure was assumed for random effects (Table 4.13), which allows for a distinct variance for each random effect within a random effects equation and assumes that all covariance are equal to zero.

Table 4.13: Random effects, estimates of variability for $Ln(NO_2^-) = DC_D + RC_R + SC_S + I + u_j + e_{ij}$

Random-Effects Parameters	Estimate	Std. Err.	[95% Confidence Interval]	
sd(u_j)	0.43	0.08	0.30	0.62
sd(e_{ij})	1.16	0.04	1.09	1.23

4.2.2 Principal Component Analysis

PCA was used to model the interrelationships between the different water quality variables across sampling locations. All of the data used were continuous and split by sampling location, with one PCA run per study area. Missing values were made to equal zero and parameters were weighted.

Newlands

PCA of water quality variables in Newlands required seven principal components. Table 4.14 shows that the water quality variables (pH, TDS, EC, orthophosphate, ammonia, nitrate, and nitrite) are not highly correlated because five principal components are required to account for more than 90% of the variation.

Table 4.14: Newlands PCA results

	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Standard Deviation	1.747	1.2727	1.0643	0.8107	0.55081	0.47669	0.0846
Proportion of Variance	0.436	0.2314	0.1618	0.0939	0.04334	0.03246	0.00102
Cumulative Proportion	0.436	0.6674	0.8293	0.9232	0.96652	0.99898	1

The biplot of PCA for Newlands locations is presented in Figure 4.1. Principal component rotations for the Newlands biplot can be found in Appendix 7a. The PCA biplot of Newlands sampling locations shows that most observations for the different locations cluster together with a low weighted average of all water quality parameters. However, some locations repeatedly exist outside of the cluster, including locations 1 and 14. Newlands location 1 appears to repeatedly display high observations of pH, nitrate, and nitrite, as well as mid-level concentrations of ammonia, TDS, and orthophosphate. Newlands location 14 appears to repeatedly show mid- to high levels of ammonia, TDS, and orthophosphate.

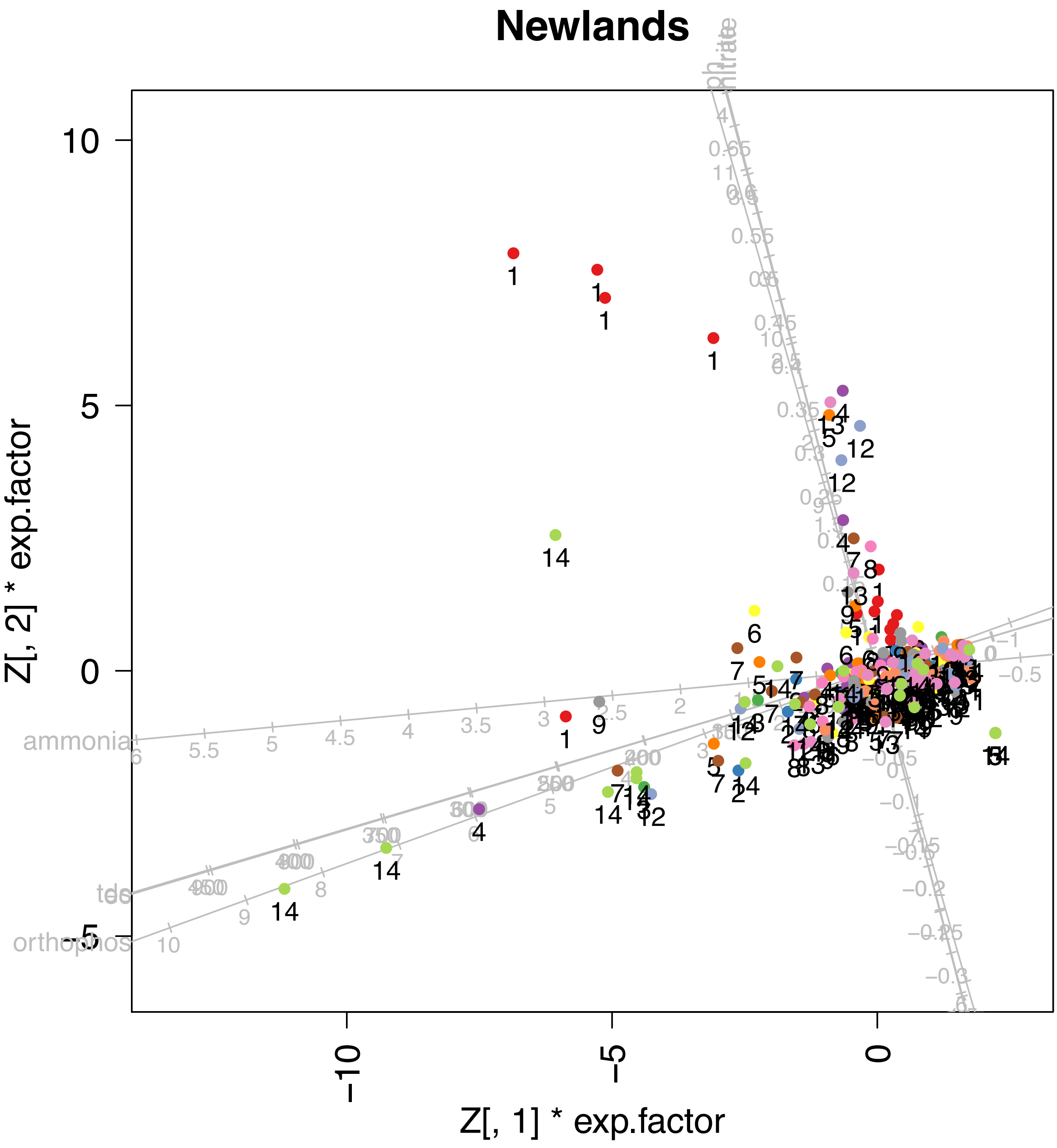

Figure 4.1: Newlands PCA biplot. Colours differentiate between locations, which are indicated by sampling location number. Points of the same location (colour, number) represent different sampling observations.

Observatory

PCA of water quality variables in Observatory required seven principal components. Table 4.15 shows that the water quality variables (pH, TDS, EC, orthophosphate, ammonia, nitrate, and nitrite) are not highly correlated because five principal components are required to account for more than 90% of the variation.

Table 4.15: Observatory PCA results

	PC1	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**	**PC7**
Standard Deviation	1.5488	1.1901	1.0172	0.9882	0.79411	0.73639	0.02652
Proportion of Variance	0.3427	0.2023	0.1478	0.1395	0.09009	0.07747	0.0001
Cumulative Proportion	0.3427	0.545	0.6928	0.8323	0.92243	0.9999	1

The biplot of PCA for Observatory locations is presented in Figure 4.2. Principal component rotations for the Observatory biplot can be found in Appendix 7b. The PCA biplot of Observatory sampling locations shows that most observations for the different locations cluster together with a low weighted average of all water quality parameters. However, some locations repeatedly exist outside of the cluster, including locations 2, 7, 11, and 12. Observatory location 2 shows one instance of high orthophosphate, nitrate, and nitrite, with a mid-level concentration of ammonia, and another instance of high TDS and ammonia, with mid-level concentrations of orthophosphate, nitrate and nitrite. Observatory location 7 shows two observations of mid or high orthophosphate, nitrate and nitrite with mid-level ammonia concentrations. Observatory locations 11 and 12 show multiple observations wherein the water quality parameters are elevated, generally with mid-level concentrations of TDS, orthophosphate, and ammonia.

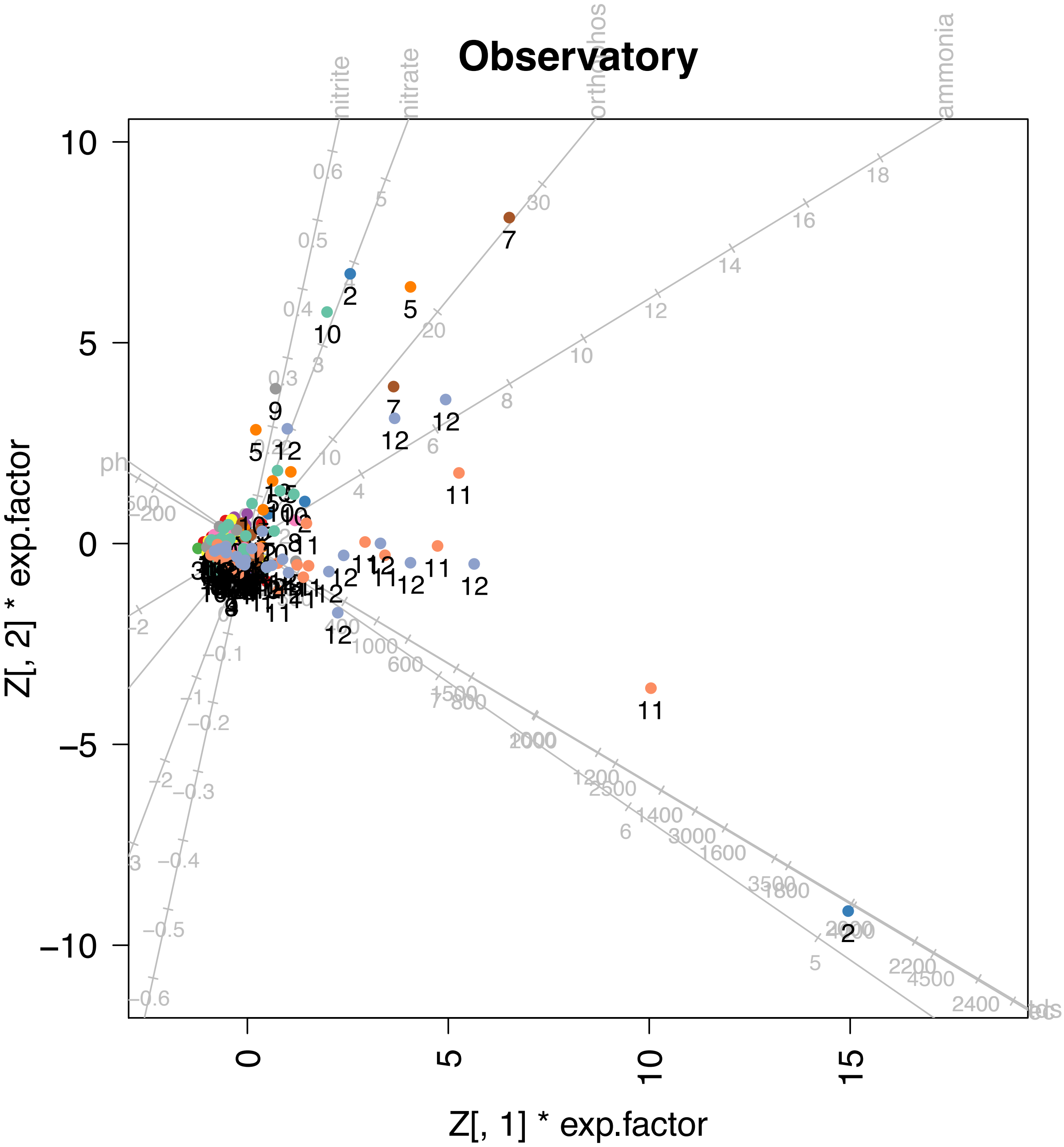

Figure 4.2: Observatory PCA biplot. Colours differentiate between locations, which are indicated by sampling location number. Points of the same location (colour, number) represent different sampling observations.

Although definitively identifying a location as a ‘hotspot’ is beyond the scope of this thesis, these data suggest that some locations contribute higher proportions of contaminants than other locations. Furthermore, an individual location may contribute elevated proportions of one contaminant but not others. The variation between locations may be the result of either continuously elevated concentrations, or episodic peaks in contaminants. This spatial and temporal variation is likely due to differences in both environmental conditions (such as the size of the drained area, surface imperviousness, vegetation cover, and climatic conditions) and human activity within the drained area (Bannerman et al., 1993; Pitt et al., 1995; Paul & Meyer, 2001; Butler & Davies, 2011).

4.3 Resident Survey

During the survey period of August 2012 through February 2013, a total of 366 households were approached, comprising all 94 households in the Newlands study area and all 272 households in the Observatory study area (see Appendix 8a). Of these, 27 households declined to participate (Newlands = 10, Observatory = 17), 96 could not be reached (i.e. there was no doorbell, post box, or other method of contact; Newlands = 6, Observatory = 90), and 175 gave no response (Newlands = 46, Observatory = 129).

The participation rate was 18.58% (Newlands = 34.04%, Observatory = 13.24%), cumulating in a total of 68 completed surveys ($N_T = 68$), of which 32 were from the Newlands study area ($N_N = 32$) and 36 were from the Observatory study area ($N_O = 36$). Discussions with residents revealed that the participation rate was hindered by social conditions whereby residents rarely answer their door for unexpected solicitors due to the high occurrence of beggars approaching houses to ask for food, clothing, and/or money. In Newlands 53.125% of surveys were conducted in person, and in Observatory 50.0% were conducted in person; the remaining surveys were completed by the resident after discussing the research project and survey questions with the researcher.

Most respondents had lived at their current address for at least two years (86.76%), and over half (54.41%) had been at their current address for six years or more. Although a few surveys were incomplete, all valid responses from the 68 administered surveys were included in the final analysis.

4.3.1 Results and Chi-Square Analysis

In this section, only the results that are most relevant to the argument of this thesis are presented. A table containing the full results of the resident survey is presented in Appendix 8b. Although this appendix shows data from the individual study areas, as well as the combined results, comparisons between Newlands and Observatory resident responses are beyond the scope of this thesis.

Chi-square analysis was performed on survey responses to determine if a correlation existed between the answers of residents to multiple questions. Because over 450 analyses were performed, only those which inform the central argument of this thesis are presented below.

Environmental Relationship and Perspective

The majority of respondents (75%) use the Liesbeek River walking paths at least monthly, with 25% of these visiting the areas daily. The remaining 25% of respondents never or rarely visit the river. As depicted in Figure 4.3, most Newlands residents consider the local sections of the Liesbeek River to be in very good (43.75%) or good condition (46.88%). However, Observatory residents reported the local area of the river to be slightly lower in quality: good (30.56%), neutral (36.11%), poor (25%), and very poor (5.56%) condition.

When asked about their level of concern for the ecological health of the river, 83.82% expressed a positive level of concern (Newlands: 81.26%; Observatory: 86.12%), including 51.47% who expressed strong concern (Newlands: 46.88%; Observatory: 55.56%), while 16.17% felt neutral or did not feel concerned (Newlands: 18.75%; Observatory: 13.89%). Level of concern for the river was not significantly correlated with frequency of visits to the Liesbeek River or with resident perspective of river conditions.

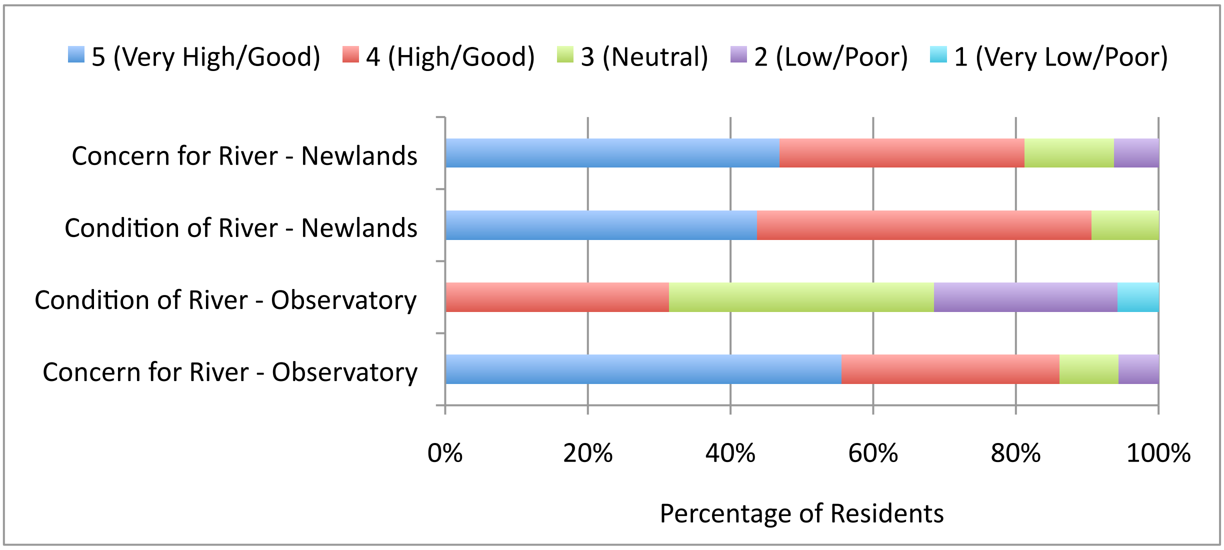

Figure 4.3: Resident perspective of the ecological health and their concern for the Liesbeek River

Residents were asked who they consider to be primarily responsible for local pollution of the Liesbeek River. Presented in Figure 4.4, responses for contributors in the top five and top three groups follow a comparable pattern. Those most commonly categorised in the top three contributors responsible for local river pollution include vagrants (i.e. homeless individuals; 69.12%), non-residents (i.e. commuters and pedestrians; 52.94%), and construction practices (50%). Less frequently cited groups include residents (29.41%), industrial practices (19.12%), and commercial properties (16.18%). It was expected that the latter two groups would be cited infrequently because industrial sites do not exist in close proximity to the study areas and only a few commercial properties exist within the suburbs.

The groups most frequently cited as primarily responsible for local river pollution include vagrants (36.76%) and construction practices (22.06%), followed by non-residents (13.24%) and industrial practices (13.24%). Only 10.29% of respondents consider local residents to be primarily responsible for local river pollution.

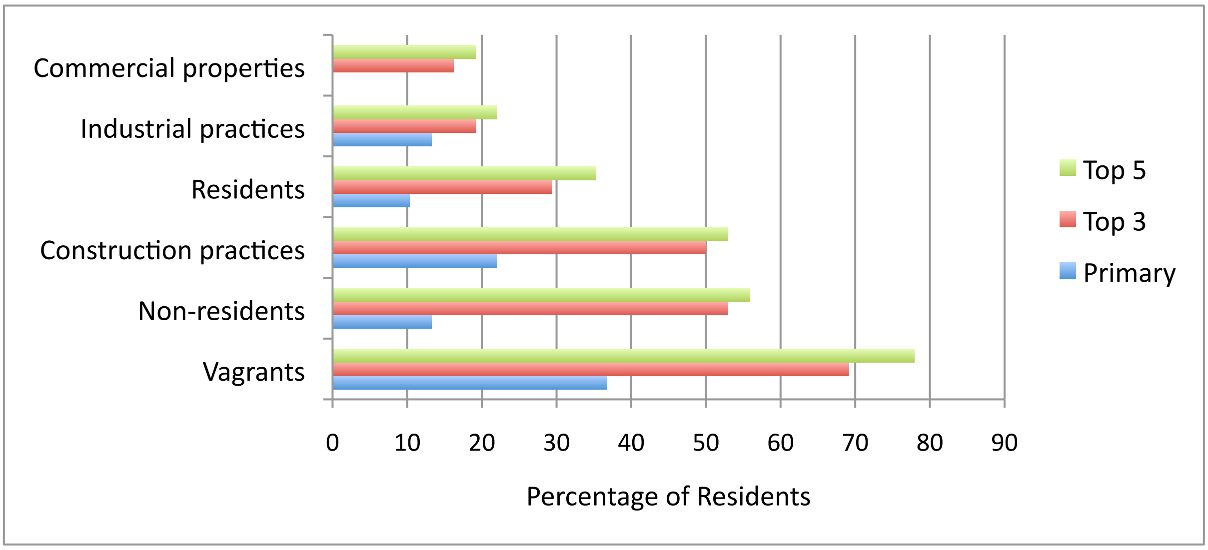

Figure 4.4: Resident perspective of groups responsible for local river pollution, indicating the percentage of residents that consider a party to be the primary responsible group and among the top three and five responsible groups

Resident perspective of contributors to local river pollution was significantly correlated with length of residence (X^2 = 9.5940, $p_{Fischers}$ = 0.039, $p_{1\text{-sided Fischers}}$ = 0.017, p = 0.048, significant at the 5% level). Residents that had lived in the area longer were more likely to include vagrants in the top five groups responsible for local pollution (see Appendix 9a).

Resident perspective of contributors to local river pollution was also significantly correlated with frequency of visiting the Liesbeek River. Residents that visit the river more frequently were more likely to include vagrants in the top five groups (X^2 = 5.8285, $p_{Fischers}$ = 0.022, p = 0.016, significant at the 5% level, see Appendix 9b). Similarly, residents that frequent the river were more likely to include non-residents in the top five (X^2 = 2.5064, $p_{Fischers}$ = 0.142, $p_{1\text{-sided Fischers}}$ = 0.091, p = 0.113, see Appendix 9c) and top three groups responsible for local river pollution (X^2 = 2.7131, $p_{Fischers}$ = 0.141, $p_{1\text{-sided Fischers}}$ = 0.080, p = 0.100, see Appendix 9d**)**.

Residents were given a list of potential pollution sources and asked to rank the top factors contributing to local river pollution. Figure 4.5 shows that those ranked as the top five and top three factors follow a similar pattern. Factors most frequently categorised in the top three causes include litter and rubbish (unintentional or small scale; 88.24%), illegal dumping (intentional or large scale; 69.12%), and building and construction waste (42.65%). Less frequently included in the top three causes are riverbank erosion (26.47%), sewage or inadequate sewerage (23.53%), garden waste/runoff (19.12%), domestic animals (11.76%) and impacts from cars (10.29%). Litter and rubbish was most frequently cited as the primary cause of local river pollution (58.82%), followed by illegal dumping (16.18%) and building and construction waste (11.76%). Each of the remaining categories was cited as the primary cause by less than 5% of respondents.

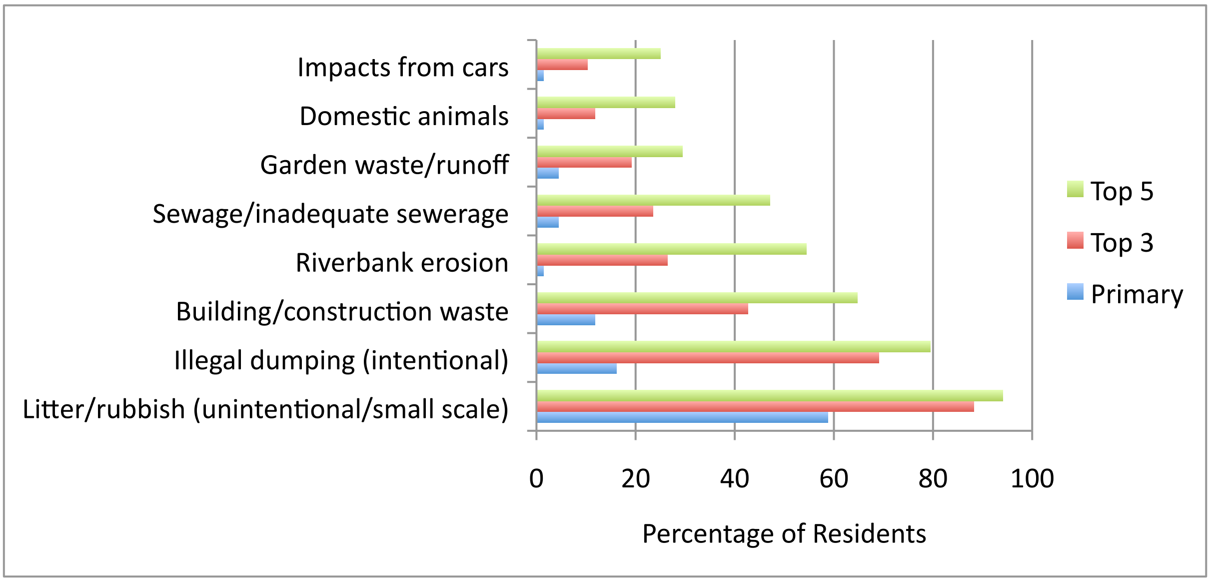

Figure 4.5: Resident perspective of the main causes of local river pollution, indicating the percentage of residents that consider the factor to be the primary cause and within the top three and five contributing causes.

Resident perspective of the causes of local river pollution was significantly correlated with frequency of visiting the Liesbeek River. Residents that visit the river more frequently were more likely to include building and construction waste in the top five causes ($X^2 = 7.3697$, $p_{Fischers} = 0.011$, $p_{1\text{-sided Fischers}} = 0.007$, $p = 0.007$, significant at the 5% level, see Appendix 9e).

There was no significant correlation between resident perspective of primary causes of local river pollution and length of residence.

Only 47.37% of respondents that consider residential garden waste/runoff to be among the top five causes of local pollution also believe that residents are among the top five groups responsible for local pollution.

Understanding of the Stormwater System

Nearly all residents (91.18%) knew that the stormwater system is separate from the sewerage system. The majority of residents understood that water entering the stormwater drainage system is designed to discharge directly to a local river (72.06%), however, 10.29% were unsure of where runoff went, 8.82% believed that it is delivered to a wastewater treatment plant, and 8.82% believed it is discharged directly into the ocean.

The majority of respondents consider it unacceptable to use stormwater drains for anything other than rainwater (70.59%), and only 1.47% considers the stormwater system to be an acceptable disposal mechanism for any materials. The remaining residents believed that as long as the material is "non-toxic" or "not a pollutant", it could be disposed of via the stormwater system (27.94%).

Knowledge of the stormwater system design was significantly correlated to resident knowledge of acceptable materials for stormwater drains. Respondents that recognize that stormwater drains discharge directly to a local river more frequently answered that no materials other than stormwater should be directed to the stormwater system ($X^2 = 15.7890$, $p_{\text{Fischers}} = 0.045$, $p = 0.015$, significant at the 5% level, see Appendix 9f).

Figure 4.6 depicts the water sources that respondents believe contribute to the Liesbeek River. The majority of residents recognized that water entering the Liesbeek River is generated by surface runoff from natural landscapes (97.06%) and street runoff (91.18%). Fewer considered sources to include runoff from residential gardens (67.65%), and roofs and paved surfaces (64.71%). Less than half believe sources to include water from pool backwashing (41.18%), vehicle washing runoff (33.82%), wastewater treatment effluent (16.18%), water from washing machines (10.29%), or kitchen and bathroom plumbing (8.82%).

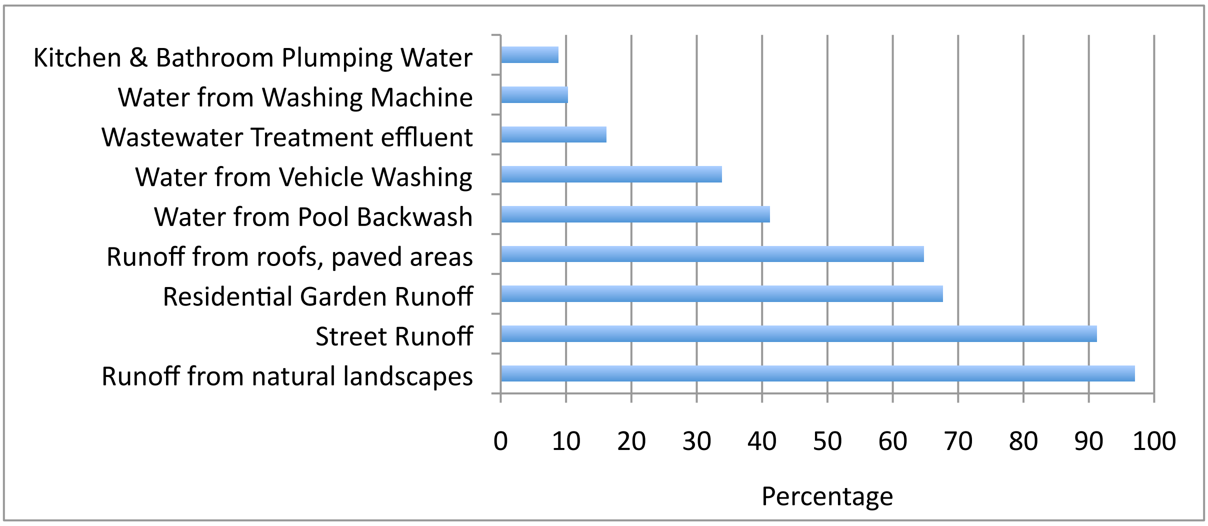

Figure 4.6: Resident perspective of water sources for the Liesbeek River

Residents that recognise street runoff as a source of water to the Liesbeek River, were more likely to recognise the potential contribution of water from car washing (X^2 = 3.3634, p_{Fischers} = 0.089, $p_{\text{1-sided Fischers}}$ = 0.074, p = 0.067, significant at the 10% level, see Appendix 9g).

Respondents that recognize residential garden runoff as contributing water to the Liesbeek River were more likely to include residents in the top five groups responsible for local river pollution (X^2 = 5.4502, p_{Fischers} = 0.026, $p_{\text{1-sided Fischers}}$ = 0.017, p = 0.020, significant at the 5% level, see Appendix 9h).

The majority of respondents believe stormwater management is primarily the responsibility of the local municipality (95.59%), although 33.82% considered that residents or property owners hold secondary responsibility as well. When asked if the respondents knew who to contact for problems associated with stormwater drainage 36.76% were unaware of the appropriate municipal body.

Resident Activity

Most residents apply fertilizer to their lawns or gardens (72.06%), while fewer apply pesticides (29.41%). Residents more frequently apply fertilizer in the spring (69.39%) and summer (61.22%), than in winter (4.08%). There was no significant correlation between the use of fertilizers or pesticides and recognition of residential garden runoff as a source of water to the Liesbeek River. There was also no significant correlation between the use of fertilizers or pesticides and including garden waste/runoff in the top causes of local river pollution.

A large proportion of respondents wash their motor vehicles on the premises (77.94%), and 80% of them allow the vehicle wash runoff to drain into the street, while 16% allow it to drain into a garden area, and 4% direct, collect and dispose of it in the sewerage system.

Recognition of street runoff as a source of water to the Liesbeek River was significantly correlated with management of vehicle wash runoff (X^2 = 5.5027, p_{Fischers} = 0.079, p = 0.064, significant at the 10% level, see Appendix 9i). Residents that recognize street runoff as a source of water to the Liesbeek River were correlated with those that allow vehicle wash runoff to run into the street. There was no correlation between management of vehicle wash runoff and knowledge of stormwater system design, understanding of acceptable materials for the stormwater system, or recognition of vehicle wash runoff as a source of water to the Liesbeek River. This indicates that the residents do not necessarily understand that car washing runoff discharged into the street is eventually discharged to the river via the stormwater system. This also suggests that respondents do not perceive a connection between car washing activities and potential impacts on the river system.

Management of vehicle wash runoff was significantly correlated with resident perspective of responsibility for stormwater management (X^2 = 11.5885, p_{Fischers} = 0.102, p = 0.003, nearly significant at the 10% level, see Appendix 9j). Residents that consider local government to be primarily responsible for management of stormwater issues were associated with residents who allow their vehicle wash runoff to flow into the street.

Of the residents that own domestic animals, 57.14% pick up and dispose of pet waste. The remaining 42.85% allow it to decompose outside in various conditions (i.e. as is, in a compost pile, or buried by the animal). There was no significant correlation between pet waste management and including domestic animals in the top causes of local river pollution.

Management of pet waste was significantly correlated with recognition of residential garden runoff as a source of water to the Liesbeek River (X^2 = 7.0352, $p_{Fischers}$ = 0.054, p = 0.071, significant at the 10% level, see Appendix 9k). Residents that recognize runoff from residential gardens as a source of water to the river were more associated with residents that picked up and disposed of pet waste than those that left it outside in the various forms. There was no correlation between management pet waste and knowledge of stormwater system design or understanding of acceptable materials for the stormwater system.

Management of pet wastes was significantly correlated with resident perspective of responsibility for local river pollution (X^2 = 7.8554, $p_{Fischers}$ = 0.049, p = 0.097, significant at the 5% level, see appendix 9l). Residents that do not own pets, put waste on a compost pile, or put waste into the rubbish were less likely to include residents in the top three groups contributing to local river pollution.

Over half of the residents that own swimming pools allow the backwash to drain into the street (51.61%; including 45.16% that drain only onto the street and 6.45% that drain to both the street and sewerage system). The remaining residents drain pool backwash to a garden area (22.58%) or the sewerage system (22.58%).

Management of pool backwash was significantly correlated with understanding of acceptable materials for disposal in stormwater drains (X^2 = 11.6018, $p_{Fischers}$ = 0.025, p = 0.071, significant at the 10% level, see Appendix 9m). Residents that believe that no material other than stormwater should be disposed of in stormwater drains were associated with residents that allow pool backwash to drain into the street or garden area. Management of pool backwash was not significantly correlated with knowledge of stormwater system design or with recognition of street runoff or pool backwash as contributing water to the Liesbeek River. This indicates that residents do not necessarily understand that pool backwash drained to the street is eventually discharged to the river via the stormwater system. This also suggests that respondents do not perceive a connection between pool backwash and potential impacts on the river system.

Very few respondents collect stormwater on the premises (7.35%), although 30.88% report that they plan to do so in the future. The reasons for collecting stormwater, among those that already do so, include economic reasons (cuts costs, 60%), environmental or conservation reasons (40%), water supply supplementation (20%), and fun or personal reasons (e.g. hobbies such as perma-culture, 20%). Of those residents who do not plan to collect stormwater cite a range of reasons, including: economic reasons (too expensive), not enough space on the property, lack of desire, lack of knowledge, lack of time, and lack of desire to invest in the property (i.e. rental tenants).

Resident Experience

Half of the residents reported having experienced problems with stormwater drainage in the past (52.78% in Observatory, 46.88% in Newlands, 50.00% in total); almost all of these were related to flooding (94.12%; 17.65% flooding of property and 76.47% road flooding). Most individuals experienced these problems at least once a year (70.59%). Many respondents took it upon themselves to address the problem (47.06%), while some called the local authority for support (20.59%) or did nothing at all (26.47%). There was no significant correlation between length of residence and past problems with stormwater drainage. There was also no significant correlation between resident response to stormwater problems and knowledge of the appropriate municipal body to contact.

A small number of residents report having observed intentional misuse of stormwater drains as a disposal mechanism (26.47%). Of these 44.44% had approached the perpetrator, while only 5.56% had both approached and reported the abuse to the local authority, and the remaining 50% had done nothing. There was no significant correlation between observed intentional misuse and resident perspective of groups contributing to local river pollution or causes of local river pollution. There was also no significant correlation between resident response to observed intentional misuse of stormwater drains and knowledge of the appropriate municipal body to contact.

Nearly half of respondents report having observed unintentional misuse of local stormwater drains (42.65%). These observations frequently involved wash-off from construction or painting sites (65.52%) or wash-off of street debris (27.59%). In response, 20.69% of respondents approached the responsible party, 10.34% managed the problem themselves, and 6.9% contacted the authority. However, the majority (62.07%) took no action to remedy the problem.

There was a significant correlation between observed unintentional misuse and resident perspective of contributors to local river pollution. Respondents that had observed unintentional misuse were more likely to include residents in the top five groups responsible for local river pollution (X^2 = 7.2386, p_{Fischers} = 0.010, $p_{\text{1-sided Fischers}}$ = 0.007, p = 0.007, significant at the 5% level, see Appendix 9n). Similarly, residents that had observed unintentional misuse were more likely to include construction practices in the top five groups responsible for local river pollution (X^2 = 6.1959, p_{Fischers} = 0.016, $p_{\text{1-sided Fischers}}$ = 0.012, p = 0.013, significant at the 5% level, see Appendix 9o).

There was a significant correlation between observed unintentional misuse of stormwater drains and resident perspective of the causes of local river pollution. Residents that had observed unintentional misuse were more likely to include garden waste/runoff in the top five causes of local river pollution (X^2 = 4.5351, p_{Fischers} = 0.055, $p_{\text{1-sided Fischers}}$ = 0.032, p = 0.033, significant at the 10% level, see Appendix 9p), and were also more likely to include building/construction waste in the top three causes (X^2 = 4.0893, p_{Fischers} = 0.051, $p_{\text{1-sided Fischers}}$ = 0.038, p = 0.043, significant at the 10% level, see Appendix 9q). This is likely because the most commonly observed misuses of drains included wash-off from construction or painting sites and wash-off of street debris.

Resident response to observed unintentional misuse of stormwater drains was significantly correlated with knowledge of which municipal body to contact regarding stormwater issues (X^2 = 6.1307, p_{Fischers} = 0.098, p = 0.105, significant at the 10% level, see Appendix 9r). Those residents that are aware of the appropriate municipal body to contact for stormwater-related problems were more associated with residents taking no action, approaching the responsible party, or managing the problem themselves than with those that contacted the authority (only 10.53% of those that knew who to contact actually did). Discussions with residents revealed a level of mistrust of the municipality to respond to reported problems. Multiple residents explicitly stated that they did not or would not contact the municipality because of previous experience of inaction.

Resident response to unintentional misuse of stormwater drains was significantly correlated with resident perspective of responsibility for stormwater management issues ($X^2 = 9.2917$, $p_{Fischers} = 0.096$, $p = 0.158$, significant at the 10% level, see Appendix 9s). Respondents that consider residents to have secondary responsibility for stormwater management were associated with those that took no action when they observed intentional misuse. However, respondents that consider property owners to hold secondary responsibility were more likely to approach the responsible party, manage it themselves or contact the authority. This indicates that some residents are willing to accept a level responsibility for managing stormwater.

Residents were asked how they would respond in a hypothetical situation where the saw a blocked or flooding drain. Most respondents believe that they would contact the authority (41.18%), manage it themselves (29.41%), or do both (23.53%). Only 5.88% of residents said they would ignore it. Similarly, residents were asked how they would respond in a hypothetical situation where they observed intentional misuse of a stormwater drain. Most respondents say that they would manage it themselves (i.e. approach the responsible party; 41.18%), contact the authority (20.59%), or do both (20.59%), with only 16.18% claiming that they would do nothing.

The responses to the above questions are summarised in Figure 4.7. In response to experienced situations, residents more often reported having managed the problem themselves or taken no action. In response to hypothetical situations, respondents more frequently claimed that they would manage it themselves and/or contact the authority.

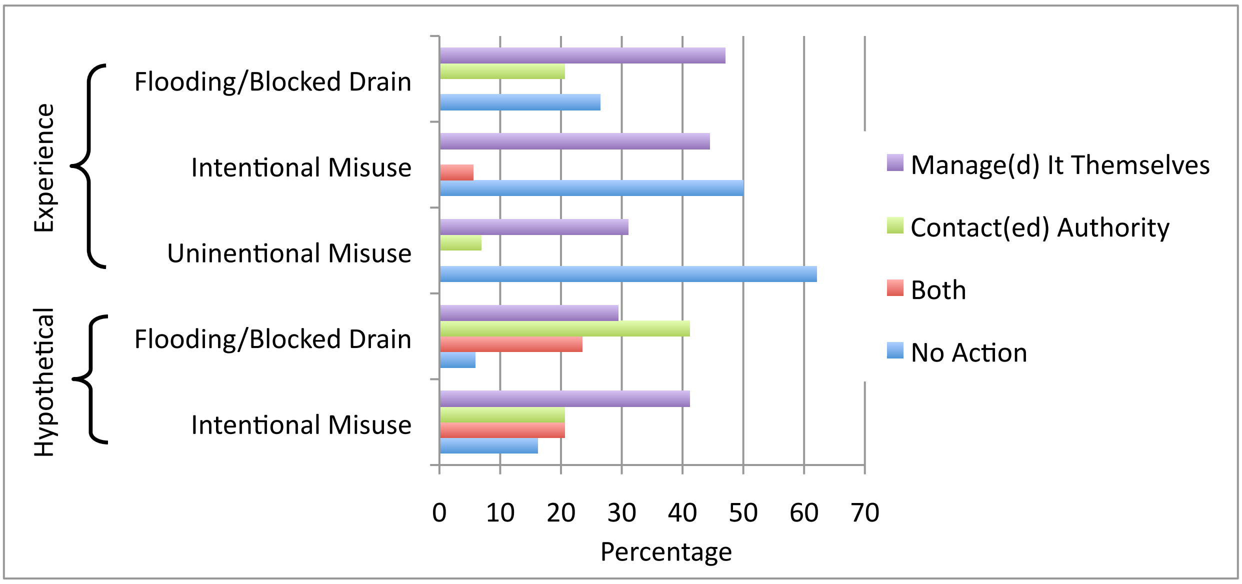

Figure 4.7: Responses to actual experiences and hypothetical questions involving stormwater drains. 'Managed it themselves' may refer to clearing a blocked drain or approaching the responsible party.

There was no significant correlation between the responses of residents to observed stormwater problems and hypothetical stormwater problems (X^2 = 9.2606, $p_{Fischers}$ = 0.156, p = 0.159, see Appendix 9t). Responses were not consistent between hypothetical and actual experiences: 69.23% of residents that claimed they would manage the problem themselves did so in the actual experience while 23.08% ignored it, and 22.22% of residents that claimed they would contact they authority did so while 33.33% managed it themselves and 44.44% ignored it. However, the responses of residents that had observed intentional misuse of stormwater drains were significantly correlated with their hypothetical response to misuse of a stormwater drain (X^2 = 21.7500, $p_{Fischers}$ = 0.001, p = 0.005, significant at the 5% level, see Appendix 9u). Responses remained mostly consistent between actual and hypothetical situations, with only 16.67% of respondents claiming to approach the responsible party or contact the authority in the hypothetical case while taking no action in the actual experience. These differences indicate a discrepancy between expected and actual public responses to stormwater problems, however, the reasons behind such differences are beyond the scope of this thesis.

Resident's hypothetical response to a blocked stormwater drain was significantly correlated with level of concern for the Liesbeek River (X^2 = 25.3870, $p_{Fischers}$ = 0.008, p = 0.013, significant at the 5% level, see Appendix 9v). Those residents with a higher level of concern for the ecological health of the river were more likely to claim that they would manage the problem, contact the authority, or do both, rather than ignore the blockage.

Resident's hypothetical response to a blocked stormwater drain was significantly correlated with resident perspective of responsibility for stormwater management (X^2 = 16.9304, $p_{Fischers}$ = 0.068, p = 0.002, significant at the 10% level, see Appendix 9w). Respondents that consider local government to be primarily responsible for management of stormwater issues were associated with residents that would hypothetically contact the authority to respond to a blocked or flooding drain.

Resident's hypothetical response to misuse of a stormwater drain was also significantly correlated with resident perspective of responsibility for stormwater management (X^2 = 20.1488, $p_{Fischers}$ = 0.028, p = 0.010, significant at the 5% level, see Appendix 9x). Respondents that consider residents and/or property owners to hold secondary responsibility for management of stormwater issues were associated with residents that would approach an individual misusing the stormwater system. Again, this indicates a level of willingness to assume some responsibility for stormwater management.

4.4 Area Observation

A total of 20 observation sessions were conducted in each of the study areas during the sampling period. Table 4.16 presents a summary of the activities observed per area.

Table 4.16: Summary of area observations

Activity	Newlands	Observatory	Total
Resident/worker washing paved surface with discharge flowing into street/culvert	10	3	13
Resident/worker sweeping debris into drain	2	0	2
Resident/worker pouring bucket into culvert/drain	5	5	10
Residential worker clearing drain/culvert	1	0	1
Street sweeping and/or drain clearing by municipal worker(s) or OBSID	2	5	7
Construction or road work	6 *	7	13
* Includes construction on one site that continued throughout the sampling period			

On 13 occasions residents or residential workers were observed washing paved surfaces, with discharge flowing into the street or drainage culvert, and on 10 occasions individuals were observed discharging wastewater (of unknown contents) directly into a storm culvert or drain. These activities are advised against by the City of Cape Town (City of Cape Town, Catchment, Stormwater and River Management, n.d.). There was also evidence of wastewater containing paint and detergents being discharged into the storm drains in both study areas (Figure 4.8).

Figure 4.8: Evidence of misuse of stormwater drains. The images show evidence of wastewater containing paint (left-hand image) and detergents (right-hand image) dumped or discharged into the storm drain. Photos taken by Elizabeth Ward.

Street sweeping and drain clearing was observed on eight occasions: most frequently by municipal or OBSID workers and once by a residential worker. On one of these occasions in Newlands, 22 workers were contracted by the municipality to clean street and roadside garden debris for five days in preparation for the coming winter storms. According to the workers, this was not enough time to remove all of the debris from the intended area.

Construction activities were common in both study areas. In the Newlands study area, construction on a single property continued throughout the sampling period (included once in the total Newlands count in Table 4.16). This site was frequently seen with large piles of sand or soil along the roadside, with no covering or protection from rain wash-off. A similar situation was recorded in Observatory, but only on one occasion of a shorter duration. The resulting delivery of sand and soil to the stormwater system was evidenced by the visible accumulation of debris both in the roadside culvert and the drain inlet. Figure 4.9 displays examples of these observations.

Figure 4.9: Images of uncovered sand pile and wash-off into the stormwater system. Photos taken by Elizabeth Ward.

4.5 Summary and Discussion

4.5.1 Water Quality

The results show that stormwater quality is highly variable, both spatially and temporally. Table 4.17 presents a summary of the water quality parameter trends for the multiple explanatory variables.

Table 4.17: Summary of water quality trends

	Antecedent Dry Days (% Change per increase of 1 day)	**Rainfall** (% Change per increase of 1 mm) *	**Season** (% Change in spring vs. winter)	**Area** (% Change in Newlands vs. Observatory)	**Intercept** (Value when D, R, S, A = 0)
pH	- 0.1	+ 0.1	+ 26	NA	8.34
TDS	+ 6.18	- 1.0	NA	NA	54.5982 ppm
Orthophosphate	+ 8.33	- 1.0	+ 89.65	NA	0.2783 mg/l
Ammonia	+ 10.52	- 1.0	+ 46.23	NA	0.2408 mg/l
Nitrate	NA	NA	NA	- 15.63	0.5066 mg/l
Nitrite	- 3.92	- 1.0	+ 37.71	NA	0.0072 mg/l
* Refers to centred average rainfall					

The results show that all parameters except nitrate were significantly influenced by rainfall (see Table 4.17). This is consistent with the literature (Pitt et al., 1995; Mulliss et al., 1996; Bertrand-Krajewski et al., 1998; Lee et al., 2002), and indicates that rainfall volume is a primary driver of contaminant loading and water quality. An increase from the centred average rainfall led to a decrease in TDS, orthophosphate, ammonia, and nitrite concentrations. This is consistent with the 'First Flush' theory, whereby contaminant concentrations decrease with increasing rainfall as surfaces are washed clean and loads are diluted (Mulliss et al., 1996; Bertrand-Krajewski et al., 1998; Lee et al., 2002). Bertrand-Krajewski et al. (1998) found that, in separate stormwater systems, 80% of the total pollutant mass is transported in the first 74% of the total runoff discharge volume for 50% of rainfall events. The first flush is influenced by many parameters, such as rainfall intensity, watershed area, impervious area, and antecedent dry weather period (Gupta & Saul, 1996; Lee et al., 2002).

Rainfall appeared to have a consistent influence on TDS, orthophosphate, ammonia and nitrite concentrations, however, the magnitude of the first flush phenomenon may vary depending on the pollutant (Lee et al., 2002). For example, research suggests that suspended solids and orthophosphate concentrations are strongly affected by the first flush phenomenon in residential areas (*ibid*). This study did not collect samples from the onset of the winter rainy season, and therefore does not attempt to examine the seasonal first flush theory, whereby initial storm events of the rainy season have higher pollutant concentrations (Lee et al., 2004). A high pollutant loading at the beginning of a storm event, or rainy season, may be consequential for managers seeking an efficient stormwater quality control method; a focus on remediating the initial load and addressing factors that amplify the first flush effect (such as impervious area) may prove beneficial.

With the exception of nitrate, all water quality parameters examined in this study are significantly influenced by the duration of the antecedent dry weather period. TDS, orthophosphate, and ammonia concentrations increased with increasing dry weather days, indicating that an increased dry weather period allows contaminants to build up on surfaces. Some research shows that the antecedent dry weather period is significantly correlated with the load of contaminants in the first flush (Gupta & Saul, 1996), which may exacerbate the influence of pollutant loads on the aquatic ecosystem. Contaminant build up may be influenced by multiple societal patterns and processes, including land use, traffic flow, street cleaning activities, seasonal activities (such as fertilizer application), and population density (Butler & Davies, 2011). Contaminant loading is also influenced by the weather conditions during the antecedent dry period (Gupta & Saul, 1996), however, such variation was not examined in this study.

Orthophosphate, ammonia, and nitrite concentrations were all significantly higher in spring than in winter months. Local activities can directly influence the pollutant availability through direct contamination of the surface area (Pitt et al., 1995), and it has been found that residential lawns and gardens are common sources of nutrients and pesticides (Paul & Meyer, 2001). Resident surveys revealed that 69.39% of residents that apply fertilizers do so in the spring, while only 4.08% apply fertilizer during the winter. Therefore, the observed increases in contaminant loads may partially be explained by an increase in fertilizer application by residents in the area.

Study area location did not significantly influence most water quality parameters. Only nitrate was influenced by area, with lower concentrations found in Newlands than in Observatory.

Like many countries, South Africa does not have set standards for stormwater quality. Developing stormwater quality standards is complicated by the highly variable nature of the runoff and contaminants themselves, but also by the catchment and climatic characteristics that influence runoff quality. South Africa does have water quality guidelines for aquatic ecosystems (see Appendix 3). Table 4.18 summarizes these guidelines as well as the ecological health category requirements put forth by the PD Naidoo & Associates (2010).

Table 4.18: Summary of water quality guidelines and ecosystem health categories (adapted from Republic of South Africa, Department of Water Affairs and Forestry, 1996; PD Naidoo & Associates, 2010)

Parameter	**Units**	**Ecosystem Health Categories**				
		Natural	**Good**	**Fair**	**Poor**	**Unacceptable**
TDS *#	ppm	Depends on background (not more than 15% different from normal cycles)				
EC *#	µS	Depends on background (not more than 15% different from normal cycles)				
pH *#	units	6.5 - 8	5.75 - 6.5 or 8 - 9	5 - 5.75 or 9 - 10	<5 or >10	
Soluble Reactive Phosphorous *#†	mg/l	<0.005	0.005 - 0.025	0.025 - 0.125	0.125 - 0.250	>0.250
Total Inorganic Nitrogen *#†	mg/l	<0.25	0.25 - 1	1 - 4	4 - 10	>10
Ammonia #	mg/l	<0.015	0.015 - 0.058	0.058 - 0.1	0.1 - 0.2	>0.2

* Need to establish typical background water quality values and cycles in order to asses deviations

\# Ecological Reserve water quality benchmarks

† Should not be changed by >15% from normal cycles; trophic status should not be increased

However, according to the guidelines, background values and normal cycles of pH, TDS, phosphorous, and nitrogen must be established if deviations from the natural conditions are to be assessed. Therefore, stormwater quality results cannot be compared against these guidelines because the quality of the cumulative stormwater inputs to the Liesbeek River and its buffering capacity against these inputs are unknown.

Although standards for stormwater quality discharged to an urban river are lacking, limits do exist for wastewater discharged into a water resource (see Appendix 3f). Table 4.19 summarizes these limits and the water quality data collected in this study. The range of pH observations in this study exceeds both the lower and upper general limits. Orthophosphate concentrations were also found to exceed the general limit, although the 75th percentile of all locations and observations was 0.94 mg/l. EC and nitrate/nitrite did not exceed the general limit, however, nitrate concentrations did exceed the special limit. These excesses are likely not unique to the Newlands and Observatory study areas. Furthermore, the water quality results in this study likely underestimate the total contaminant load to the receiving waterway because particulate matter and pollutants that bind to sediments were excluded (Pitt et al., 1995; Paul & Meyer, 2001).

Table 4.19: Summary of wastewater discharge quality limits and stormwater quality results

Parameter	**Wastewater Limits ***		**Stormwater Quality Results**			
	General Limit	**Special Limit**	**Min.**	**Max.**	**Mean**	**75th Percentile**
pH	5.5 – 9.5	5.5 – 7.5	3.20	12.80	8.14	8.40
EC (µS)	70000 – 150000 †	50000 – 100000 †	0.00	4300.00	172.04	200.00
Orthophosphate (mg/l)	10	1 (median) – 2.5 (maximum)	0.00	71.97	1.30	0.94
Ammonia (mg/l)	3	2	0.01	21.75	0.75	0.70
Nitrate (mg/l)	15	1.5	0.00	8.03	0.56	0.63
Nitrite (mg/l)			0.00	1.30	0.03	0.01

* Taken from the discharge limits and conditions set out in the National Water Act (Republic of South Africa, 1999)

† Limit indicates difference from background receiving waterway conditions

Multiple locations were identified which contributed higher concentrations of contaminants over the sampling period. This is consistent with the literature, which suggests that the contribution of contaminant load is not evenly distributed (Bannerman et al., 1993). As Bannerman et al. (1993) suggest, identification of critical source areas will allow management techniques to focus on the most important sources of various contaminants. Although the drivers of these elevated contributions are beyond the scope of this thesis, these potential 'hotspots' are likely influenced by local activities and societal patterns and processes, and present an opportunity for prioritized remediation.

Pitt et al. (1995) suggest that the beneficial uses of urban waterways are more affected by long-term pollutant exposure than acute exposure events. Observations of water quality parameters exceeding the limits set forth by the guidelines, and location-specific elevated contaminant contributions are not likely to be unique to the study areas examined. It is therefore possible that high contaminant concentrations discharged into a receiving waterway may be variably generated by multiple source locations, cumulating in long term exposure. This is representative of the concern that diffuse pollution (such as from stormwater) poses a greater risk than point discharges (such as wastewater effluent outfalls) for aquatic ecosystems (Butler & Davies, 2011).

4.5.2 Resident Survey

The survey results indicate that residents have a good general knowledge of the stormwater system and a positive level of concern for the condition of the Liesbeek River. Nearly all residents are aware that the stormwater system is separate from the sewerage system and the majority understand that the water is discharged directly to the local river. Nearly a third of residents believe that some materials other than storm runoff may be disposed of through the stormwater system. These residents indicated that as long as the material is "non-toxic" or "not a pollutant" then it may be discharged into the stormwater system. However, this would require that residents have a good understanding of what these terms mean and the possible implications that such materials could have on water quality and ecological systems in the receiving waterway.

There was a tendency for respondents to place blame for locally caused river pollution externally. For example, residents most frequently cited vagrants, construction practices and non-residents to be the primary contributors to local pollution, while only 10.29% reported residents as the primary contributor. Less than half of respondents that consider residential garden waste/runoff to be among the top five causes of local pollution also believe that residents are among the top five contributors to local pollution. This is similar to the findings of Norris and Burgin (2009), who reported that the majority of residents did not consider themselves as contributing to local stormwater pollution, with residents instead indicating that an intangible 'other' is at fault. These findings are likely driven by various context-specific societal patterns and processes, and further investigation is required to understand the underlying causes.

There was also a tendency to identify highly visible pollutants as the main degrading contaminants. Litter and rubbish, illegal dumping, and building and construction waste were the most commonly reported causes of local river pollution. Research by Norris and Burgin (2009) also found that most respondents specified litter/rubbish and illegal dumping as major causes of local stormwater pollution, while few considered waste and runoff from households, buildings, and gardens to be contributors. This may be due to a lack of education regarding pollutants and water quality impacts. It is also suggestive of the 'out of sight, out of mind' perspective discussed in Section 2.4.2; the stormwater system and associated ecological processes and conditions are largely concealed, resulting in urban residents with a limited understanding of downstream impacts on biophysical processes and water quality (Wong & Eadie, 2000; Stokman, 2008).

Activities reported by residents indicate that they may have a more significant impact on stormwater quality than they currently perceive. Many residents regularly apply fertilizers, discharge vehicle wash runoff to the street, and allow pet wastes to decompose outside. Although the effect of individual activities on stormwater quality was not examined in this study, research indicates that these types of activities negatively affect water quality (e.g. Bannerman et al., 1993; Pitt et al., 1995; Paul & Meyer, 2001; Butler & Davies, 2011). This is supported by water quality results showing higher nutrient levels in spring months, when most residents apply fertilizers.

In addition, residents do not fully comply with the City of Cape Town's Stormwater Management Bylaw. The policy allows pool overflow to be discharged into the stormwater system, but prohibits discharge of pool backwash, which is to be directed into the sewerage system (City of Cape Town, 2005, 2011b). In addition, residents and residential workers were observed misusing the stormwater system (e.g. discharging wastewater into culverts or drains), an activity also prohibited by the stormwater policy. Whether this discrepancy is due to a lack of awareness of the policy or a disregard of its mandates was not investigated. Furthermore, residents may not be aware of the methods taken by their employed workers to maintain the premises.

Many residents reported problems with the function or misuse of the stormwater system. Although stormwater management is largely considered to be primarily the responsibility of local municipality, approximately a third of respondents consider residents or property owners to hold secondary responsibility. In response to observed malfunction or misuse of the stormwater system, there was a tendency for residents to manage the problem themselves or do nothing rather than contact the authority. Furthermore, in response to a hypothetical blocked storm drain, residents with a higher level of concern for the Liesbeek River were more likely to take action. This indicates a level of investment and receptivity to stormwater issues, and willingness to take responsibility for stormwater problems should they arise.

The results indicate that residents do not clearly understand how their actions might impact water quality or river conditions. For example, use of fertilizers was not correlated with recognizing residential garden runoff as a source of water or pollution in the Liesbeek River. Although residents recognize street runoff as a source of water to the Liesbeek River and believe that pollutants should not be disposed of in storm drains, they continue to discharge vehicle wash runoff into the street.

This indicates that the residents do not necessarily perceive a connection between these activities and potential impacts on the river system.

There were, however, some instances that suggest a level of understanding the interconnections between activity and river conditions. For example, respondents that have observed wash-off of street debris and construction sites were more likely to consider residents and/or constructions practices as contributors to local river pollution. Residents that recognize runoff from residential gardens as a source of water to the river were more associated with residents that pick up and dispose of pet waste than those that leave it outside. However, the anomalies in resident understanding and actions indicate that protecting river conditions by minimizing negative impacts on stormwater quality is not a cognitive priority; many residents stated that they simply didn't think about it very much. This is demonstrated by comparing pool backwash management with resident understanding of the stormwater system: 88.24% of those that discharge pool backwash into the street report that no material other than runoff should be discharged into the stormwater system. Furthermore, 100% of those that discharge pool backwash into the street recognize that street runoff contributes water to the Liesbeek River. Therefore, the resident survey results suggest that a certain disconnect exists between people and ecological/technological patterns and processes. This is likely due to a lack of understanding of water quality impacts and interconnections, or a lack of consideration and extrapolation of these interconnections.

CHAPTER 5: CONCLUSIONS AND IMPLICATIONS

5.1 Conclusions

Progress toward more sustainable urban stormwater management and realising the characteristics of a 'waterways city' begins with an in-depth understanding of societal and environmental linkages that interact in urban stormwater systems. This is not a simple task, however, as each catchment is characterized by unique environmental and societal patterns and processes. Sustainable stormwater management techniques will need to be specially designed to address the local interactions between environmental, ecological, technological and societal contexts.

This study describes the 'Ecological patterns and processes' and 'Changes in perceptions and attitudes' that are informed by the Urban Ecology model (Figure 1.1 and its application in Figure 2.2). The results have generated multiple insights into the linkages between the ecological and societal conditions, as well as the potential for individual and collective aspirations to influence and adapt to changing conditions, needs, and values. In conclusion, new insights are presented in the applied Urban Ecology model (Figure 5.1), informed by the study site contexts and findings. In Figure 5.1, some interconnections are represented as stronger (bold) or weaker (dashed) linkages, the justification for which is described further below. Although quantifying the strength and exhaustively defining the complexities of individual linkages and variables is beyond the scope of this thesis, further investigation to understand and address the apparently weak linkages may improve the City of Cape Town's ability to evolve its management of urban stormwater and improve the condition of its urban waterways.

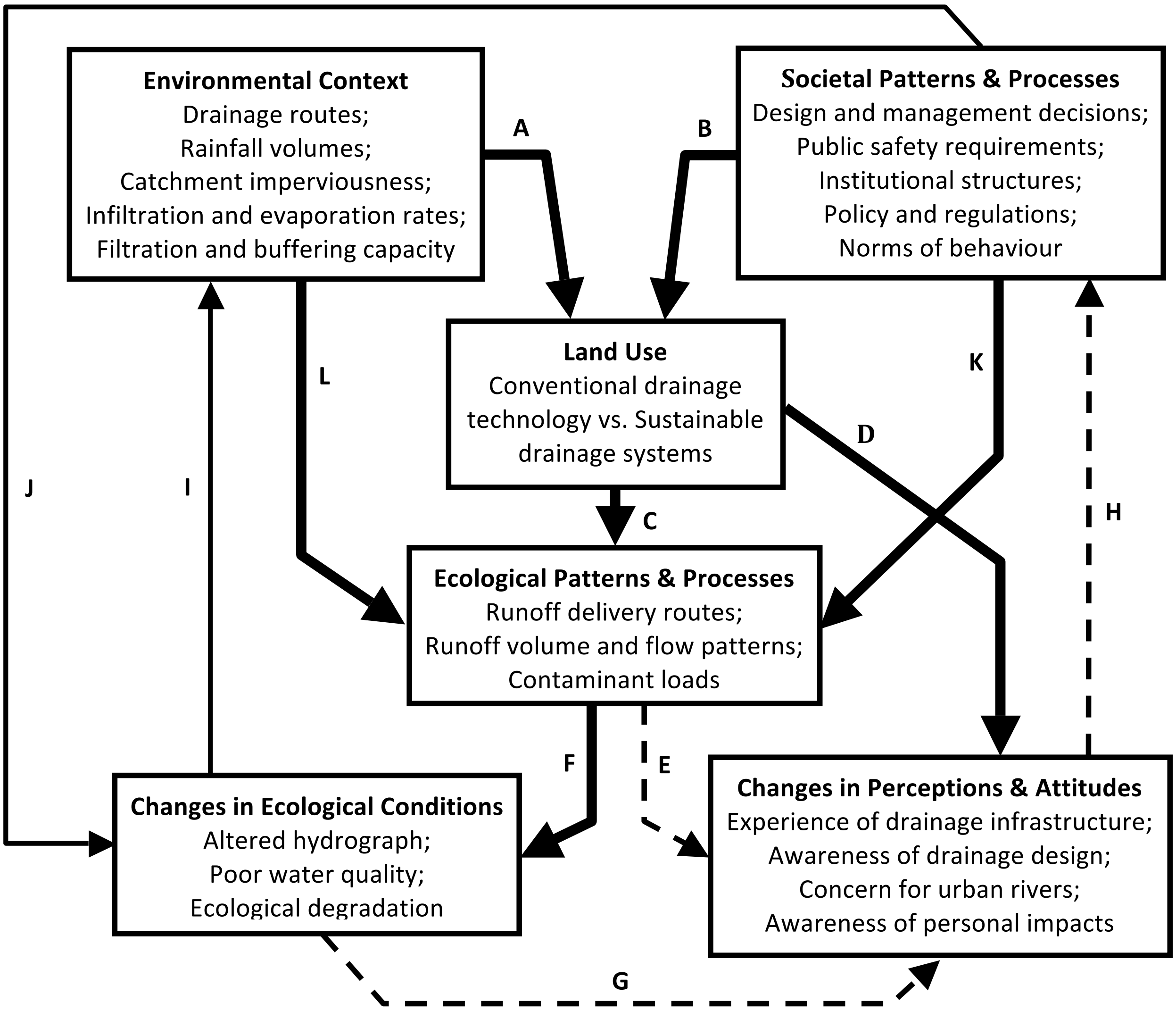

Figure 5.1: Insights into the applied Urban Ecology model

Stormwater quality is highly variable over space and time. Some environmental conditions (namely rainfall, antecedent dry days, and season) were shown to be primary drivers of water quality, creating a strong linkage represented as ‘L’ in Figure 5.1. Even with societal interventions such as litter grids, street sweeping, and clearing of the drainage inlets (process ‘K’), debris and contaminants continue to enter the drainage systems and are discharged into the waterway (PD Naidoo & Associates, 2010). The literature clearly shows that the current environmental context (e.g. catchment hardening and reduced infiltration capacity) strongly influences ecological patterns and processes through land use and management (i.e. conventional drainage techniques) (Arnold & Gibbons, 1996; Allan, 2004; Konrad & Booth, 2005), suggesting that processes ‘A’ and ‘C’ are strong linkages. Since urban drainage techniques and management decisions are largely a product of the hydro-social contract and societal patterns and processes (Brown et al., 2009), linkage 'B' must also be a strong interconnection.

There is also abundant evidence that the changes in ecological patterns and processes associated with conventional drainage negatively impact the ecological condition of urban waterways (e.g. Paul & Meyer, 2001; Allan, 2004; Butler & Davies, 2011). This indicates that process 'F' is a strong interconnection, acting through process 'C'. Therefore, the current environmental context and land use choices (i.e. conventional drainage techniques as driven by societal processes and environmental conditions) are responsible for generating some of the negative impacts on Cape Town's urban rivers, with significant implications for the City's sustainable management of urban stormwater and waterway health.

Although residents consider stormwater management to be primarily the responsibility of the local municipality, residents are reluctant to rely on these services. Problems of flooding and misuse of the drainage system indicate that the expected societal benefits of these systems are not being fulfilled. Residents perceive this shortcoming and are highly aware that efficient stormwater drainage is critical for flood avoidance and public safety, indicating a strong linkage represented as 'D'. Furthermore, residents exhibit a level of willingness to take partial responsibility for stormwater management. This willingness may be beneficial for the implementation of sustainable stormwater management techniques, such as those associated with the SUDS approach (Charlesworth et al., 2003; Morison & Brown, 2011).

Consistent with the literature (i.e. Bannerman et al., 1993; Pitt et al., 1995; Paul & Meyer, 2001; Butler & Davies, 2011) the results indicate that residential activity may have a significant influence on stormwater quality (process 'K'). However, residents do not necessarily perceive these impacts in the absence of highly visible effects. A weak understanding of the connection between certain activities and stormwater quality inhibits the ability of the public to interpret and respond to their own impacts on ecological patterns and processes, creating in a weakness in linkage ‘E’.

Residents are generally concerned with the ecological health of the urban waterway. Restoration and urban greening projects, such as those undertaken by the FoL, have created open spaces for residents to visit regularly. Although this increases the visibility of the urban waterway, lacking a clear understanding of the linkages described above inhibits residents from clearly interpreting ecological conditions in relation to environmental and societal influences. The result is a weak linkage between changes in ecological conditions and changes in perceptions and attitudes (process ‘G’).

Although residents have a general knowledge of the design of the stormwater system, there was little appreciation for its complexities and interconnections. Residents generally do not see a complete picture in which an emergent social-ecological system is generated by complex interactions between people, stormwater technology and management, and ecological systems. Responding to undesirable changes in ecological patterns, processes or conditions is inhibited because complete knowledge does not appear to have entered the normative and cognitive faculties of the societal context.

Residents express a level of mistrust in the municipality and a reluctance to communicate concerns and problems associated with the stormwater system. The evolution towards a more sustainable urban ecosystem partially depends on society’s ability to perceive and respond to changing needs and conditions in the built and natural environment (Picket et al., 1997; Brown et al., 2009). The public plays an important role in shaping these responses and adaptations; however, the public influence on societal patterns and processes is likely hindered by its lack of awareness of stormwater system complexities. Therefore, inadequate awareness and poor communication weakens connection ‘H’, and further inhibits the ability of residents and the municipality to progress towards a more desirable state, such as a more sustainable city. Moving to a ‘Waterways City’ will require an overhaul of the conventional hydro-social contract (Brown et al., 2009) and would represent a new ‘time-step’ (Grimm et al., 2000, p. 576) in the Urban Ecology model of Figure 5.1, with significant changes in societal patterns and processes.

5.2 Special Considerations in the Applied Urban Ecology Model

In applying the Urban Ecology model to a complex social-environmental system, it is important to take into consideration all interactions and feedbacks contained within the multiple variables and linkages described by the model (boxes and arrows, respectively, in Figures 1.1, 2.2 and 5.1). As Burns and Weaver (2008) note, “the generation of knowledge of complex systems is an exploratory process; as the context in which this knowledge is to be useful changes, we will have to continually revise the framework which generates this knowledge” (p. 52). Therefore, as societal and/or environmental conditions change, such as through the development of new knowledge and technologies, these new considerations must be worked into the model, as well as their implications and feedbacks to other model components.

This study uses the Urban Ecology model to describe the ‘Ecological patterns and processes’ and ‘Changes in perceptions and attitudes’ associated with urban drainage in the context of formal residential development in Cape Town, South Africa. In this limited application of the model, it is important to recognise that multiple societal or environmental patterns and processes influence the findings, as well as their implications for sustainability applications. For example, cultural considerations, which may engender certain responses from residents, are central components of decision-making and are thus key to understanding environmentally relevant decisions in policy development and implementation (Grimm et al., 2000). Understanding how these underlying processes may influence the application of this knowledge is vital in creating and implementing future sustainable stormwater policy. Although beyond the scope of this thesis, this would require a deeper investigation of the Urban Ecology model as applied to urban stormwater drainage.

In order to use the Urban Ecology model as a tool to create socially and environmentally sound policy decisions, the entire model must be explored. Multiple scales of societal systems should be investigated, including formal and less formal institutions, all of which contribute to the interactions between the urban environmental and society (Grimm et al., 2000). Policy and management decisions must incorporate technical information that is balanced with considerations of socio-economic factors, and local needs and values (Haskins, 2012). As Pickett et al. (2011) note, while the "regulatory and institutional landscapes may determine the flow of water and pollution, the social landscape may determine where environmental regulations are actually enforced" (p. 324). Further, how the mutually reinforcing pillars of social institutions (cognitive, regulative, and normative) will influence the adoption of new sustainable approaches must be considered within the local context (Scott, 1995; Pickett et al., 2011). Therefore, the implications and recommendations described below, while informed by the results of this study, would benefit from a deeper application of the Urban Ecology model, with all societal scales and interactions taken into account. However, full application of the Urban Ecology model would require an integrated research team, bringing scientists from the natural, social and engineering sciences together in a unified research endeavour (Grimm et al., 2000).

5.3 Implications for Management

The City of Cape Town's progressive stormwater management policies have achieved limited success (Haskins, 2012). Although the policies are aligned with SUDS principles, conventional stormwater management techniques persist. This requires large amounts of resources in order to manage and maintain the system, by a significantly underfunded department fragmented from other departments managing the urban water cycle (Fisher-Jeffes & Armitage, 2013). The current approach, with its focus on technological solutions and flood prevention, does not meet the requirements for sustainable management and environmental protection put forth by the National

Environmental Management Act of 1998, the National Water Act of 1998, and the City of Cape Town's stormwater policies.

Diffuse pollution from urban stormwater requires significantly more attention and resources in order to manage and reduce pollution in urban waterways (PD Naidoo & Associates, 2010). It is recommended that the City of Cape Town employ targeted management techniques capable of prioritizing events likely to generate elevated contaminant inputs, taking into consideration rainfall, dry weather periods, and seasonality. In addition, identification of critical source areas throughout the City could reduce the required resources by more efficiently managing contaminant inputs. For example, Bannerman et al. (1993) indicate that management of only 14% of a residential area can control over 75% of most contaminant loads. Employing these strategies in new and existing developments will necessitate review of SUDS best management practices and further research to identify the most efficient and effective techniques appropriate for location-specific contexts.

Stormwater management in the City of Cape Town appears to lack a functional public link and feedback system. This likely leads to underreporting of pollution incidents by the public (PD Naidoo & Associates, 2010). There are also no local community or public interest groups that focus on sustainable stormwater, creating a situation of 'policy without publics' and leaving the political, technical and scientific community to regulate the policy agenda (Morison & Brown, 2011). While community perspectives and values play an important role in shaping the hydro-social contract and societal context, there is limited opportunity for the public to influence Cape Town's approach to stormwater management.

The City of Cape Town's adoption of sustainable drainage principles demonstrates a necessary cognitive shift towards urban sustainability, however, in such a transition changes in societal perceptions and values must occur before regulations and management can successfully evolve (Brown et al., 2009; Scott, 1995). Although the City has attempted to communicate its stormwater policies to municipal officials, the public, and environmental interest groups (Haskins, 2012), awareness does not appear to have permeated the general public mindset. It is recommended that the City of Cape Town incorporate a more intensive educational initiative to raise awareness of the human-ecological linkages associated with stormwater drainage and waterway health, as well as SUDS theories and principles. Public education of human-ecological linkages can foster change in social expectations and behaviours (Dietz et al., 2004; Feinstein & Hammond, 2004), and enable the public to interpret and react to undesirable ecological patterns and conditions, thereby facilitating processes 'E' and 'G' in Figure 5.1. Researchers elsewhere have noted that while financial resources influence the local capacity for institutional sustainability efforts (White & Boswell, 2006; Butler & Davies, 2011), receptivity to education is critical to enable reflection and evaluation of social-ecological linkages (Dietz et al., 2004; Feinstein & Hammond, 2004; White & Boswell, 2006). Furthermore, awareness and understanding of these interconnections often increases support for sustainable institutional initiatives (White & Boswell, 2006; Wagner, 2008; Morison & Brown, 2011). Thus, increased public awareness would be mutually reinforcing of public responsibility and the City's implementation of sustainable drainage techniques.

The valuable role of the public in stormwater drainage research, planning, management and pollution prevention has gained significant recognition (e.g. Maksimovic & Tajada-Guilbert, 2001; Dietz et al., 2004; Rauch et al., 2005). It is recommended that the City of Cape Town more effectively integrate the public into the institutional processes that direct and determine stormwater management approaches. Such integration is a vital component in addressing problems of conventional urban drainage and progressing towards sustainability (Lundqvist et al., 2001; Rauch et al., 2005). Public participation is increasingly advocated in the SUDS literature and allows responsibility to shift toward the community and individual, away from top-down decision making and end-of-pipe technocratic solutions (Rauch et al., 2005).

Education and integration initiatives have been implemented elsewhere (e.g. Dietz et al., 2004; Mitchell, 2006; Morison & Brown, 2011) and the DWAF has generated guidelines for department officials to include the public in decision-making processes (see Republic of South Africa, Department of Water Affairs and Forestry, 2001). These initiatives provide opportunity for more effective communication of stormwater policies and regulations, such as those pertaining to pool backwash, as well as the formation of stormwater-focused public interest groups. Furthermore, they would help to address the 'out of sight, out of mind' phenomenon associated with conventional drainage. Raising the 'catchment consciousness' of local communities encourages active engagement with the urban environment (Selman et al., 2010). Successful integration of the public into institutional processes would facilitate process 'H' in Figure 5.1 by providing the opportunity and awareness required for the public to effectively influence the evolution of stormwater management.

Targeted stormwater management techniques and improving public education and integration in institutional processes could improve the overall societal response to poor stormwater quality and degraded urban waterways in the City of Cape Town. These initiatives provide opportunity for more efficient use of resources to achieve departmental objectives through directed water quality management and pollution prevention. They also allow some of the responsibility to shift away from the experts, engineers, and institutional structures that are already struggling with service delivery and SUDS implementation, and onto the main system users. By bridging the human-biophysical gap, the role of the public may prove to be a valuable asset in successfully enhancing local SUDS initiatives.

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Appendix 1: Study Area Demographic Information

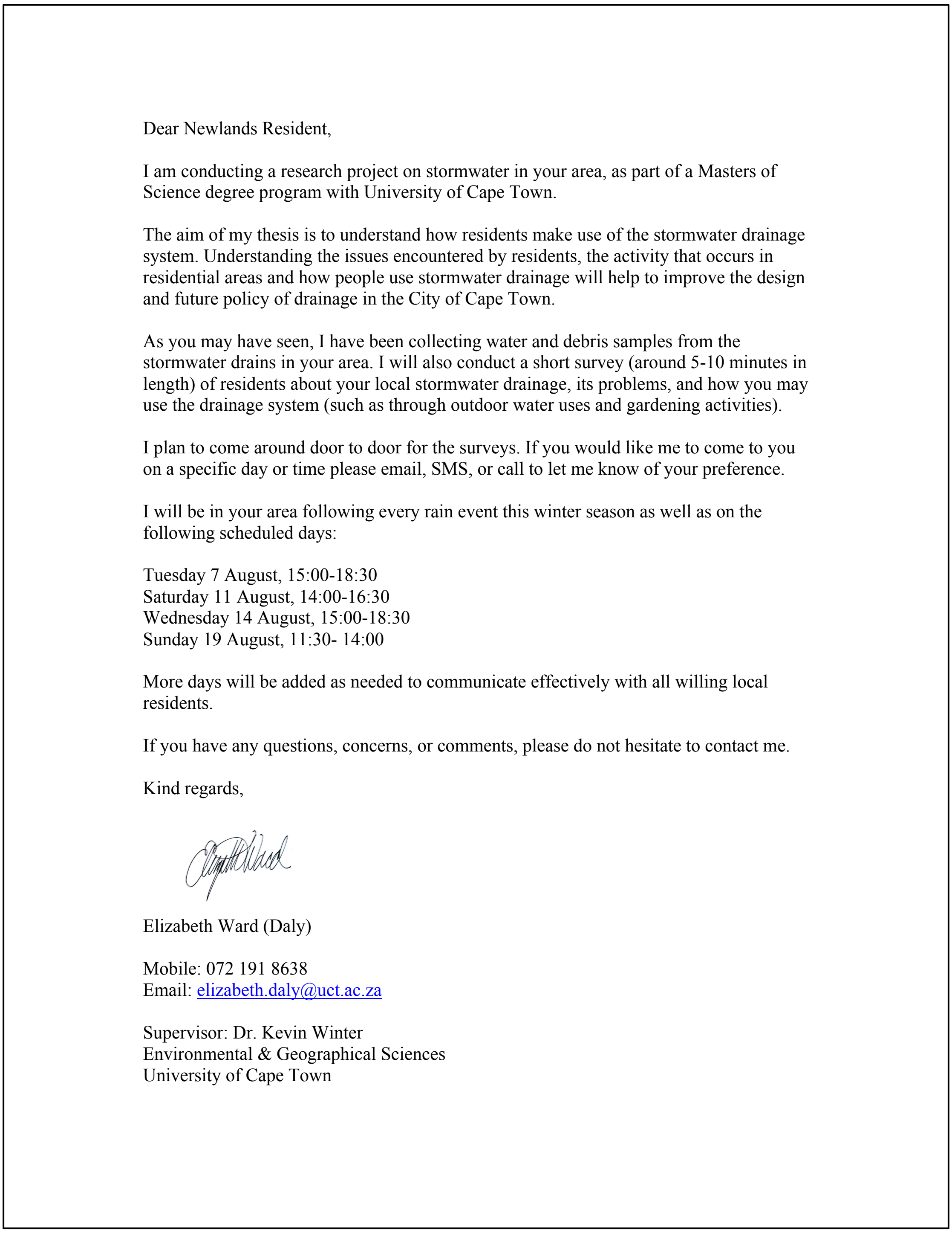
Appendix 1a: Breakdown of socio-economic and housing conditions in Newlands and Observatory suburbs of Cape Town, South Africa (City of Cape Town, Strategic Development Information & GIS Department, Statistics South Africa, 2013)

		Newlands	Observatory
Area (hectares)		358	349
Population		5,100	9,207
Population Density (per hectare)		14.25	26.38
Households		2,034	3,060
Household density (per hectare)		5.68	8.77
Housing Type (%)	Formal	99.2	98.9
	Informal	0.2	0.2
	Other	0.5	0.9
Home Ownership (%)	Owned	67.4	41.1
	Rented	28.7	56.5
	Rent-free non-owner	1.8	2.5
Education (%) *	None	0.2	0.4
	Less than grade 12	8.7	13.9
	Grade 12 and/or certificate	21.0	34.9
	Higher education	68.8	50.8
Monthly Income (%)	R 0 – R 6,400	10.2	43.0
	R 6,401 – R 25,600	37.4	32.9
	R 25,601 – R 102,400	40.6	22.5
	Over R 102,400	11.8	1.9
Study Area (hectares)		10.459	10.544
Households in Study Area		94	272
Study Area Surfaces (%)	Impervious	42.50	69.64
	Pervious	55.62	30.08
	Pools	1.88	0.28
Total Catchpits in Study Area		40	38
Sample Catchpits		13	12

* Education levels in Observatory sum to 100.3%, this is an error within the original publication

Appendix 2: Resident Survey

Appendix 2a: Letter of intent delivered to all residences of the Newlands study area in July 2012.



Dear Newlands Resident,

I am conducting a research project on stormwater in your area, as part of a Masters of Science degree program with University of Cape Town.

The aim of my thesis is to understand how residents make use of the stormwater drainage system. Understanding the issues encountered by residents, the activity that occurs in residential areas and how people use stormwater drainage will help to improve the design and future policy of drainage in the City of Cape Town.

As you may have seen, I have been collecting water and debris samples from the stormwater drains in your area. I will also conduct a short survey (around 5-10 minutes in length) of residents about your local stormwater drainage, its problems, and how you may use the drainage system (such as through outdoor water uses and gardening activities).

I plan to come around door to door for the surveys. If you would like me to come to you on a specific day or time please email, SMS, or call to let me know of your preference.

I will be in your area following every rain event this winter season as well as on the following scheduled days:

Tuesday 7 August, 15:00-18:30
Saturday 11 August, 14:00-16:30
Wednesday 14 August, 15:00-18:30
Sunday 19 August, 11:30- 14:00

More days will be added as needed to communicate effectively with all willing local residents.

If you have any questions, concerns, or comments, please do not hesitate to contact me.

Kind regards,

Elizabeth Ward (Daly)

Mobile: 072 191 8638
Email: elizabeth.daly@uct.ac.za

Supervisor: Dr. Kevin Winter
Environmental & Geographical Sciences
University of Cape Town

Appendix 2b: Letter of intent delivered to all residences of the Observatory study area in July 2012.

Dear Observatory Resident,

I am conducting a research project on stormwater in your area, as part of a Masters of Science degree program with University of Cape Town.

The aim of my thesis is to understand how residents make use of the stormwater drainage system. Understanding the issues encountered by residents, the activity that occurs in residential areas and how people use stormwater drainage will help to improve the design and future policy of drainage in the City of Cape Town.

As you may have seen, I have been collecting water and debris samples from the stormwater drains in your area. I will also conduct a short survey (around 5-10 minutes in length) of residents about your local stormwater drainage, its problems, and how you may use the drainage system (such as through outdoor water uses and gardening activities).

I plan to come around door to door for the surveys. If you would like me to come to you on a specific day or time please email, SMS, or call to let me know of your preference.

I will be in your area following every rain event this winter season as well as on the following scheduled days:

Wednesday 8 August, 15:00-18:30
Saturday 11 August, 11:30-14:00
Tuesday 14 August, 15:00-18:30
Sunday 19 August, 14:00-16:30

More days will be added as needed to communicate effectively with all willing local residents.

If you have any questions, concerns, or comments, please do not hesitate to contact me.

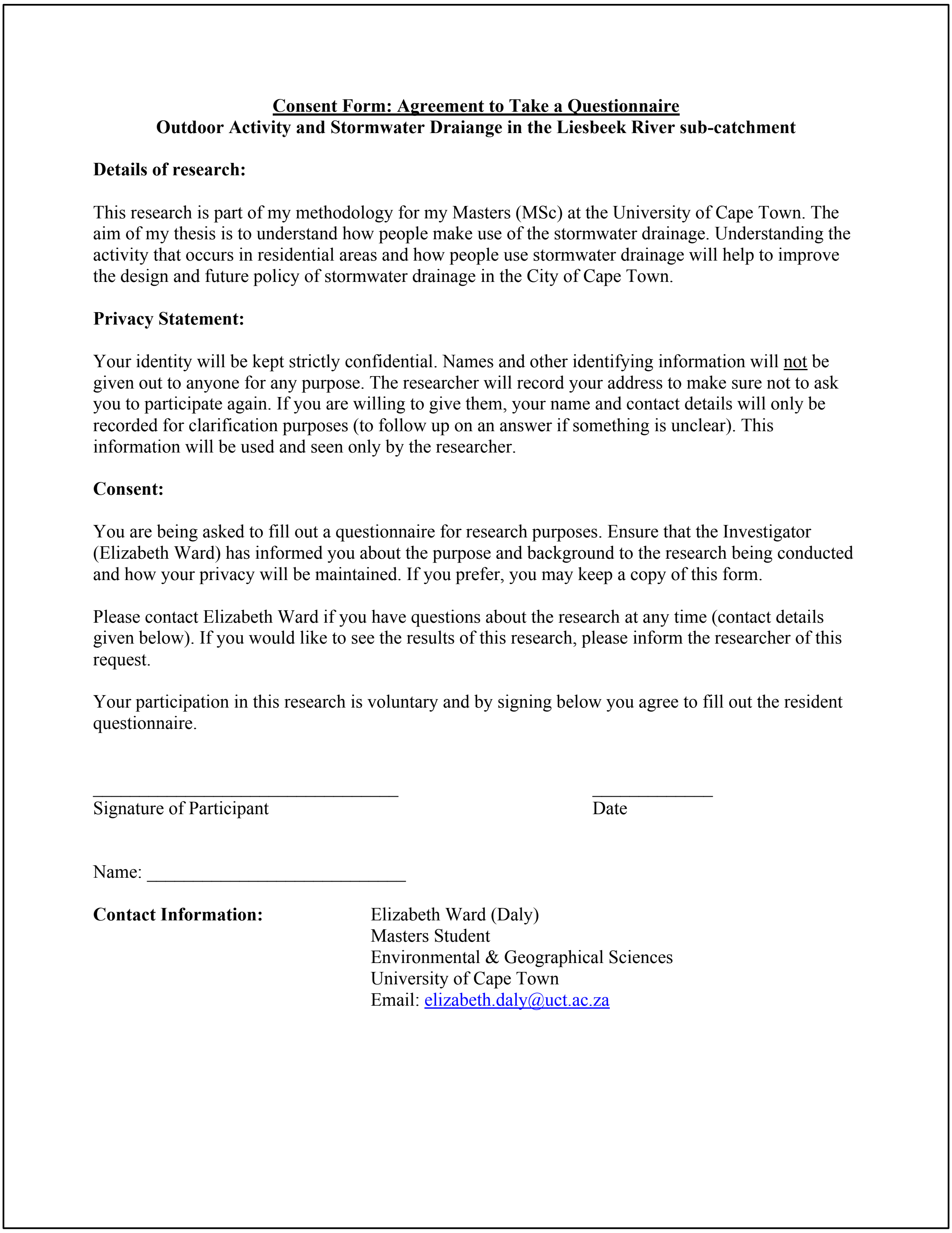
Kind regards,

Elizabeth Ward (Daly)

Mobile: 072 191 8638
Email: elizabeth.daly@uct.ac.za

Supervisor: Dr. Kevin Winter
Environmental & Geographical Sciences
University of Cape Town

Appendix 2c: Consent form completed by all survey respondents prior to completing the questionnaire.



Consent Form: Agreement to Take a Questionnaire
Outdoor Activity and Stormwater Draiange in the Liesbeek River sub-catchment

Details of research:

This research is part of my methodology for my Masters (MSc) at the University of Cape Town. The aim of my thesis is to understand how people make use of the stormwater drainage. Understanding the activity that occurs in residential areas and how people use stormwater drainage will help to improve the design and future policy of stormwater drainage in the City of Cape Town.

Privacy Statement:

Your identity will be kept strictly confidential. Names and other identifying information will not be given out to anyone for any purpose. The researcher will record your address to make sure not to ask you to participate again. If you are willing to give them, your name and contact details will only be recorded for clarification purposes (to follow up on an answer if something is unclear). This information will be used and seen only by the researcher.

Consent:

You are being asked to fill out a questionnaire for research purposes. Ensure that the Investigator (Elizabeth Ward) has informed you about the purpose and background to the research being conducted and how your privacy will be maintained. If you prefer, you may keep a copy of this form.

Please contact Elizabeth Ward if you have questions about the research at any time (contact details given below). If you would like to see the results of this research, please inform the researcher of this request.

Your participation in this research is voluntary and by signing below you agree to fill out the resident questionnaire.

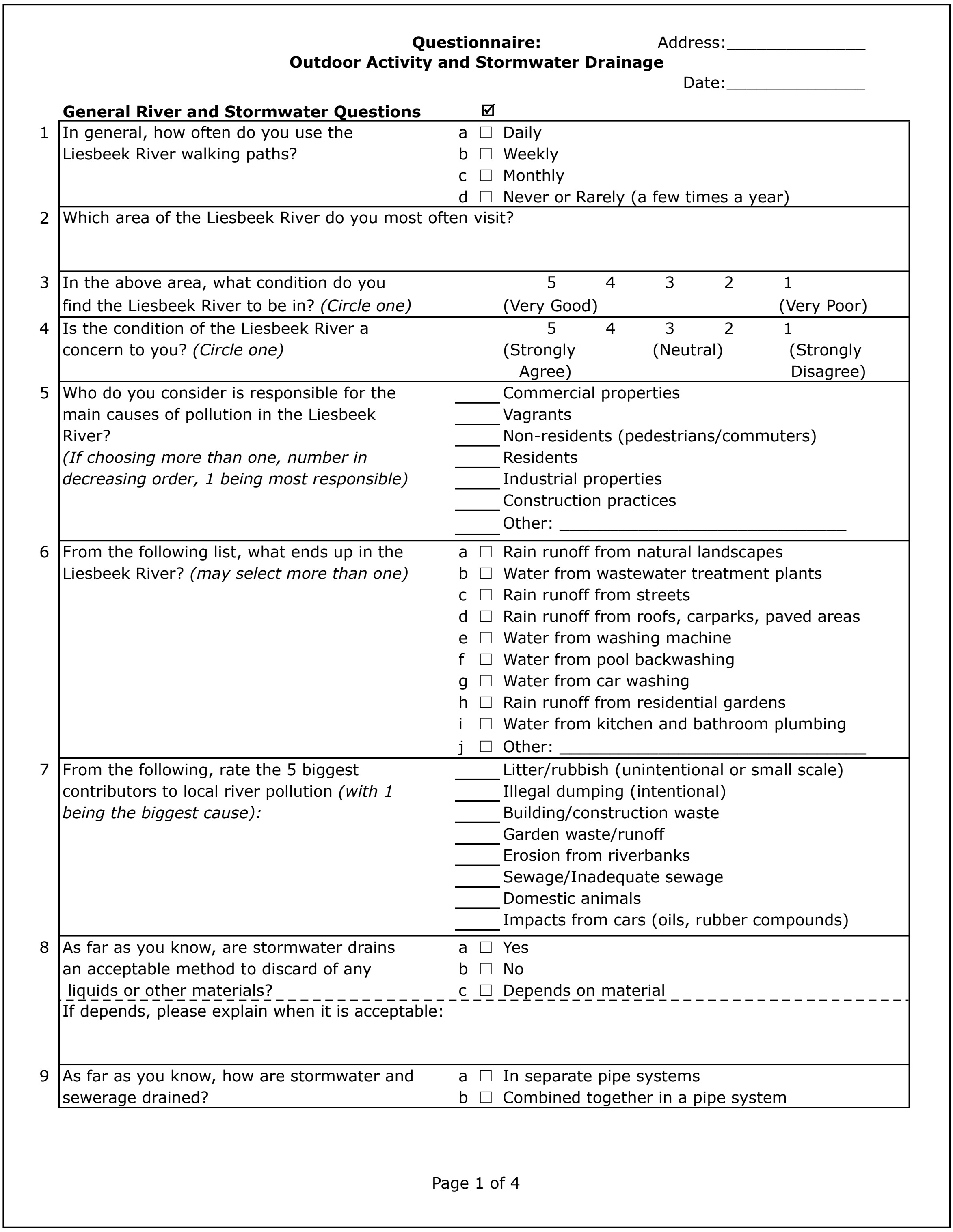
___________________________________ _____________
Signature of Participant Date

Name: ____________________________

Contact Information:

Elizabeth Ward (Daly)
Masters Student
Environmental & Geographical Sciences
University of Cape Town
Email: elizabeth.daly@uct.ac.za

Appendix 2d: Questionnaire administered to participants in the Newlands and Observatory study areas.

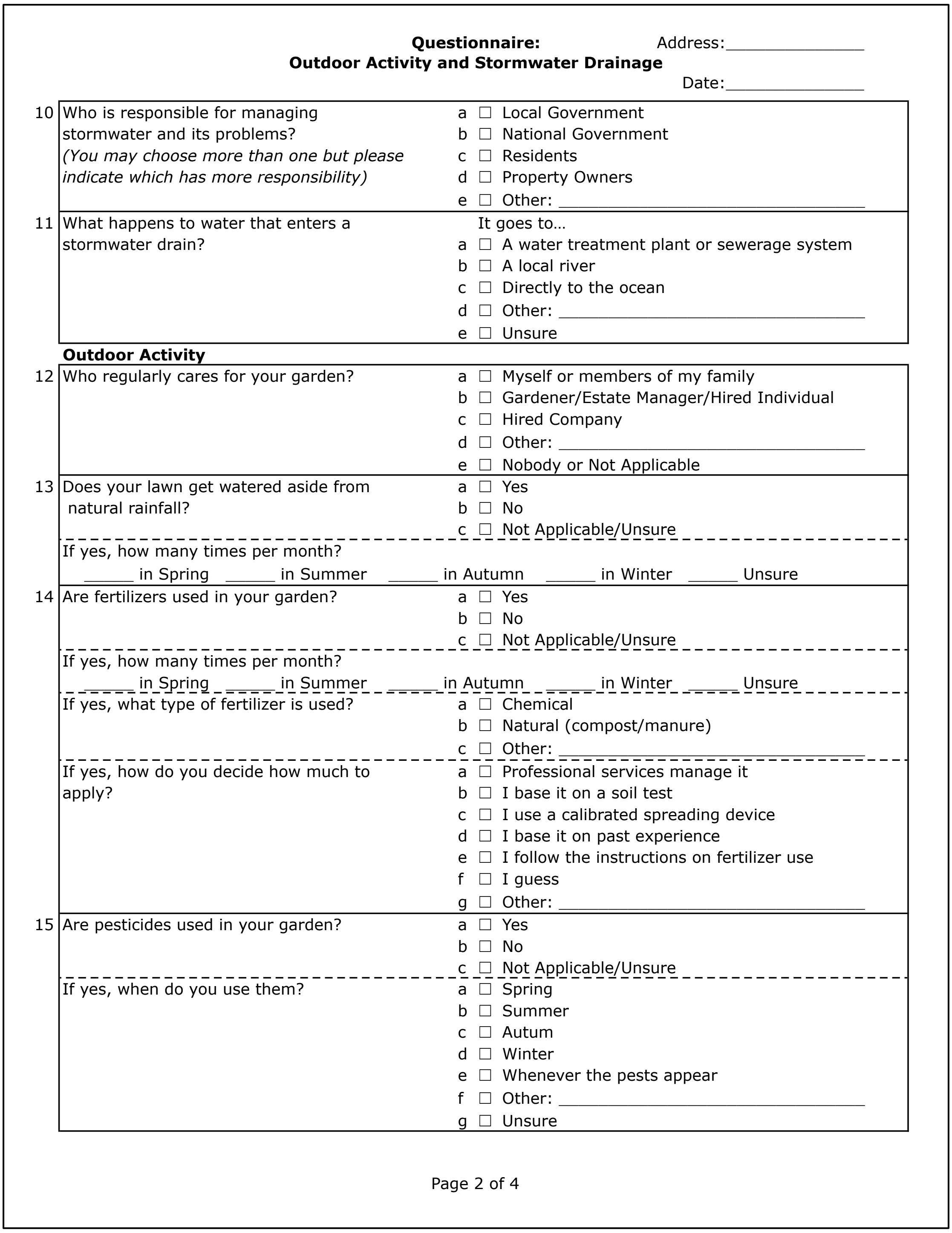


Questionnaire:
Outdoor Activity and Stormwater Drainage

Address:_______________
Date:_______________

General River and Stormwater Questions ☑

1	In general, how often do you use the Liesbeek River walking paths?	a ☐ Daily b ☐ Weekly c ☐ Monthly d ☐ Never or Rarely (a few times a year)
2	Which area of the Liesbeek River do you most often visit?	
3	In the above area, what condition do you find the Liesbeek River to be in? *(Circle one)*	5 4 3 2 1 (Very Good) (Very Poor)
4	Is the condition of the Liesbeek River a concern to you? *(Circle one)*	5 4 3 2 1 (Strongly Agree) (Neutral) (Strongly Disagree)
5	Who do you consider is responsible for the main causes of pollution in the Liesbeek River? *(If choosing more than one, number in decreasing order, 1 being most responsible)*	_____ Commercial properties _____ Vagrants _____ Non-residents (pedestrians/commuters) _____ Residents _____ Industrial properties _____ Construction practices _____ Other: ______________________________
6	From the following list, what ends up in the Liesbeek River? *(may select more than one)*	a ☐ Rain runoff from natural landscapes b ☐ Water from wastewater treatment plants c ☐ Rain runoff from streets d ☐ Rain runoff from roofs, carparks, paved areas e ☐ Water from washing machine f ☐ Water from pool backwashing g ☐ Water from car washing h ☐ Rain runoff from residential gardens i ☐ Water from kitchen and bathroom plumbing j ☐ Other: ________________________________
7	From the following, rate the 5 biggest contributors to local river pollution *(with 1 being the biggest cause):*	_____ Litter/rubbish (unintentional or small scale) _____ Illegal dumping (intentional) _____ Building/construction waste _____ Garden waste/runoff _____ Erosion from riverbanks _____ Sewage/Inadequate sewage _____ Domestic animals _____ Impacts from cars (oils, rubber compounds)
8	As far as you know, are stormwater drains an acceptable method to discard of any liquids or other materials?	a ☐ Yes b ☐ No c ☐ Depends on material
	If depends, please explain when it is acceptable:	
9	As far as you know, how are stormwater and sewerage drained?	a ☐ In separate pipe systems b ☐ Combined together in a pipe system



Questionnaire:
Outdoor Activity and Stormwater Drainage

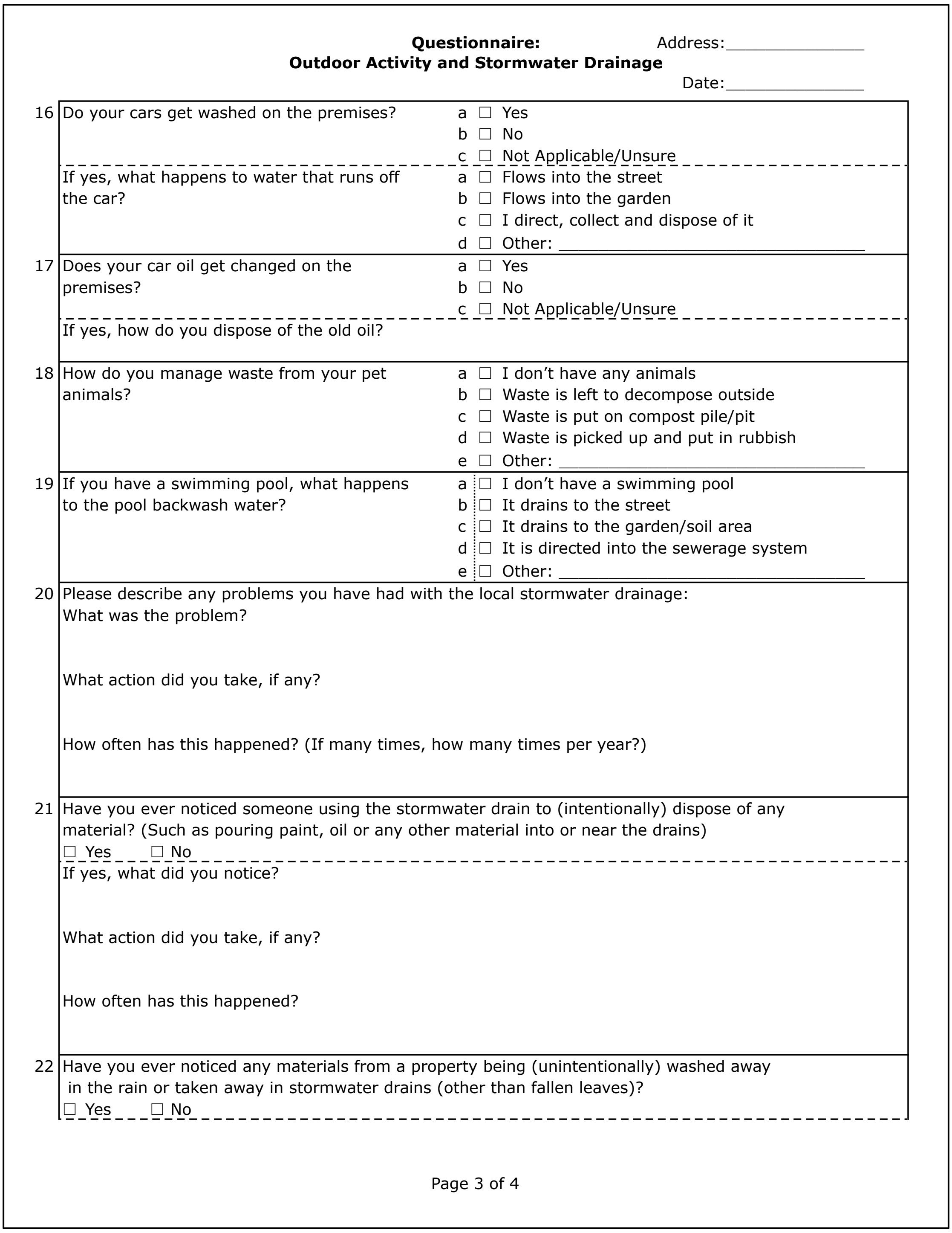
Address:_______________

Date:_______________

10	Who is responsible for managing stormwater and its problems? *(You may choose more than one but please indicate which has more responsibility)*	a ☐ Local Government b ☐ National Government c ☐ Residents d ☐ Property Owners e ☐ Other: _________________________________
11	What happens to water that enters a stormwater drain?	It goes to… a ☐ A water treatment plant or sewerage system b ☐ A local river c ☐ Directly to the ocean d ☐ Other: _________________________________ e ☐ Unsure

Outdoor Activity

12	Who regularly cares for your garden?	a ☐ Myself or members of my family b ☐ Gardener/Estate Manager/Hired Individual c ☐ Hired Company d ☐ Other: _________________________________ e ☐ Nobody or Not Applicable
13	Does your lawn get watered aside from natural rainfall?	a ☐ Yes b ☐ No c ☐ Not Applicable/Unsure
	If yes, how many times per month? ______ in Spring ______ in Summer ______ in Autumn ______ in Winter ______ Unsure	
14	Are fertilizers used in your garden?	a ☐ Yes b ☐ No c ☐ Not Applicable/Unsure
	If yes, how many times per month? ______ in Spring ______ in Summer ______ in Autumn ______ in Winter ______ Unsure	
	If yes, what type of fertilizer is used?	a ☐ Chemical b ☐ Natural (compost/manure) c ☐ Other: _________________________________
	If yes, how do you decide how much to apply?	a ☐ Professional services manage it b ☐ I base it on a soil test c ☐ I use a calibrated spreading device d ☐ I base it on past experience e ☐ I follow the instructions on fertilizer use f ☐ I guess g ☐ Other: _________________________________
15	Are pesticides used in your garden?	a ☐ Yes b ☐ No c ☐ Not Applicable/Unsure
	If yes, when do you use them?	a ☐ Spring b ☐ Summer c ☐ Autum d ☐ Winter e ☐ Whenever the pests appear f ☐ Other: _________________________________ g ☐ Unsure



Questionnaire:
Outdoor Activity and Stormwater Drainage

Address:_______________

Date:_______________

16 Do your cars get washed on the premises?
a ☐ Yes
b ☐ No
c ☐ Not Applicable/Unsure

If yes, what happens to water that runs off the car?
a ☐ Flows into the street
b ☐ Flows into the garden
c ☐ I direct, collect and dispose of it
d ☐ Other: _________________________________

17 Does your car oil get changed on the premises?
a ☐ Yes
b ☐ No
c ☐ Not Applicable/Unsure

If yes, how do you dispose of the old oil?

18 How do you manage waste from your pet animals?
a ☐ I don't have any animals
b ☐ Waste is left to decompose outside
c ☐ Waste is put on compost pile/pit
d ☐ Waste is picked up and put in rubbish
e ☐ Other: _________________________________

19 If you have a swimming pool, what happens to the pool backwash water?
a ☐ I don't have a swimming pool
b ☐ It drains to the street
c ☐ It drains to the garden/soil area
d ☐ It is directed into the sewerage system
e ☐ Other: _________________________________

20 Please describe any problems you have had with the local stormwater drainage:
What was the problem?

What action did you take, if any?

How often has this happened? (If many times, how many times per year?)

21 Have you ever noticed someone using the stormwater drain to (intentionally) dispose of any material? (Such as pouring paint, oil or any other material into or near the drains)
☐ Yes ☐ No

If yes, what did you notice?

What action did you take, if any?

How often has this happened?

22 Have you ever noticed any materials from a property being (unintentionally) washed away in the rain or taken away in stormwater drains (other than fallen leaves)?
☐ Yes ☐ No

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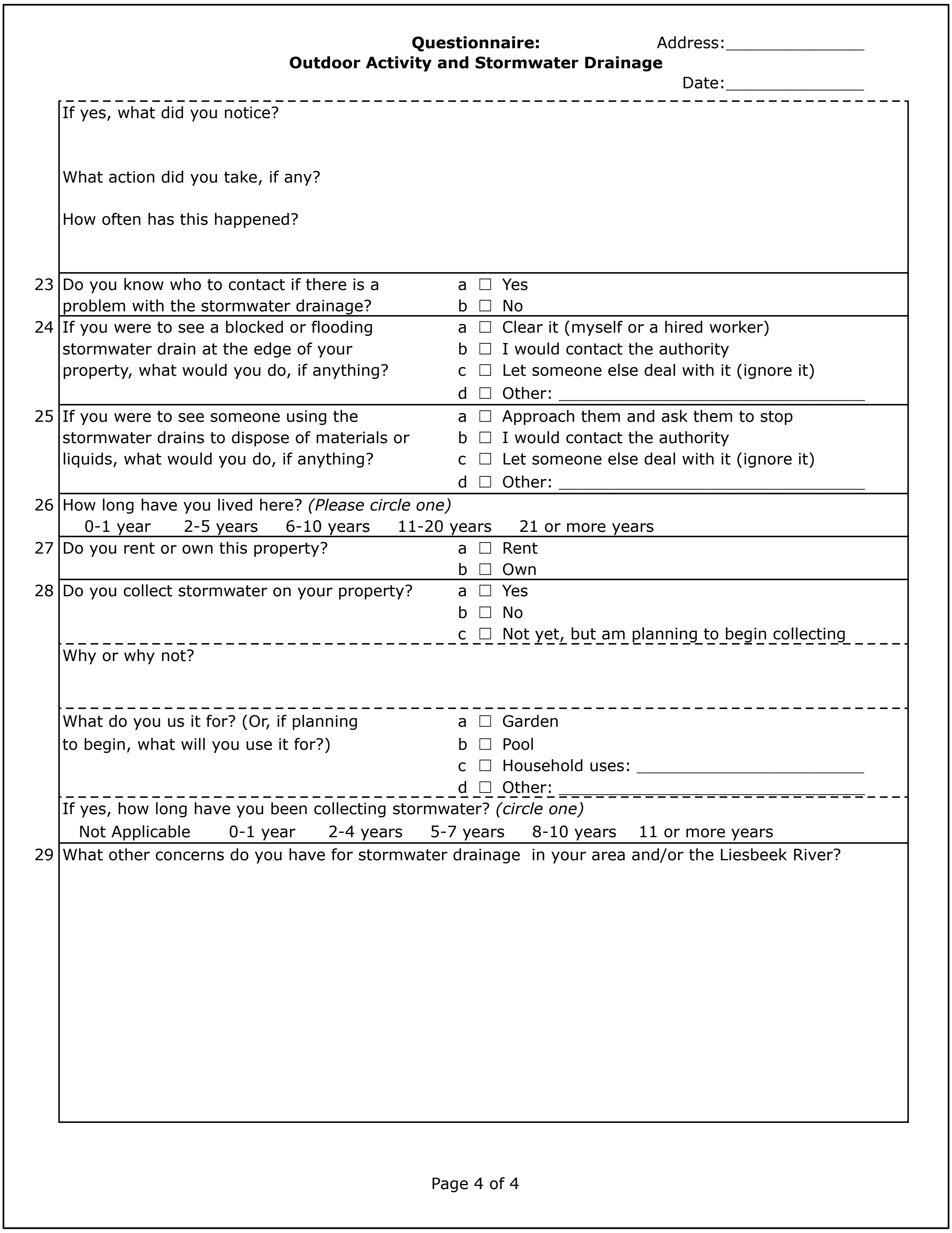

Questionnaire: Address:_______________

Outdoor Activity and Stormwater Drainage

Date:_______________

	If yes, what did you notice? What action did you take, if any? How often has this happened?	
23	Do you know who to contact if there is a problem with the stormwater drainage?	a ☐ Yes b ☐ No
24	If you were to see a blocked or flooding stormwater drain at the edge of your property, what would you do, if anything?	a ☐ Clear it (myself or a hired worker) b ☐ I would contact the authority c ☐ Let someone else deal with it (ignore it) d ☐ Other: ________________________________
25	If you were to see someone using the stormwater drains to dispose of materials or liquids, what would you do, if anything?	a ☐ Approach them and ask them to stop b ☐ I would contact the authority c ☐ Let someone else deal with it (ignore it) d ☐ Other: ________________________________
26	How long have you lived here? *(Please circle one)* 0-1 year 2-5 years 6-10 years 11-20 years 21 or more years	
27	Do you rent or own this property?	a ☐ Rent b ☐ Own
28	Do you collect stormwater on your property?	a ☐ Yes b ☐ No c ☐ Not yet, but am planning to begin collecting
	Why or why not?	
	What do you us it for? (Or, if planning to begin, what will you use it for?)	a ☐ Garden b ☐ Pool c ☐ Household uses: ________________________ d ☐ Other: ________________________________
	If yes, how long have you been collecting stormwater? *(circle one)* Not Applicable 0-1 year 2-4 years 5-7 years 8-10 years 11 or more years	
29	What other concerns do you have for stormwater drainage in your area and/or the Liesbeek River?	

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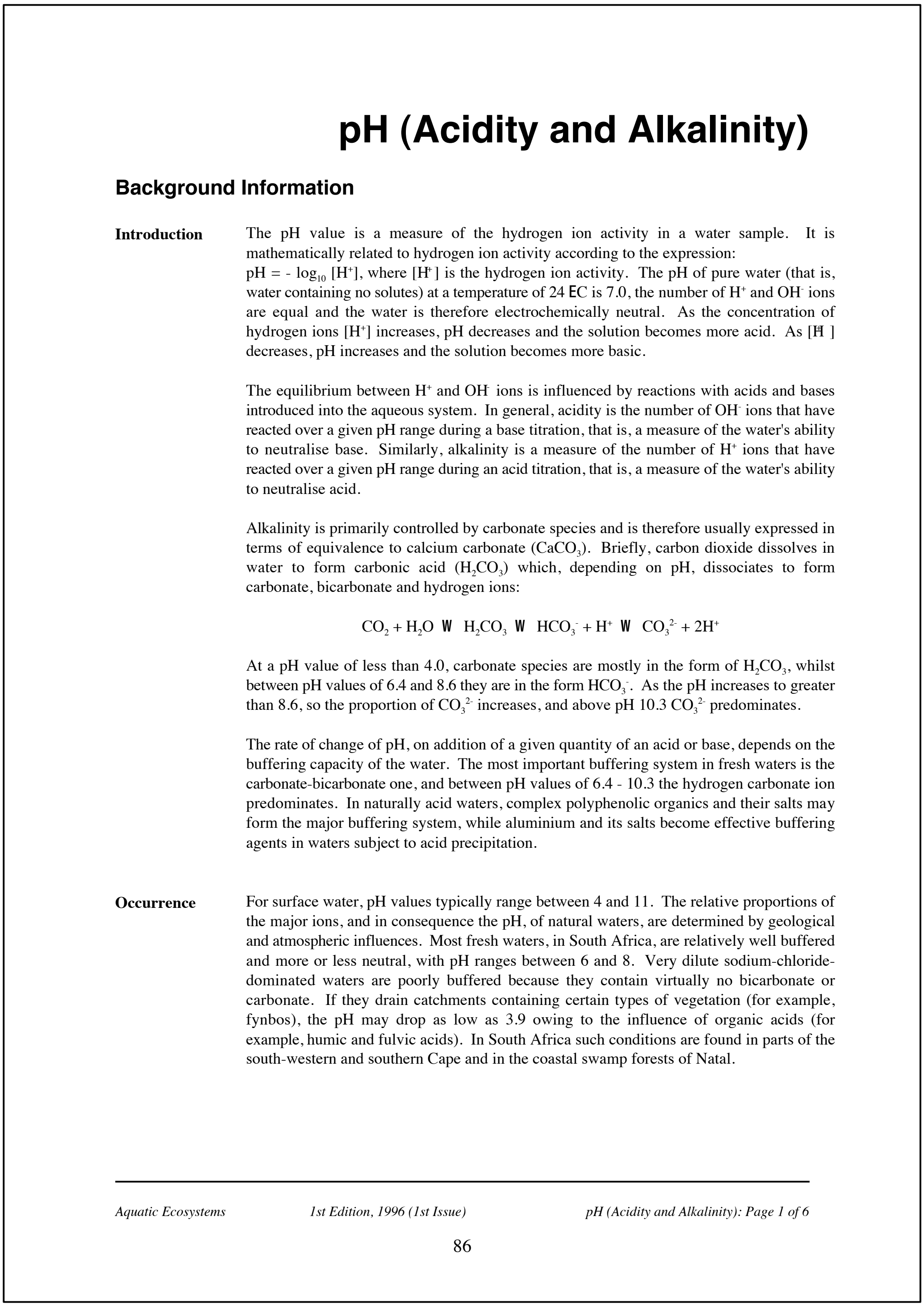
Appendix 3: South African Water Quality Guidelines

Appendix 3a: South African Water Quality Guidelines for Aquatic Ecosystems: pH (Republic of South Africa, Department of Water Affairs and Forestry, 1996)



pH (Acidity and Alkalinity)

Background Information

Introduction

The pH value is a measure of the hydrogen ion activity in a water sample. It is mathematically related to hydrogen ion activity according to the expression:
$pH = -\log_{10} [H^+]$, where $[H^+]$ is the hydrogen ion activity. The pH of pure water (that is, water containing no solutes) at a temperature of 24 °C is 7.0, the number of H^+ and OH^- ions are equal and the water is therefore electrochemically neutral. As the concentration of hydrogen ions $[H^+]$ increases, pH decreases and the solution becomes more acid. As $[H^+]$ decreases, pH increases and the solution becomes more basic.

The equilibrium between H^+ and OH^- ions is influenced by reactions with acids and bases introduced into the aqueous system. In general, acidity is the number of OH^- ions that have reacted over a given pH range during a base titration, that is, a measure of the water's ability to neutralise base. Similarly, alkalinity is a measure of the number of H^+ ions that have reacted over a given pH range during an acid titration, that is, a measure of the water's ability to neutralise acid.

Alkalinity is primarily controlled by carbonate species and is therefore usually expressed in terms of equivalence to calcium carbonate ($CaCO_3$). Briefly, carbon dioxide dissolves in water to form carbonic acid (H_2CO_3) which, depending on pH, dissociates to form carbonate, bicarbonate and hydrogen ions:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+ \rightleftharpoons CO_3^{2-} + 2H^+$$

At a pH value of less than 4.0, carbonate species are mostly in the form of H_2CO_3, whilst between pH values of 6.4 and 8.6 they are in the form HCO_3^-. As the pH increases to greater than 8.6, so the proportion of CO_3^{2-} increases, and above pH 10.3 CO_3^{2-} predominates.

The rate of change of pH, on addition of a given quantity of an acid or base, depends on the buffering capacity of the water. The most important buffering system in fresh waters is the carbonate-bicarbonate one, and between pH values of 6.4 - 10.3 the hydrogen carbonate ion predominates. In naturally acid waters, complex polyphenolic organics and their salts may form the major buffering system, while aluminium and its salts become effective buffering agents in waters subject to acid precipitation.

Occurrence

For surface water, pH values typically range between 4 and 11. The relative proportions of the major ions, and in consequence the pH, of natural waters, are determined by geological and atmospheric influences. Most fresh waters, in South Africa, are relatively well buffered and more or less neutral, with pH ranges between 6 and 8. Very dilute sodium-chloride-dominated waters are poorly buffered because they contain virtually no bicarbonate or carbonate. If they drain catchments containing certain types of vegetation (for example, fynbos), the pH may drop as low as 3.9 owing to the influence of organic acids (for example, humic and fulvic acids). In South Africa such conditions are found in parts of the south-western and southern Cape and in the coastal swamp forests of Natal.

The pH may also vary both diurnally and seasonally. Diurnal fluctuations occur in productive systems where the relative rates of photosynthesis and respiration vary over a 24-hour period, because photosynthesis alters the carbonate/bicarbonate equilibrium by removing CO_2 from the water. Seasonal variability is largely related to the hydrological cycle, particularly in rivers draining catchments with vegetation such as fynbos, where the concentration of organic acids is consistently lower during the rainy season.

Industrial activities generally cause acidification rather than alkalinization of rivers. Acidification is normally the result of three different types of pollution, namely:

- low-pH point-source effluents from industries, such as pulp and paper and tanning and leather industries;
- mine drainage, which is nearly always acid, leading to the pH of receiving streams dropping to below 2; and
- acid precipitation resulting largely from atmospheric pollution caused by the burning of coal (and subsequent production of sulphur dioxide (SO_2)) and the exhausts of combustion engines (nitrogen oxides). Both sulphur oxides (SO_x) and nitrogen oxides (NO_x) form strong mineral acids when dissolved in water. When acid rain falls on a catchment, the strong acids leach calcium and magnesium from the soil and also interfere with nutrient availability.

Elevated pH values can be caused by increased biological activity in eutrophic systems. The pH values may fluctuate widely from below 6 - above 10 over a 24-hour period as a result of changing rates of photosynthesis and respiration.

Interactions

The pH is affected by factors such as temperature, the concentrations of inorganic and organic ions, and biological activity. The pH may also affect the availability and toxicity of constituents such as trace metals, non-metallic ions such as ammonium, and essential elements such as selenium.

The pH of fresh water decreases by 0.1 of a unit for a temperature increase of 20 EC, and changes in temperature are therefore unlikely to be of any significance in the measure of pH in aquatic ecosystems.

The toxic effects of acid pH values on fish increase as the concentrations of calcium, chloride and sodium decrease.

Extreme rates photosynthesis, whether natural or as a result of eutrophication, commonly result in very high pH values in standing waters. High rates of consumption of CO_2 during photosynthesis drive the carbonate species equilibrium toward carbonic acid and hence to extremely high pH values (> 10). This process occurs only in the light. At night, the major biotic processes of respiration and decomposition release CO_2, resulting in a decrease in pH. Very eutrophic systems may, therefore, exhibit significant diel fluctuations in pH. Extreme eutrophication, however, is not common in rivers, where large fluctuations in pH are rare.

In relation to this, high concentrations of dissolved oxygen may decrease the effect of high pH values on fish, particularly if alkaline conditions are the result of intense photosynthetic activity of aquatic plants, which is normally accompanied by high levels of dissolved oxygen.

The buffering capacity affects the rate of change of pH in aquatic systems. In poorly buffered waters, pH can change rapidly, which in turn may have severe effects on the aquatic biota.

The degree of dissociation of weak acids and bases is affected by changes in pH. Thus, pH determines the chemical species of many metals, and thereby alters the availability and toxicity of metals in the aquatic environment. The metals most likely to have increased detrimental environmental effects as a result of lowered pH are silver, aluminium, cadmium, cobalt, copper, mercury, manganese, nickel, lead and zinc.

Non-metallic ions can be similarly affected by changes in pH. Ammonium ions (NH_4^+), which are not toxic, are the main form in which nitrogen is assimilated by aquatic plants. However, at pH values greater than 8, the NH_4^+ ions are converted to the highly toxic un-ionized ammonia (NH_3).

A decrease in pH can also decrease the solubility of certain essential elements such as selenium. Human populations from areas polluted by acid rain are at risk of being subject to selenium deficiencies.

Since the adsorptive properties of large molecules (such as polyphenolics) and of particulate matter in water depend on their surface charges, altering the pH can also alter the degree to which nutrients such as PO_4^{3-}, trace metals and biocides adsorb to these materials. This is of particular significance where lowered pH levels can lead to the release of toxic metals from sediments.

Measurement

The mean pH is calculated from the mean hydrogen ion ($[H^+]$) concentration. The accuracy is normally ± 0.1 of a pH unit. The pH may also be measured by storing water in bottles and using a laboratory pH meter. Such meters have a greater accuracy (± 0.02 of a pH unit). Where possible laboratory pH metres should not be used for poorly buffered systems, because the pH can increase by greater than 2 units in stored water samples. Ideally, pH should be measured over a 24-hour period so that diel variations are determined, although "spot" or instantaneous measurements are more often taken. In systems with significant biological activity, however, these measurements are almost valueless unless taken under comparable conditions of ambient light and temperature, preferably at night.

By definition, pH values are calculated arithmetically, and mean values are estimated from the logarithms of the reciprocals. Reporting the range of pH values, in addition to the mean value, is recommended.

Data Interpretation

Background pH values, in addition to diel and seasonal variability, need to be established if deviation from natural pH values for a particular water body at a particular time is to be assessed. The significance of pH changes to aquatic biota depends on the extent, duration and timing of the changes. Small changes in pH often cause large changes in the concentration of available metallic complexes and can lead to significant increases in the availability and toxicity of most metals.

All pH measurements for the site in question should be within the Target Water Quality Range (TWQR).

Effects and Criteria

Norms

The norms for assessing the effects of pH on aquatic ecosystems are:

- acute and chronic physiological effects on aquatic organisms;
- changes in background site-specific pH values, which result in changes to ecosystem structure and function.

Effects

A change in pH from that normally encountered in unimpacted streams may have severe effects upon the biota. The extent of acidification or alkalinization is important in determining the severity of the effects, which do not vary linearly either with pH or over time. When assessing the potential effect of a change in pH, it is important to note that some streams are naturally more acidic than others and their biotas are often adapted to these conditions.

Direct effects of pH changes consist of alterations in the ionic and osmotic balance of individual organisms, in particular changes in the rate and type of ion exchange across body surfaces. This requires greater energy expenditure, with subsequent effects such as slow growth and reduced fecundity becoming apparent. Aquatic organisms, however, generally have well developed mechanisms for maintaining ionic and osmotic balance. Impacts of indirect pH changes include changes in the availability of toxic substances such as aluminium and ammonia.

Acidic pH

Gradual reductions in pH may result in a change in community structure, with acid-tolerant organisms replacing less tolerant organisms.

Streams with acidic pH values have different periphyton (micro flora and fauna living on solid surfaces) communities and lower overall production compared with less acidic streams.

The discharge of acid wastes into water containing bicarbonate alkalinity results in the formation of free carbon dioxide. If the water is alkaline, free CO_2 may be liberated and be toxic to fish even though the pH does not drop to a level normally considered toxic.

Alkaline pH

Limited information is available on the effects of elevated pH.

Criteria

The criteria for pH in aquatic ecosystems are:

Water Resource	Target Water Quality Range
All aquatic ecosystems	C pH values should not be allowed to vary from the range of the background pH values for a specific site and time of day, by > 0.5 of a pH unit, **or** by > 5 %, **and should be assessed by whichever estimate is the more conservative**.

The TWQR for pH should be stated in terms of the background site-specific pH regime. In all cases, local background conditions should be determined (including diel and seasonal variability where appropriate) before a water quality objective for a particular aquatic ecosystem is set.

Both spatial and temporal variability in pH need to be determined on a case- and site-specific basis.

Spatial variability includes:

! geographic differences; and
! longitudinal differences (upper, middle and lower reaches of rivers and streams).
differences in pH at various depths of water

Temporal variability includes:

! diel differences; and
! seasonal differences.

Modifications

In certain areas, or at certain sites, it may be necessary to modify the pH criteria provided in this guideline. Where any modification is anticipated, *the user of the guidelines must obtain expert advice*. All modifications must afford the same level of protection to aquatic ecosystems as stipulated by the criteria given in this guideline.

The following circumstances may require that case- and site-specific pH criteria be derived:

! Where untested locally important species may be very sensitive to changes in pH;
! Where aquatic organisms in field situations may be stressed by diseases, parasites, predators, other contaminants, contaminated or insufficient food, and fluctuating or extreme conditions of flow and water quality; and
! Where background pH values have a range of variation which is greater than that specified by the TWQR.

Conditions for Modification

The following conditions should be satisfied before criteria for pH are altered:

! Adequate site-specific analytical data, covering at least one annual cycle, and diel cycles are available; and
! Site-specific studies demonstrate that there are no adverse effects on the ecosystem for the proposed changes in pH range.

All modifications that result in criteria that are higher than those specified here are subject to approval by the Department of Water Affairs and Forestry.

Sources of Information

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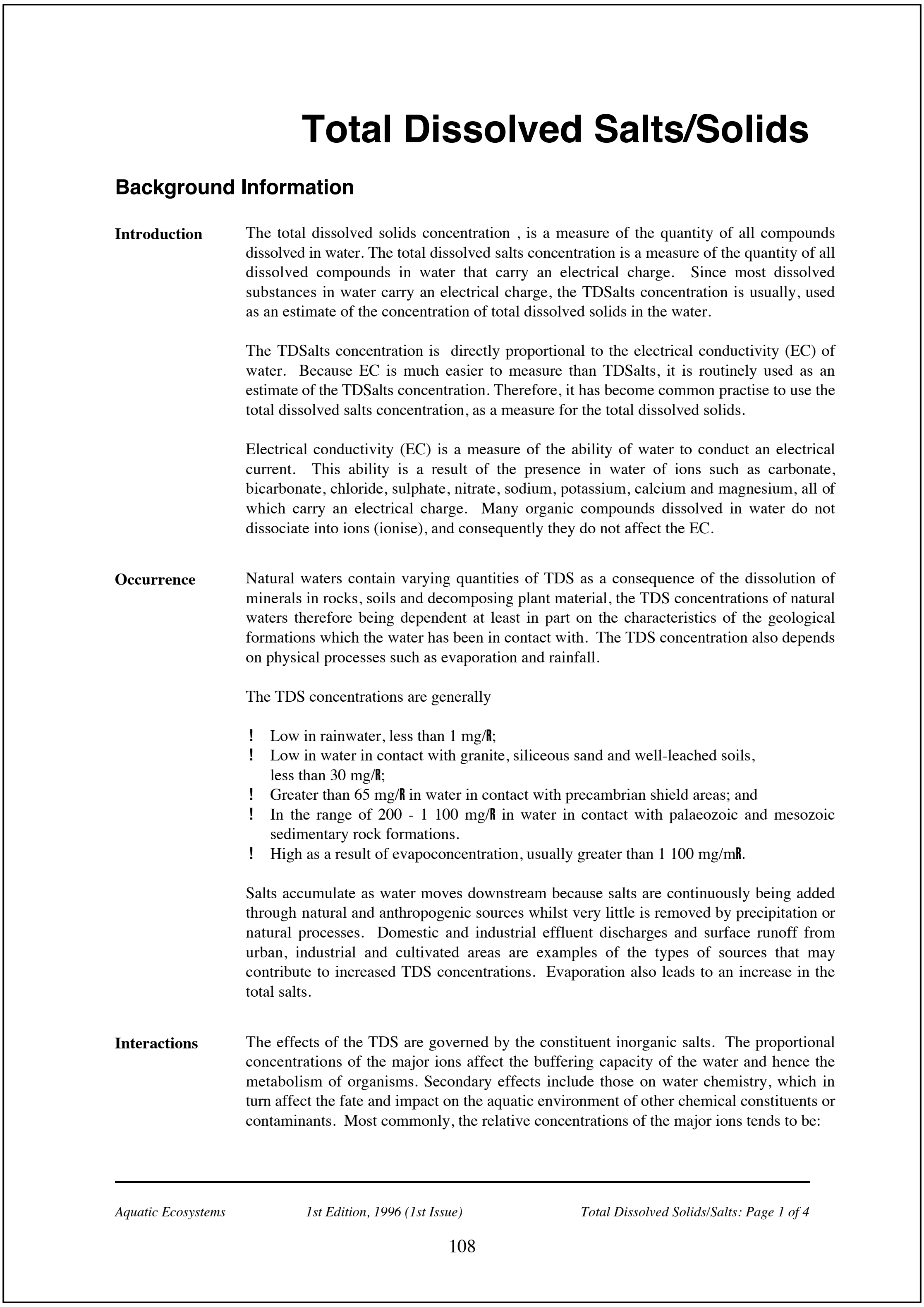
Appendix 3b: South African Water Quality Guidelines for Aquatic Ecosystems: Total Dissolved Solids (Republic of South Africa, Department of Water Affairs and Forestry, 1996)



Total Dissolved Salts/Solids

Background Information

Introduction

The total dissolved solids concentration , is a measure of the quantity of all compounds dissolved in water. The total dissolved salts concentration is a measure of the quantity of all dissolved compounds in water that carry an electrical charge. Since most dissolved substances in water carry an electrical charge, the TDSalts concentration is usually, used as an estimate of the concentration of total dissolved solids in the water.

The TDSalts concentration is directly proportional to the electrical conductivity (EC) of water. Because EC is much easier to measure than TDSalts, it is routinely used as an estimate of the TDSalts concentration. Therefore, it has become common practise to use the total dissolved salts concentration, as a measure for the total dissolved solids.

Electrical conductivity (EC) is a measure of the ability of water to conduct an electrical current. This ability is a result of the presence in water of ions such as carbonate, bicarbonate, chloride, sulphate, nitrate, sodium, potassium, calcium and magnesium, all of which carry an electrical charge. Many organic compounds dissolved in water do not dissociate into ions (ionise), and consequently they do not affect the EC.

Occurrence

Natural waters contain varying quantities of TDS as a consequence of the dissolution of minerals in rocks, soils and decomposing plant material, the TDS concentrations of natural waters therefore being dependent at least in part on the characteristics of the geological formations which the water has been in contact with. The TDS concentration also depends on physical processes such as evaporation and rainfall.

The TDS concentrations are generally

- Low in rainwater, less than 1 mg/ℓ;
- Low in water in contact with granite, siliceous sand and well-leached soils, less than 30 mg/ℓ;
- Greater than 65 mg/ℓ in water in contact with precambrian shield areas; and
- In the range of 200 - 1 100 mg/ℓ in water in contact with palaeozoic and mesozoic sedimentary rock formations.
- High as a result of evapoconcentration, usually greater than 1 100 mg/mℓ.

Salts accumulate as water moves downstream because salts are continuously being added through natural and anthropogenic sources whilst very little is removed by precipitation or natural processes. Domestic and industrial effluent discharges and surface runoff from urban, industrial and cultivated areas are examples of the types of sources that may contribute to increased TDS concentrations. Evaporation also leads to an increase in the total salts.

Interactions

The effects of the TDS are governed by the constituent inorganic salts. The proportional concentrations of the major ions affect the buffering capacity of the water and hence the metabolism of organisms. Secondary effects include those on water chemistry, which in turn affect the fate and impact on the aquatic environment of other chemical constituents or contaminants. Most commonly, the relative concentrations of the major ions tends to be:

- Cations: $Na^+ > Ca^{2+}/Mg^{2+} > K^+$
- Anions: $Cl^- > HCO_3^- > SO_4^{2-} > CO_3^{2-}$

Measurement

The TDS content of a water sample is measured gravimetrically. The water sample should be filtered through a 0.45 µm pore size filter, and the filtrate evaporated to dryness at 60 °C. The mass of the residue will approximate the TDS present in the filtrate. If the filtrate is evaporated at a high temperature (> 100 °C), some carbonate and all organic dissolved solids will be lost; at lower evaporation temperatures (65 - 85 °C), virtually no material is lost.

Electrical conductivity (EC) is a rapid and useful surrogate measure of the TDS content of those waters with a low organic content. Electrical Conductivity is determined by measuring the electrical conductance of water and is usually expressed in units of milli-Siemens per metre (mS/m). Owing to the dependence of EC measurements on temperature, EC measurements are reported at a standard reference temperature of 25 °C. Conversion factors for different temperatures are given in standard textbooks.

The TDS concentration of most natural waters can be estimated by multiplying EC by a constant. If EC is measured in units of mS/m and the TDS concentration is to be expressed in mg/ℓ, this factor generally falls in the range 5.5 - 7.5. The following general relationship is commonly used as an approximation for TDS concentrations from EC for South African inland waters:

- TDS (mg/ℓ) = EC (mS/m at 25 °C) x 6.5

The exact value of the conversion factor depends on the ratio of divalent to monovalent ions and the organic and inorganic content. Waters with a low or high pH typically require a conversion factor greater than 6.5. If very accurate estimates of the TDS concentration from EC measurements are required then the conversion factor should be experimentally determined for each specific site and for specific runoff event.

Data Interpretation

Changes in the EC values provide useful and rapid estimates of changes in the TDS concentration, once the relationship between EC and TDS has been established for a particular water body. However, changes in EC values provide no information on the changes in the proportional concentrations of the major ions. Similarly, the relationship between TDS and EC will not reflect changes in the concentration of minor ions and nutrients such as phosphate and nitrate.

Changes in the long-term shifts in the TDS concentration are more important than single values. Therefore, mean or seasonal mean values for the concentrations in a data set should be compared with the Target Water Quality Range (TWQR).

Effects and Criteria

Norms

The norms for assessing the effects of the total dissolved solids on aquatic ecosystems are:

- chronic and acute physiological effects on aquatic biota; and
- changes in the "natural" site-specific TDS levels which cause changes in ecosystem structure and function.

Effects

Plants and animals possess a wide range of physiological mechanisms and adaptations to maintain the necessary balance of water and dissolved ions in cells and tissues. This ability is extremely important in any consideration of the effects of changes in total dissolved solids on aquatic organisms. The individual ions making up the TDS also exert physiological effects on aquatic organisms.

Changes in the concentration of the total dissolved solids can affect aquatic organisms at three levels, namely:

- effects on, and adaptations of, individual species;
- effects on community structure; and
- effects on microbial and ecological processes such as rates of metabolism and nutrient cycling.

The rate of change of the TDS concentration, and the duration of change, appears to be more important than absolute changes in the TDS concentration, particularly in systems where the organisms may not be adapted to fluctuating levels of TDS. Seasonal timing of the change in TDS concentration may also have important synergistic effects with water temperature on the total community composition and functioning. Organisms adapted to low-salinity habitats are generally sensitive to changes in the TDS concentration.

Criteria

The TWQR for TDS is stated in terms of case- and site-specific TDS concentrations. In all cases, local conditions should be determined (i.e. TDS concentrations, variability and seasonal changes) before water quality criteria are set.

Water Resource	Target Water Quality Range
All inland waters	C TDS concentrations should not be changed by > 15 % from the normal cycles of the water body under unimpacted conditions at any time of the year; **and** C The amplitude and frequency of natural cycles in TDS concentrations should not be changed.

Modifications

Modifications can be considered where case- and site-specific measurements indicate the TWQR to be too stringent or inappropriate. In particular, site-specific derivation of TDS criteria which are different from the TWQR should be considered in the cases of:

- naturally saline systems;
- rivers or streams which have been subjected to increased TDS concentrations over a long period of time, such that their original biota have either adapted to the new conditions or have been replaced by more salt-tolerant species; and
- where endemic or introduced organisms might be more sensitive to changes in TDS concentrations and may therefore have more stringent TDS requirements, e.g., in unimpacted cold-water habitats.

The following conditions should be satisfied before the TWQR for TDS concentrations is altered:

- ! Adequate site-specific analytical data, covering at least one annual cycle, are available; and
- ! Site-specific studies demonstrate that there are no adverse effects on the ecosystem for the proposed changes in TDS concentrations.

All modifications that result in criteria that are higher than those specified here are subject to approval by the Department of Water Affairs and Forestry.

Sources of Information

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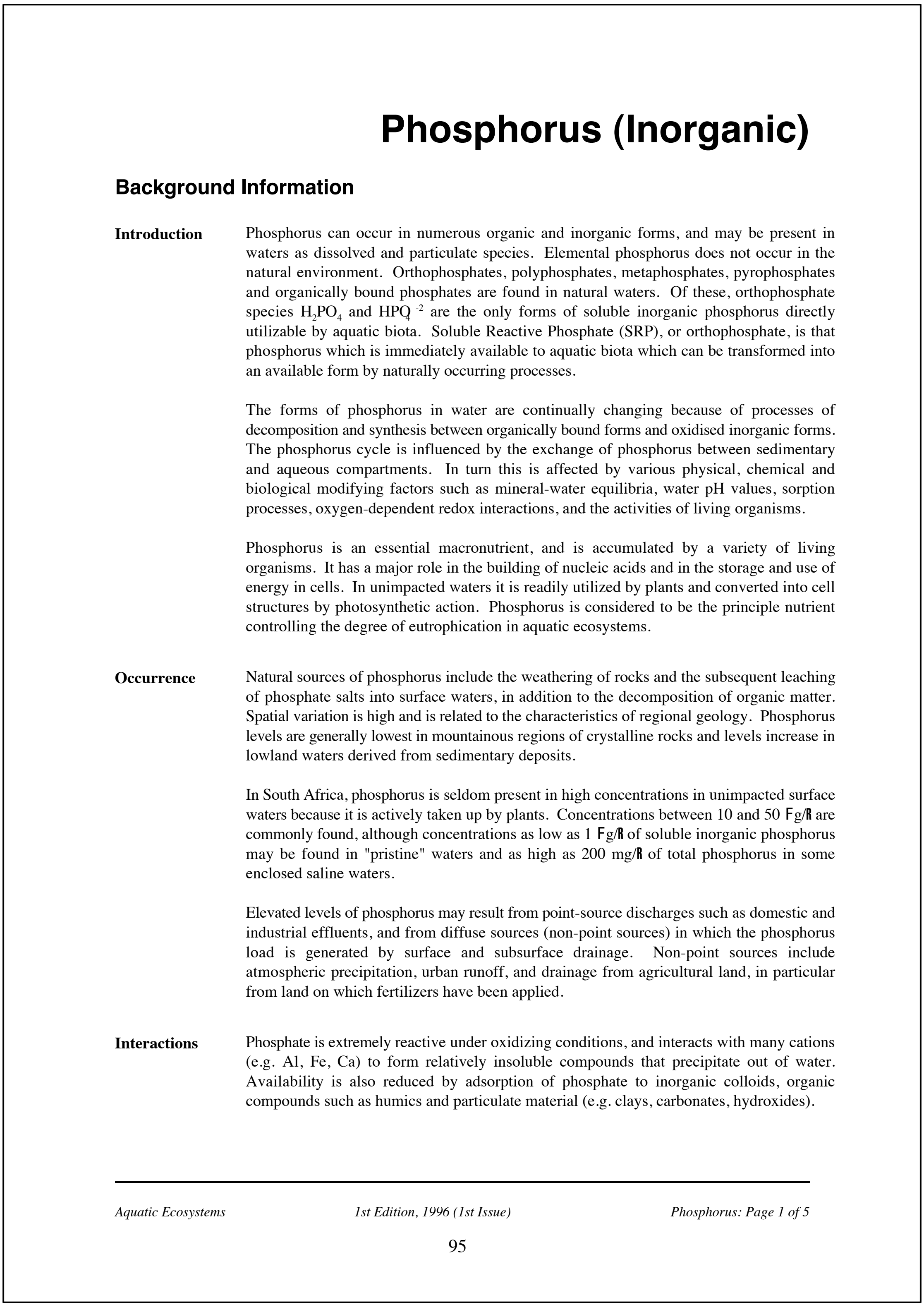
Appendix 3c: South African Water Quality Guidelines for Aquatic Ecosystems: Phosphorous (Republic of South Africa, Department of Water Affairs and Forestry, 1996)



Phosphorus (Inorganic)

Background Information

Introduction

Phosphorus can occur in numerous organic and inorganic forms, and may be present in waters as dissolved and particulate species. Elemental phosphorus does not occur in the natural environment. Orthophosphates, polyphosphates, metaphosphates, pyrophosphates and organically bound phosphates are found in natural waters. Of these, orthophosphate species H_2PO_4 and HPO_4^{-2} are the only forms of soluble inorganic phosphorus directly utilizable by aquatic biota. Soluble Reactive Phosphate (SRP), or orthophosphate, is that phosphorus which is immediately available to aquatic biota which can be transformed into an available form by naturally occurring processes.

The forms of phosphorus in water are continually changing because of processes of decomposition and synthesis between organically bound forms and oxidised inorganic forms. The phosphorus cycle is influenced by the exchange of phosphorus between sedimentary and aqueous compartments. In turn this is affected by various physical, chemical and biological modifying factors such as mineral-water equilibria, water pH values, sorption processes, oxygen-dependent redox interactions, and the activities of living organisms.

Phosphorus is an essential macronutrient, and is accumulated by a variety of living organisms. It has a major role in the building of nucleic acids and in the storage and use of energy in cells. In unimpacted waters it is readily utilized by plants and converted into cell structures by photosynthetic action. Phosphorus is considered to be the principle nutrient controlling the degree of eutrophication in aquatic ecosystems.

Occurrence

Natural sources of phosphorus include the weathering of rocks and the subsequent leaching of phosphate salts into surface waters, in addition to the decomposition of organic matter. Spatial variation is high and is related to the characteristics of regional geology. Phosphorus levels are generally lowest in mountainous regions of crystalline rocks and levels increase in lowland waters derived from sedimentary deposits.

In South Africa, phosphorus is seldom present in high concentrations in unimpacted surface waters because it is actively taken up by plants. Concentrations between 10 and 50 Fg/R are commonly found, although concentrations as low as 1 Fg/R of soluble inorganic phosphorus may be found in "pristine" waters and as high as 200 mg/R of total phosphorus in some enclosed saline waters.

Elevated levels of phosphorus may result from point-source discharges such as domestic and industrial effluents, and from diffuse sources (non-point sources) in which the phosphorus load is generated by surface and subsurface drainage. Non-point sources include atmospheric precipitation, urban runoff, and drainage from agricultural land, in particular from land on which fertilizers have been applied.

Interactions

Phosphate is extremely reactive under oxidizing conditions, and interacts with many cations (e.g. Al, Fe, Ca) to form relatively insoluble compounds that precipitate out of water. Availability is also reduced by adsorption of phosphate to inorganic colloids, organic compounds such as humics and particulate material (e.g. clays, carbonates, hydroxides).

The flow regime is a major factor in the mobility, availability and spatial distribution of phosphorus within a river. Settlement of particulate matter and biotic uptake result in the removal of phosphorus from the water column to the sediments, and during periods of low discharge, stream bed sediments act as a sink for phosphorus. During rainfall events, phosphorus levels may be elevated by runoff from the land, and by re-suspension and flushing of deposited material from the river bed to the water column.

Several chemical bonding processes regulate the amount of inorganic phosphorus which is bonded to iron, aluminium, calcium or organic polyphenols and adsorbed onto suspended particulate material. Adsorbed phosphorus may be released from the sediments under conditions of high flow and under anoxic conditions from both sediments and water. The form of phosphorus in natural surface waters and the equilibrium of the different forms, is influenced by pH.

Measurement

Phosphorus concentrations are usually determined as orthophosphates, total inorganic phosphate or total dissolved phosphorus (which includes organically bound phosphorus and all phosphates). The dissolved forms are measured after filtering the sample through a pre-washed 0.45 Fm filter. Concentrations of particulate phosphorus can be calculated from the difference between the concentrations of the total and dissolved fractions.

Chemical analysis of phosphorus usually centres around the reactivity of phosphates with molybdate ions. During enzymatic and acidic hydrolysis complexes of phosphorus are converted to phosphate species, which are then measured colorimetrically. Four operational categories of phosphates result; these are soluble reactive P, soluble unreactive P, particulate reactive P, and particulate unreactive P. The most commonly measured is Soluble Reactive Phosphate (SRP).

Analysis of phosphorus in the laboratory should be started as soon as possible after sample collection to minimize the possible effects of bacterial transformation and pH changes. Water samples should preferably not be preserved with acid before analysis; rather, the samples should be kept at low temperature (< 4 EC).

Data Interpretation

Occasional increases in the inorganic phosphorus concentration above the Target Water Quality Range (TWQR) are less important than continuously high concentrations. Single measurements of phosphorus are a poor basis for assessment. Average summer inorganic phosphorus concentrations provide the best basis from which to estimate the likely biological consequences of phosphorus. Weekly inorganic phosphorus concentrations, averaged over a period of at least 4 weeks, should be compared with the TWQR.

Any assessment of the influence of the inorganic phosphorus concentrations should be coupled with an evaluation of the ratio of inorganic nitrogen to inorganic phosphorus. Unimpacted streams typically have an N:P ratio greater than 25 - 40:1, whilst most impacted (i.e., eutrophic or hypertrophic) systems have an N:P ratio of less than 10:1.

Effects and Criteria

Norms

Changes in trophic status accompanied by the growth of algae and other aquatic plants in rivers, lakes and reservoirs, are the norms used to assess the effects of inorganic phosphorus on aquatic ecosystems.

Effects

The most significant effect of elevated phosphorus concentrations is its stimulation of the growth of aquatic plants. Both phosphorus and nitrogen limit plant growth, and of these, phosphorus is likely to be more limiting in fresh water. The effect is dependent on the form of phosphorus present in the water, since not all forms are available for uptake by plants. Other factors, such as water temperature, light and the availability of other nutrients, also play an important role in limiting plant growth.

Inorganic phosphorus concentrations of less than 5 Fg P/R are considered to be sufficiently low to reduce the likelihood of algal and other plant growth.

The information given in the table below illustrates typical symptoms associated with selected ranges of inorganic phosphorus concentrations, if all other nutrients and environmental conditions are within favourable ranges for the organisms concerned.

Average Summer Inorganic Phosphorus Concentration (Fg/R)	Effects
< 5	Oligotrophic conditions; usually moderate levels of species diversity; usually low productivity systems with rapid nutrient cycling; no nuisance growth of aquatic plants or blue-green algae.
5 - 25	Mesotrophic conditions; usually high levels of species diversity; usually productive systems; nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms seldom toxic.
25 - 250	Eutrophic conditions; usually low levels of species diversity; usually highly productive systems, with nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms may include species which are toxic to man, livestock and wildlife.
> 250	Hypertrophic conditions; usually very low levels of species diversity; usually very highly productive systems; nuisance growth of aquatic plants and blooms of blue-green algae, often including species which are toxic to man, livestock and wildlife.

Criteria

The inorganic phosphorus concentration for a specific system must be based on the existing trophic status of the system. It is undesirable to allow inorganic phosphorus concentrations to rise to a level which will change the trophic status of the system. A Target Water Quality Range should be derived only after case- or site-specific studies.

Water Resource	Target Water Quality Range
All surface waters	C Inorganic phosphorus concentrations should not be changed by > 15 % from that of the water body under local, unimpacted conditions at any time of the year; **and** C The trophic status of the water body should not increase above its present level, though a *decrease* in trophic status is permissible (see *Effects*); **and** C The amplitude and frequency of natural cycles in inorganic phosphorus concentrations should not be changed.

Modifications The inorganic phosphorus criteria given in the above table may be modified upwards in the case of turbid systems. Limited light penetration or increased turbulence will reduce the extent and density of algal growths at a given inorganic phosphorus concentration. Growths of free-floating aquatic macrophytes (e.g. Water Hyacinth) will not be reduced in such cases.

The following conditions should be satisfied before a decision is taken to modify the Target Water Quality Range for inorganic phosphorus:

! Adequate data (covering at least one summer season) are available;
! Site-specific studies demonstrate that there are no adverse effects on the ecosystem for the proposed changes in inorganic phosphorus concentration in trophic status; and
! Other contributory factors, such as low inorganic nitrogen concentrations, high turbidity and turbulence, will reduce the effects of increased inorganic phosphorus.

Sources of Information

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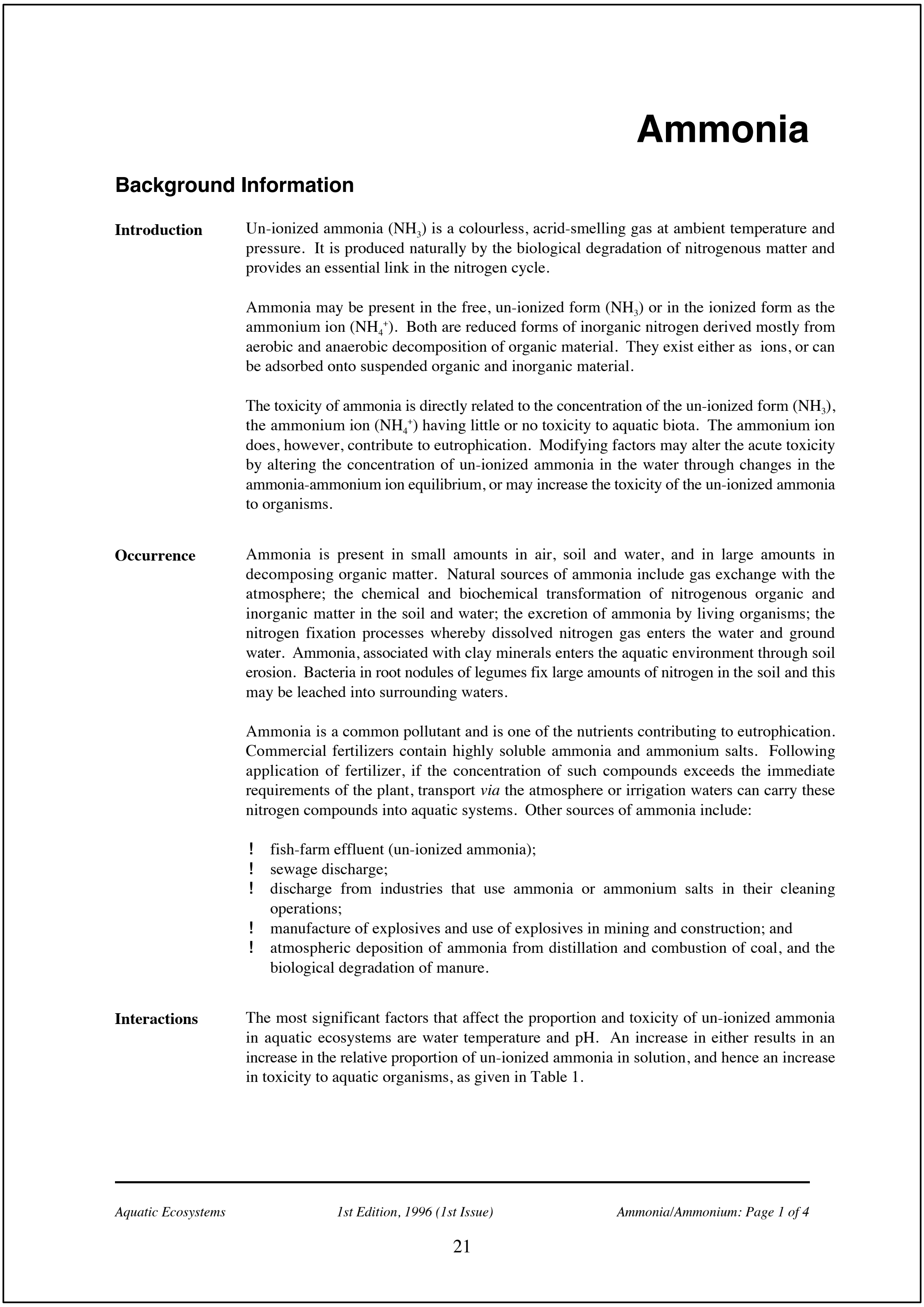
Appendix 3d: South African Water Quality Guidelines for Aquatic Ecosystems: Ammonia (Republic of South Africa, Department of Water Affairs and Forestry, 1996)



Ammonia

Background Information

Introduction

Un-ionized ammonia (NH_3) is a colourless, acrid-smelling gas at ambient temperature and pressure. It is produced naturally by the biological degradation of nitrogenous matter and provides an essential link in the nitrogen cycle.

Ammonia may be present in the free, un-ionized form (NH_3) or in the ionized form as the ammonium ion (NH_4^+). Both are reduced forms of inorganic nitrogen derived mostly from aerobic and anaerobic decomposition of organic material. They exist either as ions, or can be adsorbed onto suspended organic and inorganic material.

The toxicity of ammonia is directly related to the concentration of the un-ionized form (NH_3), the ammonium ion (NH_4^+) having little or no toxicity to aquatic biota. The ammonium ion does, however, contribute to eutrophication. Modifying factors may alter the acute toxicity by altering the concentration of un-ionized ammonia in the water through changes in the ammonia-ammonium ion equilibrium, or may increase the toxicity of the un-ionized ammonia to organisms.

Occurrence

Ammonia is present in small amounts in air, soil and water, and in large amounts in decomposing organic matter. Natural sources of ammonia include gas exchange with the atmosphere; the chemical and biochemical transformation of nitrogenous organic and inorganic matter in the soil and water; the excretion of ammonia by living organisms; the nitrogen fixation processes whereby dissolved nitrogen gas enters the water and ground water. Ammonia, associated with clay minerals enters the aquatic environment through soil erosion. Bacteria in root nodules of legumes fix large amounts of nitrogen in the soil and this may be leached into surrounding waters.

Ammonia is a common pollutant and is one of the nutrients contributing to eutrophication. Commercial fertilizers contain highly soluble ammonia and ammonium salts. Following application of fertilizer, if the concentration of such compounds exceeds the immediate requirements of the plant, transport *via* the atmosphere or irrigation waters can carry these nitrogen compounds into aquatic systems. Other sources of ammonia include:

! fish-farm effluent (un-ionized ammonia);
! sewage discharge;
! discharge from industries that use ammonia or ammonium salts in their cleaning operations;
! manufacture of explosives and use of explosives in mining and construction; and
! atmospheric deposition of ammonia from distillation and combustion of coal, and the biological degradation of manure.

Interactions

The most significant factors that affect the proportion and toxicity of un-ionized ammonia in aquatic ecosystems are water temperature and pH. An increase in either results in an increase in the relative proportion of un-ionized ammonia in solution, and hence an increase in toxicity to aquatic organisms, as given in Table 1.

Table 1: Contribution of un-ionised NH_3 to Total Ammonia (expressed as a percentage), as a Function of pH Value and Water Temperature

pH	Water Temperature (°C)							
	0	5	10	15	20	25	30	35
6.0	0.0083	0.012	0.019	0.027	0.039	0.056	0.079	0.11
6.5	0.026	0.039	0.059	0.086	0.12	0.18	0.25	0.35
7.0	0.083	0.12	0.18	0.27	0.39	0.56	0.79	1.1
7.5	0.26	0.39	0.58	0.85	1.2	1.7	2.4	3.4
8.0	0.82	1.2	1.8	2.6	3.8	5.3	7.3	9.9
8.5	2.6	3.8	5.5	7.9	11	15	20	26
9.0	7.6	11	16	21	28	36	44	52
9.5	21	28	37	46	55	64	71	78

Ammonia toxicity is also affected by the concentrations of dissolved oxygen, carbon dioxide and total dissolved solids, and the presence of other toxicants, such as metal ions. The acute toxicity of ammonia to fish increases as dissolved oxygen decreases. Ammonia is oxidized to nitrate in well oxygenated waters. Ammonia may also be adsorbed onto suspended and bed sediments and to colloidal particles.

Measurement

Ammonia criteria for aquatic ecosystems are calculated from the total ammonia concentration, that is, the sum of the NH_3 and NH_4^+ concentrations. The reference method for the determination of total ammonia is the phenate hypochlorite method, followed by spectrophotometry or colorimetry. The concentration of free ammonia is estimated from Table 1. The most reliable results are obtained on fresh samples. However, if prompt analysis is not possible, samples should be preserved with H_2SO_4, stored at 4 EC, and neutralised with NaOH or KOH prior to analysis.

As with all determinations of nutrients, care must be taken to prevent contamination of water samples. Glass bottles/vials, suitably pre-cleaned to remove nitrogenous contaminants, are required. Samples should not be preserved with nitric acid and no head space in the bottle should be allowed.

Data Interpretation

Single measurements of ammonia are of limited use. Preferably, weekly ammonia concentrations, averaged over a period of at least 4 weeks, with the minimum and maximum values reported, should be compared with the Target Water Quality Range (TWQR).

Interpretation of the ammonia criteria is based on the free ammonia concentrations. The potential effect of ammonia on the aquatic environment is modified by the chemical species present, the relative proportions of each, and other factors such as pH, temperature and dissolved oxygen concentration.

Ninety percent (90 %) of all free ammonia estimates should be within the TWQR. All free ammonia estimates should be below the chronic effect value (CEV). In the case of accidental spills, chronic and acute toxicity effects will occur if ammonia estimates exceed the Acute Effect Value (AEV).

Effects and Criteria

Norms

The norms for assessing the effects of free ammonia on aquatic ecosystems are chronic and acute toxic effects of ammonia on aquatic organisms.

Effects

The toxicity of ammonia and ammonium salts to aquatic organisms is directly related to the amount of free ammonia in solution. At low to medium pH values, the ammonium ion dominates, but as pH increases ammonia is formed, the latter being considerably more toxic to aquatic organisms. Prior exposure or acclimation to ammonia increases the tolerance of fish to ammonia and enables them to withstand concentrations that would otherwise be acutely lethal.

Un-ionized ammonia affects the respiratory systems of many animals, either by inhibiting cellular metabolism or by decreasing oxygen permeability of cell membranes. Acute toxicity to fish may cause a loss of equilibrium, hyper-excitability, an increased breathing rate, an increased cardiac output and oxygen intake, and in extreme cases convulsions, coma and death.

Chronic effects include a reduction in hatching success, reduction in growth rate and morphological development, and pathological changes in tissue of gills, liver and kidneys. An increased ventilation of the gills following exposure to ammonia indicating a respiratory effect has been observed in mayfly larvae *Ecdyonurus dispar*.

Criteria

The TWQR and criteria for un-ionised ammonia in aquatic ecosystems are :

TWQR and Criteria	**Un-ionised Ammonia Concentration (Fg N/R)**
Target Water Quality Range (TWQR)	***# 7***
Chronic Effect Value (CEV)	15
Acute Effect Value (AEV)	100

Note:

C The data available satisfied the minimum database requirements, therefore no safety factors were applied.

Modifications

In certain areas, or at certain sites, it may be necessary to modify the ammonia criteria provided in this guideline. Where any modification is anticipated, *the user of the guidelines must obtain expert advice*. All modifications must afford the same level of protection to aquatic ecosystems as stipulated by the criteria given in this guideline.

The following circumstances may require that case- and site-specific criteria be derived:

- Where untested locally important species may be very sensitive to ammonia;
- Where aquatic organisms may be stressed by diseases, parasites, predators, other contaminants, contaminated or insufficient food, and fluctuating or extreme conditions of flow, water quality and temperature; and
- Where natural background ammonia concentrations are higher than the TWQR.

Conditions for Modification

The following conditions should be satisfied before criteria for ammonia are altered:

- Adequate site-specific analytical data, covering at least one annual cycle, are available; and
- Site-specific studies demonstrate that there are no adverse effects on the ecosystem for the proposed changes in ammonia concentrations.

All modifications that result in criteria that are higher than those specified here are subject to approval by the Department of Water Affairs and Forestry.

Sources of Information

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Appendix 3e: South African Water Quality Guidelines for Aquatic Ecosystems: Nitrogen (Republic of South Africa, Department of Water Affairs and Forestry, 1996)

Nitrogen (Inorganic)

Background Information

Introduction

The term inorganic nitrogen includes all the major inorganic nitrogen components (NH_3 + NH_4^+ + NO_2^- + NO_3^-) present in water. Both the dissolved forms of inorganic nitrogen and those adsorbed onto suspended inorganic and organic material are included, since they are all available for uptake by algae and higher plants.

Ammonia (NH_3) and ammonium (NH_4^+) are reduced forms of inorganic nitrogen and their relative proportions are controlled by water temperature and pH. Both forms can exist as dissolved ions, or can be adsorbed onto suspended material.

Nitrite (NO_2^-) is the inorganic intermediate, and nitrate (NO_3) the end product, of the oxidation of organic nitrogen and ammonia. Nitrate is the more stable of the two forms and is usually far more abundant in the aquatic environment. In view of their co-occurrence and rapid inter-conversion, nitrite and nitrate are usually measured and considered together. Inter-conversions between the different forms of inorganic nitrogen are part of the nitrogen cycle in aquatic ecosystems.

Inorganic nitrogen is primarily of concern due to its stimulatory effect on aquatic plant growth and algae. Most aquatic organisms are sensitive to the toxic effects of ammonia. See guideline for ammonia.

Occurrence

Surface runoff from the surrounding catchment area, the discharge of effluent streams containing human and animal excrement, agricultural fertilizers and organic industrial wastes are the major sources of inorganic nitrogen which enters aquatic systems. In highly impacted catchments, the inorganic nitrogen arising from human activities can greatly exceed "natural" sources. In addition, many groups of bacteria are able to transform organic nitrogen to inorganic nitrogen during the decomposition of organic material.

Inorganic nitrogen is seldom present in high concentrations in unimpacted surface waters. This is because inorganic nitrogen is rapidly taken up by aquatic plants and converted into proteins and other organic forms of nitrogen in plant cells. In South Africa, inorganic nitrogen concentrations in unimpacted, aerobic surface waters are usually below 0.5 mg N/ℓ but may increase to above 5 - 10 mg N/ℓ in highly enriched waters.

Oxidized forms of inorganic nitrogen (usually nitrate) can sometimes be present in very high concentrations (> 150 mg NO_3-N/ℓ) in ground water. Such high concentrations can occur under natural conditions (e.g., mineral salts derived from rocks and soil, not due to man's activity), or due to seepage from sewage systems and leaching of organic and inorganic fertilizers from soil.

Interactions

The processes of ammonification, nitrification, denitrification, and the active uptake of nitrate by algae and higher plants, are regulated by water temperature, oxygen availability and pH. Changes to water temperature and pH affect the rates at which these processes occur and the concentration of inorganic nitrogen present in water.

Nitrite can be transformed rapidly to nitrate, and vice versa, by bacterial processes. Under aerobic conditions, nitrite is oxidized to nitrate by nitrifying bacteria. Conversely, under anaerobic conditions, nitrate is reduced to nitrite (and then to molecular nitrogen) by denitrifying bacteria. Denitrification is the most important process whereby nitrate is lost from aquatic systems.

Enrichment of waters with dissolved organic carbon (e.g., through the discharge of treated sewage effluent) can increase rates of nitrogen loss via denitrification by providing an energy source for denitrifying bacteria.

Several chemical bonding processes, as well as the forces which control the charge on the surface of sediment particles, regulate the amount of inorganic nitrogen which may be adsorbed to, or desorbed from, suspended particulate material. Typically, these reactions are strongly influenced by water temperature and pH, as well as by bacterial activity.

When particulate material settles out of the water onto the sediments, bound inorganic nitrogen becomes trapped in the sediments. Some of the bound inorganic nitrogen can be released by diffusion into the overlying water; nitrate present in anaerobic sediments can be lost from the system via denitrification.

Measurement

The concentration of inorganic nitrogen species in water is obtained by adding together the individual concentrations of ammonia ($NH_3 + NH_4^+$), plus nitrite (NO_2^-) and nitrate (NO_3^-). No single analytical technique will provide a measure of inorganic nitrogen.

Nitrite plus nitrate is determined by the cadmium reduction method followed by diazotisation and spectrophotometry. Nitrite alone is determined by diazotisation without prior reduction of the nitrate present to nitrite. Total ammonia, the sum of the NH_3 and NH_4^+ concentrations, is determined by the phenate hypochlorite method, followed by spectrophotometry or colorimetry.

Where other analytical methods are used, their characteristics relative to the reference type methods should be known. Concentrations are usually expressed as milligrams of inorganic nitrogen per litre of water sample (mg N/ℓ).

Prior filtration may be required where water samples are turbid. Considerable difficulty is experienced in the analysis of any inorganic nitrogen that is adsorbed onto the surface of suspended material or associated with bottom sediments.

Analysis of inorganic nitrogen in the laboratory should be started as soon as possible after sample collection to minimize the effects of bacterial transformation and pH changes. Water samples should preferably not be preserved with acid before analysis; rather, the samples should be kept at low temperature (< 4 °C).

Data Interpretation

Occasional increases in the inorganic nitrogen concentration above the Target Water Quality Range (TWQR) are less important than continuously high concentrations. Single measurements of inorganic nitrogen are a poor basis for assessment. Average summer inorganic nitrogen concentrations provide the best basis from which to estimate the likely biological consequences of inorganic nitrogen.

Weekly inorganic nitrogen concentrations, averaged over a period of at least 4 weeks, should be compared with the TWQR.

Any assessment of the influence of inorganic nitrogen concentrations should be coupled to an evaluation of the inorganic nitrogen to inorganic phosphorus ratio. Unimpacted systems typically have an N:P ratio greater than 25-40 : 1, whilst most impacted (i.e., eutrophic or hypertrophic) systems have an N:P ratio of less than 10:1. At such low N:P ratios, nitrogen fixation is likely to occur; this will provide additional inorganic nitrogen to the system.

In unimpacted, well-oxygenated (dissolved oxygen concentration 80-120 % saturation) waters, most (> 80 %) of the inorganic nitrogen should be present as nitrate; typically, ammonia concentrations will be below 0.1 mg N/ℓ, or less than 20 % of the inorganic nitrogen present.

Where effluent discharges containing high ammonia or nitrate concentrations have impacted on aerobic waters, background inorganic nitrogen concentrations rise. This will usually be accompanied by a decrease in the dissolved oxygen concentration and an increase in the BOD, COD and pH.

Effects and Criteria

Norms

Changes in the trophic status accompanied by the growth of algae and other aquatic plants in rivers, lakes and reservoirs, is the norm used to assess the effects of inorganic nitrogen on aquatic ecosystems.

Effects

Site-specific conditions, especially the availability of phosphorus, are critically important in modifying the influence of inorganic nitrogen on eutrophication. Inorganic nitrogen toxicity is not considered to be important for setting inorganic nitrogen water quality guidelines for protection of aquatic ecosystems.

Inorganic nitrogen concentrations below 0.5 mg N/ℓ are considered to be sufficiently low that they can limit eutrophication and reduce the likelihood of nuisance growths of blue-green algae and other plants. However, in the presence of sufficient available phosphorus, nitrogen-fixing organisms will be able to fix atmospheric nitrogen, thereby compensating for any deficit caused by low inorganic nitrogen concentrations.

The information given in the table below illustrates typical symptoms associated with selected ranges of inorganic nitrogen concentrations, if all other nutrients and environmental conditions are within favourable ranges for the organisms concerned.

Average Summer Inorganic Nitrogen Concentration (mg/ℓ)	Effects
< 0.5	Oligotrophic conditions; usually moderate levels of species diversity; usually low productivity systems with rapid nutrient cycling; no nuisance growth of aquatic plants or the presence of blue-green algal blooms.
0.5 - 2.5	Mesotrophic conditions; usually high levels of species diversity; usually productive systems; nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms seldom toxic.
2.5 - 10	Eutrophic conditions; usually low levels of species diversity; usually highly productive systems, nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms may include species which are toxic to man, livestock and wildlife.
> 10	Hypertrophic conditions; usually very low levels of species diversity; usually very highly productive systems; nuisance growth of aquatic plants and blooms of blue-green algae, often including species which are toxic to man, livestock and wildlife.

Criteria

The inorganic nitrogen concentration for a specific system must be based on the existing trophic status of the system. It is undesirable to allow inorganic nitrogen concentrations to rise to a level which will change the trophic status of the system. A Target Water Quality Range should be derived only after case- and site-specific studies.

Water Resource	*Target Water Quality Range*
All surface waters	- ***Inorganic nitrogen concentrations should not be changed by more than 15 % from that of the water body under local unimpacted conditions at any time of the year; and*** - ***The trophic status of the water body should not increase above its present level, though a decrease in trophic status is permissible (see Effects); and*** - ***The amplitude and frequency of natural cycles in inorganic nitrogen concentrations should not be changed.***

Modifications

The inorganic nitrogen criteria given in the above table should only be modified in the case of turbid systems. Limited light penetration or increased turbulence will reduce the extent of nuisance algal growths at a given inorganic nitrogen concentration. Nuisance growths of free-floating aquatic macrophytes (e.g. Water Hyacinth) will not be reduced in such cases.

The following conditions should be satisfied before a decision is taken to modify the TWQR for inorganic nitrogen:

- Adequate data, covering at least one summer season, are available;
- Site-specific studies demonstrate that there are no adverse effects on the ecosystem for the proposed changes in inorganic nitrogen concentration in trophic status; and
- Account for other contributory factors, such as low inorganic phosphorus concentrations, high turbidity and turbulence, which will reduce the effects of increased inorganic nitrogen.

All modifications that result in criteria that are higher than those specified here are subject to approval by the Department of Water Affairs and Forestry.

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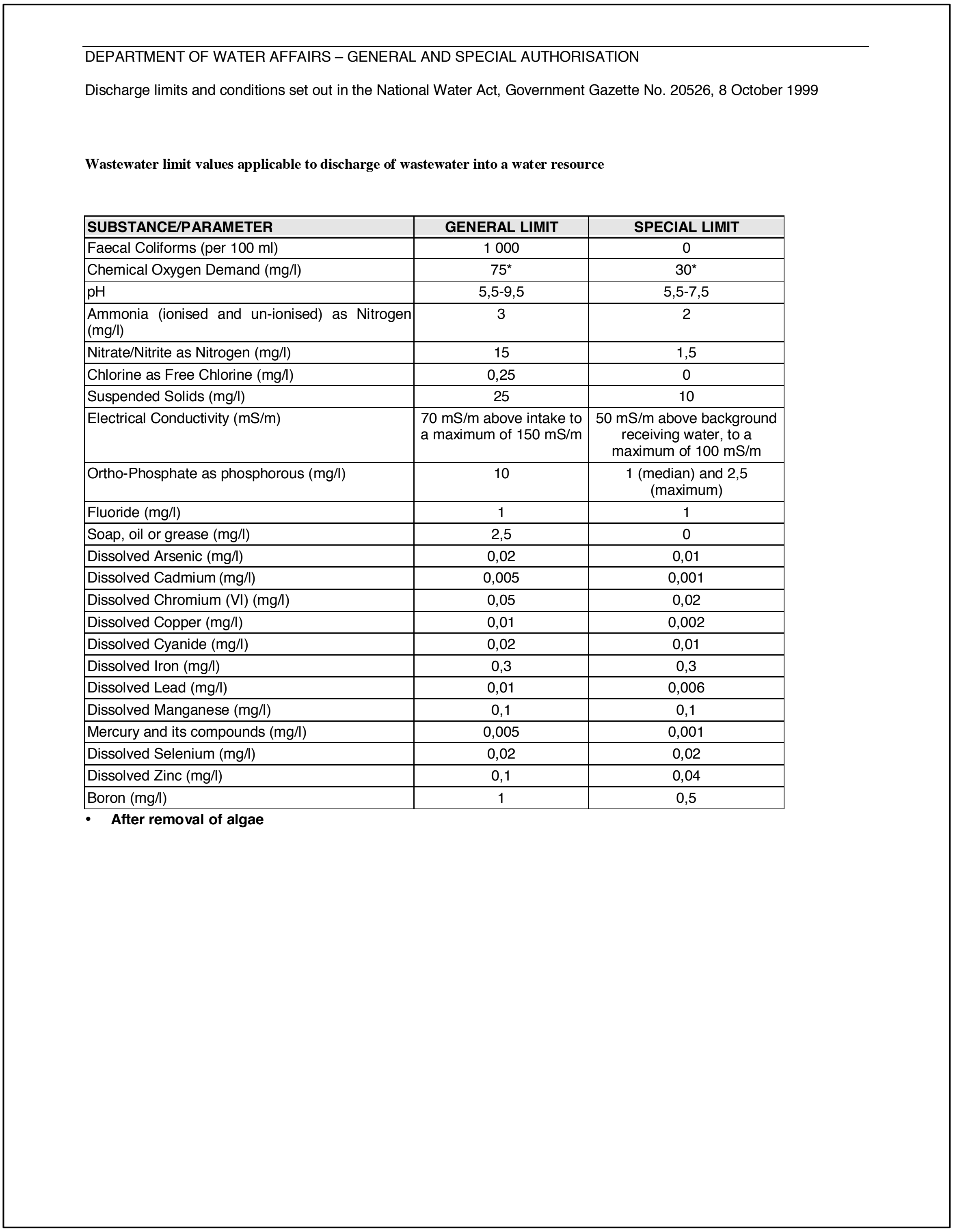
Appendix 3f: Department of Water Affairs effluent discharge standards (Republic of South Africa, 1999)



DEPARTMENT OF WATER AFFAIRS – GENERAL AND SPECIAL AUTHORISATION

Discharge limits and conditions set out in the National Water Act, Government Gazette No. 20526, 8 October 1999

Wastewater limit values applicable to discharge of wastewater into a water resource

SUBSTANCE/PARAMETER	GENERAL LIMIT	SPECIAL LIMIT
Faecal Coliforms (per 100 ml)	1 000	0
Chemical Oxygen Demand (mg/l)	75*	30*
pH	5,5-9,5	5,5-7,5
Ammonia (ionised and un-ionised) as Nitrogen (mg/l)	3	2
Nitrate/Nitrite as Nitrogen (mg/l)	15	1,5
Chlorine as Free Chlorine (mg/l)	0,25	0
Suspended Solids (mg/l)	25	10
Electrical Conductivity (mS/m)	70 mS/m above intake to a maximum of 150 mS/m	50 mS/m above background receiving water, to a maximum of 100 mS/m
Ortho-Phosphate as phosphorous (mg/l)	10	1 (median) and 2,5 (maximum)
Fluoride (mg/l)	1	1
Soap, oil or grease (mg/l)	2,5	0
Dissolved Arsenic (mg/l)	0,02	0,01
Dissolved Cadmium (mg/l)	0,005	0,001
Dissolved Chromium (VI) (mg/l)	0,05	0,02
Dissolved Copper (mg/l)	0,01	0,002
Dissolved Cyanide (mg/l)	0,02	0,01
Dissolved Iron (mg/l)	0,3	0,3
Dissolved Lead (mg/l)	0,01	0,006
Dissolved Manganese (mg/l)	0,1	0,1
Mercury and its compounds (mg/l)	0,005	0,001
Dissolved Selenium (mg/l)	0,02	0,02
Dissolved Zinc (mg/l)	0,1	0,04
Boron (mg/l)	1	0,5

- **After removal of algae**

Appendix 4: Stormwater Sampling Data

Appendix 4a: Newlands and Observatory rainfall data throughout the sampling period in 2012

	Average Area Rainfall (mm) *		Antecedent Dry Weather Days †	
Date	**Newlands**	**Observatory**	**Newlands**	**Observatory**
4-Jul	31.25	20.5	3	6
7-Jul	41	28.25	2	2
9-Jul	82.25	59	0	1
11-Jul	19.25	7.85	1	2
16-Jul	13.5	11	0	4
21-Jul	69	23	2	4
22-Jul	21.5	6.5	0	0
27-Jul	13.5	6	3	4
1-Aug	6.5	8	4	3
6-Aug	18.5	7	5	5
12-Aug	87	22.5	3	4
16-Aug	67	18	2	2
20-Aug	33.5	19	1	2
22-Aug	14.25	4.25	1	1
26-Aug	40.5	9.25	3	3
1-Sep	28.5	15	3	5
10-Sep	20	7.75	8	8
14-Sep	4.5	6	3	4
22-Sep	36	28.5	7	6
24-Sep	14.5	7.25	1	1
27-Sep	21	5.5	2	2
29-Sep	23.5	27.5	0	1
4-Oct	10.25	4.5	4	4
20-Oct	19	16.75	11	14

* Average area rainfall as determined by two rain gauge measurements per study area.

† Antecedent dry weather days include all days prior to the sampled storm event during which ≤ 4 mm of rainfall fell in a 24-hour period. This volume was required for sufficient stormwater flow into the sampling bin.

Appendix 4b: pH measurements at the 13 sampling locations of the Newlands study area

pH – Newlands Study Area								
Site	4-Jul	7-Jul	9-Jul	11-Jul	16-Jul	21-Jul	22-Jul	27-Jul
1	8.6	8.1	8.4	8.3	7.8	7.6	7.3	8.1
2	8.4	8.2	8.4	8.3	8.2	8.2	7.8	8.2
3	8.4	8.2	8.3	8.3	8.3	8.4	7.7	8.1
4	8.3	8.1	8.1	8.2	8.1	7.9	7.7	8
5	8.3	8.2	8.5	8.2	8.1	8.1	7.9	8.3
6	8.5	8.9	8.2	8.2	8.2	8.5	8.4	8.3
7	8.8	9.2	8.7	8.5	12.5	8.9	9.6	9
8	8.3	7.8	8.1	8.2	8.2	7.9	8	8.1
9	8.4	8.3	8.3	8.3	8.3	8	8	8.2
11	8.4	8.3	8.5	8.5	9.5	8.3	7.7	8.2
12	8.2	8.1	8.3	8.1	8.6	8.5	7.6	7.9
13	8.2	8.1	8.3	7.9	8.8	9.2	7.8	7.9
14	-	-	-	-	-	6.5	7.8	7.8
Site	1-Aug	6-Aug	12-Aug	16-Aug	20-Aug	22-Aug	26-Aug	1-Sep
1	7.8	7.6	9	7.8	7.8	7.6	8.6	8.8
2	7.5	8.2	9.5	7.9	7.9	7.9	8.2	8.3
3	7.8	8.1	9	7.8	7.8	7.8	8.2	8.4
4	7.7	8	9.4	7.9	7.9	7.8	8.2	7.8
5	8.1	8.2	9.6	8	8.1	8.1	8.1	8
6	7.6	8.2	9.8	8.2	8.2	8.2	8.3	8.1
7	9.2	8.6	10.6	8.1	8.2	8.2	8.4	8.2
8	8	8.3	9.7	7.9	8	7.9	8.4	8.1
9	7.8	8.2	9.4	8	8	8.1	8.2	8.2
11	8.1	8.6	10.3	8.2	8.3	8	8.3	7.9
12	7.2	8.3	9.8	7.7	7.4	7.5	8	7.6
13	7.7	8.3	9.9	7.8	7.8	7.9	7.9	8
14	7	7.2	8.9	8.3	7	6.5	8	8.6
Site	10-Sep	14-Sep	22-Sep	24-Sep	27-Sep	29-Sep	4-Oct	20-Oct
1	8.2	7.8	8	8.4	9.6	9.1	6.4	7.3
2	8.1	7.9	7.9	8.9	9.8	9.5	6.8	6.7
3	8.1	7.2	7.4	8.4	9.6	9.6	6.4	-
4	7.9	7.6	7.6	8.6	9.4	9.5	6.2	6.1
5	7.9	7.7	-	-	-	-	-	-
6	7.8	7.5	7.4	8.8	9.8	9.4	7.2	8.4
7	7.4	7.2	8.3	9	10.2	10.1	7.4	8.7
8	7.9	7.9	7.3	8.6	9.4	9.4	6.8	7.2
9	8	8	8	8.7	9.3	9.4	6.9	6.8
11	7.8	7.7	7.8	8.7	9.9	9.5	6.4	7.3
12	7	7.6	7.5	8.6	9.7	9.3	6.5	6.6
13	7.8	7.6	7.9	8.2	9.4	9.2	6.6	6.3
14	8.2	7.5	7.6	7.4	9.3	8.8	5.9	7.4

Appendix 4c: pH measurements at the 12 sampling locations of the Observatory study area

pH – Observatory Study Area								
Site	4-Jul	7-Jul	9-Jul	11-Jul	16-Jul	21-Jul	22-Jul	27-Jul
1	8.7	8	8.2	7.7	7.9	8.3	9	9.3
2	8.8	9	8.1	8.4	7.2	8	8.1	3.2
3	-	8.4	8.6	8.7	7.4	7.7	7.3	7.1
4	8.4	8.2	8.5	8.7	7.5	7.7	7.9	8.3
5	8.7	8.1	8.7	8.7	7.8	7.7	7.8	8.1
6	8.6	8.1	8.4	8.5	7.7	7.8	8	8.1
7	8.2	8.2	8.5	7.2	7.8	7.6	7.7	8
8	8.6	8.3	8.6	8.1	8.3	7.7	7.6	8.2
9	8.7	8.3	8.3	8.3	8.3	7.8	7.9	8.2
10	8.8	8.3	8.3	8.1	7.6	7.4	7.8	8.1
11	8.5	8.1	8.2	7.3	7.6	7.4	7.6	7.4
12	7.5	8.1	8.3	6.7	6.9	7.2	7.5	7.5
Site	1-Aug	6-Aug	12-Aug	16-Aug	20-Aug	22-Aug	26-Aug	1-Sep
1	8.3	8.3	9.5	7.8	8.1	7.8	8	7.7
2	7.6	7.9	9.8	8.2	8.2	8.9	7.8	7.8
3	7.3	7.8	9.5	8.2	8.3	8.3	8.1	7.5
4	7.7	7.9	9.6	8.1	8.2	7.9	8	8
5	7.7	7.8	9.1	8	7.9	7.7	8.3	8.1
6	7.5	7.8	9.4	8.1	8	7.7	8.3	8.1
7	7.4	8.2	9.6	8.1	8.1	7.6	7.8	7.3
8	7.7	8.2	9.7	8.3	8.1	7.9	8.3	8.4
9	7.6	8.3	9.7	8.4	8	8	8.3	8.5
10	7.5	7.7	9.1	7.9	8.1	7.9	7.9	8.1
11	6.8	7.4	9.5	7.8	8.1	7.9	7.8	7.4
12	6.9	7.4	8.8	7.2	8.6	7.5	7.7	6.7
Site	10-Sep	14-Sep	22-Sep	24-Sep	27-Sep	29-Sep	4-Oct	20-Oct
1	8.2	8.1	8	8.7	9.3	9.1	7.3	7.9
2	8.1	8.2	8	8.6	10.2	9.1	6.4	7.6
3	8.1	7.8	8.2	8.6	9.8	9.1	6.4	7.6
4	8.5	8.3	8.1	8.7	10.3	9.2	8.9	-
5	8.5	8.4	8	8	9.7	8.9	6.4	7.5
6	9.3	8.4	8.4	8.2	9.5	9.2	6.4	7.5
7	6.6	5.9	6.9	8.1	8.8	9.1	6	7.5
8	7.6	7.2	7.9	8.6	9.9	9.4	6.3	7.6
9	7.3	7.4	-	8.7	10.2	9.8	5.9	6.6
10	7.6	7.5	7.4	8.4	9.8	9.5	6.3	7
11	12.8	10.2	7.7	8.2	8.8	9.3	6.2	7.2
12	8.6	7.7	8	7.9	9.5	9.3	6.3	7

Appendix 4d: Total dissolved solids (ppm) measurements at the 13 sampling locations of the Newlands study area

Total Dissolved Solids (ppm) – Newlands Study Area								
Site	4-Jul	7-Jul	9-Jul	11-Jul	16-Jul	21-Jul	22-Jul	27-Jul
1	43	49	43	35	147	33	-	50
2	159	45	24	32	41	26	-	50
3	121	51	19	26	37	22	-	50
4	102	53	46	27	64	28	-	50
5	114	38	15	36	43	20	-	50
6	109	36	40	30	49	21	-	50
7	148	69	28	49	161	44	-	100
8	129	60	34	46	52	35	-	50
9	133	53	14	26	22	21	-	50
11	86	41	23	12	20	33	-	0
12	54	45	22	21	64	20	-	50
13	123	38	17	21	120	15	-	50
14	-	-	-	-	-	96	-	100
Site	1-Aug	6-Aug	12-Aug	16-Aug	20-Aug	22-Aug	26-Aug	1-Sep
1	150	50	50	50	0	50	50	50
2	150	100	100	50	50	50	50	100
3	150	100	100	50	50	50	50	100
4	100	100	100	50	50	50	50	100
5	150	100	100	100	50	50	100	100
6	100	150	100	50	50	50	50	100
7	150	150	100	50	50	50	100	100
8	100	150	100	50	50	50	100	100
9	100	100	50	50	50	50	50	100
11	50	50	100	50	0	50	50	50
12	150	50	50	50	0	100	50	100
13	50	50	100	50	50	50	50	100
14	200	200	50	50	100	300	50	50
Site	10-Sep	14-Sep	22-Sep	24-Sep	27-Sep	29-Sep	4-Oct	20-Oct
1	50	100	36	27	50	50	150	206
2	50	50	30	31	0	50	100	129
3	100	250	181	76	50	100	100	-
4	50	50	38	32	0	50	100	171
5	250	50	-	-	-	-	-	-
6	50	50	49	79	50	50	50	67
7	50	150	154	64	50	50	100	241
8	100	50	58	52	50	50	100	113
9	350	50	45	100	0	100	50	98
11	50	50	51	32	0	50	50	108
12	150	50	42	30	0	50	100	230
13	25	50	25	77	0	50	50	85
14	50	100	113	179	50	100	100	392

Appendix 4e: Total dissolved solids (ppm) measurements at the 12 sampling locations of the Observatory study area

Total Dissolved Solids (ppm) – Observatory Study Area

Site	4-Jul	7-Jul	9-Jul	11-Jul	16-Jul	21-Jul	22-Jul	27-Jul
1	195	73	37	88	100	-	-	50
2	100	48	60	142	53	-	-	2150
3	-	37	63	29	37	-	-	50
4	80	47	73	31	111	-	-	50
5	89	47	62	35	45	-	-	50
6	33	36	44	26	45	-	-	50
7	93	73	60	45	36	39	-	50
8	115	60	63	43	103	59	-	50
9	25	37	46	28	56	-	-	50
10	62	30	50	38	91	-	-	50
11	137	44	62	192	88	-	-	150
12	158	72	109	194	476	143	-	150
Site	1-Aug	6-Aug	12-Aug	16-Aug	20-Aug	22-Aug	26-Aug	1-Sep
1	150	50	100	100	50	100	150	150
2	100	150	100	50	50	100	50	100
3	100	50	100	50	50	50	50	0
4	100	50	50	50	50	50	100	100
5	150	100	100	50	50	50	150	100
6	100	50	50	50	50	50	50	50
7	100	50	100	50	50	50	50	100
8	100	100	100	50	50	50	100	100
9	50	50	50	50	50	50	50	100
10	100	50	100	50	50	50	100	50
11	350	100	100	50	50	100	100	150
12	300	600	400	400	50	100	50	250
Site	10-Sep	14-Sep	22-Sep	24-Sep	27-Sep	29-Sep	4-Oct	20-Oct
1	125	100	48	60	50	50	100	36
2	50	50	113	48	50	50	100	71
3	100	50	23	43	0	50	50	19
4	50	50	43	69	50	100	100	-
5	150	150	61	109	50	50	100	85
6	150	50	21	74	50	50	50	44
7	100	100	259	78	150	100	100	71
8	50	50	30	48	50	50	100	90
9	50	50	-	56	50	50	100	189
10	150	100	70	76	50	50	150	147
11	1400	300	466	212	300	100	400	242
12	100	100	85	91	50	50	50	210

Appendix 4f: Electrical conductivity (µS) measurements at the 13 sampling locations of the Newlands study area

Electrical Conductivity (µS) – Newlands Study Area								
Site	4-Jul	7-Jul	9-Jul	11-Jul	16-Jul	21-Jul	22-Jul	27-Jul
1	86	98	84	70	296	61	-	100
2	318	91	51	66	83	52	-	100
3	242	104	38	52	74	44	-	100
4	207	107	96	55	130	57	-	100
5	129	79	32	75	87	40	-	100
6	219	72	82	62	81	52	-	100
7	295	138	56	99	380	92	-	200
8	262	121	68	92	105	70	-	100
9	267	105	29	53	44	42	-	100
11	172	83	46	24	41	66	-	0
12	108	90	45	42	128	39	-	100
13	249	76	36	43	43	34	-	100
14	-	-	-	-	-	191	-	200
Site	1-Aug	6-Aug	12-Aug	16-Aug	20-Aug	22-Aug	26-Aug	1-Sep
1	300	100	100	100	0	100	100	100
2	300	200	200	100	100	100	100	200
3	300	200	200	100	100	100	100	200
4	200	200	200	100	100	100	100	200
5	300	200	200	200	100	100	200	200
6	200	300	200	100	100	100	100	200
7	300	300	200	100	100	100	200	200
8	200	300	200	100	100	100	200	200
9	200	200	100	100	100	100	100	200
11	100	100	200	100	0	100	100	100
12	300	100	100	100	0	200	100	200
13	100	100	200	100	100	100	100	200
14	400	400	100	100	200	600	100	100
Site	10-Sep	14-Sep	22-Sep	24-Sep	27-Sep	29-Sep	4-Oct	20-Oct
1	100	200	70	51	100	100	300	419
2	100	100	53	62	0	100	200	262
3	200	500	326	152	100	200	200	-
4	100	100	98	65	0	100	200	349
5	500	100	-	-	-	-	-	-
6	100	100	105	160	100	100	100	135
7	100	300	310	127	100	100	200	478
8	200	100	114	104	100	100	200	235
9	700	100	91	199	0	200	100	195
11	100	100	97	63	0	100	100	213
12	300	100	88	61	0	100	200	452
13	50	100	51	154	0	100	100	172
14	100	200	225	365	100	200	200	795

Appendix 4g: Electrical conductivity (µS) measurements at the 12 sampling locations of the Observatory study area

Electrical Conductivity (µS) – Observatory Study Area								
Site	4-Jul	7-Jul	9-Jul	11-Jul	16-Jul	21-Jul	22-Jul	27-Jul
1	388	146	76	178	201	-	-	100
2	201	95	120	287	111	-	-	4300
3	-	74	127	59	77	-	-	100
4	162	102	147	63	221	-	-	100
5	178	95	124	70	91	-	-	100
6	64	74	89	53	83	-	-	100
7	188	143	120	91	75	81	-	100
8	234	120	130	85	209	118	-	100
9	50	72	93	59	111	-	-	100
10	124	60	101	77	181	-	-	100
11	277	89	124	380	190	-	-	300
12	317	150	229	378	755	286	-	300
Site	1-Aug	6-Aug	12-Aug	16-Aug	20-Aug	22-Aug	26-Aug	1-Sep
1	300	100	200	200	100	200	300	300
2	200	300	200	100	100	200	100	200
3	200	100	200	100	100	100	100	0
4	200	100	100	100	100	100	200	200
5	300	200	200	100	100	100	300	200
6	200	100	100	100	100	100	100	100
7	200	100	200	100	100	100	100	200
8	200	200	200	100	100	100	200	200
9	100	100	100	100	100	100	100	200
10	200	100	200	100	100	100	200	100
11	700	200	200	100	100	200	200	300
12	600	1200	800	800	100	200	100	500
Site	10-Sep	14-Sep	22-Sep	24-Sep	27-Sep	29-Sep	4-Oct	20-Oct
1	250	200	97	134	100	100	200	76
2	100	100	229	96	100	100	200	146
3	200	100	53	85	0	100	100	41
4	100	100	86	135	100	200	200	-
5	300	300	125	219	100	100	200	170
6	300	100	38	144	100	100	100	92
7	200	200	519	148	300	200	200	141
8	100	100	60	98	100	100	200	182
9	100	100	-	114	100	100	200	380
10	300	200	139	153	100	100	300	287
11	2800	600	941	486	600	200	800	478
12	200	200	191	193	100	100	100	425

Appendix 4h: Orthophosphate (mg/l) measurements at the 13 sampling locations of the Newlands study area

Orthophosphate (mg/l) – Newlands Study Area								
Site	4-Jul	7-Jul	9-Jul	11-Jul	16-Jul	21-Jul	22-Jul	27-Jul
1	0.43	0.28	0.21	0.82	3.19	0.94	0.57	1.98
2	0.39	0.71	0.24	0.35	0.23	0.34	0.5	0.63
3	0.21	0.24	0.13	0.24	0.49	0.16	0.15	0.36
4	0.49	0.58	0.41	0.61	0.79	0.7	0.54	1.02
5	0.34	0.64	0.2	0.69	0.64	0.24	0.27	0.52
6	0.14	0.21	0.23	0.05	0.22	0.24	0.1	0.28
7	0.75	1.43	0.44	0.7	0.31	0.58	0.37	-
8	0.63	0.8	0.48	0.47	0.72	0.39	0.27	0.62
9	0.05	0.03	0.1	0.08	0.12	0.12	0.07	0.2
11	0.44	0.46	0.14	0.6	0.03	0.2	0.2	0.26
12	0.04	0.09	0.05	0.18	0.08	0.12	0.07	0.28
13	0.08	0.06	0.05	0.04	0.05	0.11	0.23	0.15
14	-	-	-	-	-	4.84	0.08	1.41
Site	1-Aug	6-Aug	12-Aug	16-Aug	20-Aug	22-Aug	26-Aug	1-Sep
1	2.01	0.85	0.35	0.23	0.29	0.58	0.25	0.54
2	0.97	0.27	0.38	0.13	0.41	0.45	0.16	0.19
3	0.08	0.05	0.2	0.11	0.15	0.17	0.27	0.24
4	0.68	0.55	0.51	0.39	0.27	0.37	0.47	0.66
5	0.73	0.12	0.32	0.32	0.23	0.48	0.22	0.17
6	0.65	0.14	0.11	0.04	0.43	0.16	0.07	0.06
7	0.15	0.06	0.42	0.37	0.48	0.24	0.25	0.31
8	0.37	0.25	0.17	0.13	0.36	0.42	0.14	0.66
9	0.27	0.07	0	0.09	0.31	0.1	0.12	0.02
11	0.07	0.06	0.08	0.17	0.24	0.08	0.12	0.07
12	0.31	0.06	0.3	0.14	1.33	0.47	0.03	0.37
13	0.25	0.15	0.12	0.15	0.09	0.11	0.14	-
14	4.44	2.09	0.05	0.03	5.44	7.4	0.06	0.78
Site	10-Sep	14-Sep	22-Sep	24-Sep	27-Sep	29-Sep	4-Oct	20-Oct
1	1.18	0.99	0.8	0.56	0.66	0.64	2.92	6
2	0.48	0.28	0.35	0.14	0.17	0.24	1.03	5.6
3	0.39	1.94	0.22	0.2	0.33	0.61	1.34	-
4	0.88	2.68	1.58	0.37	0.64	0.3	2.16	13.5
5	0.41	0.66	-	-	-	-	-	-
6	0.7	4.78	4.96	0.18	0.82	0.4	0.33	0.26
7	1.2	2.14	1.06	0.41	0.49	0.49	0.08	0.3
8	3.43	0.26	5.08	0.85	2.91	0.57	0.66	0.3
9	0.25	0.37	0.48	0.33	0.25	0.1	0.2	1.32
11	0.25	1.13	1.04	0.73	0.23	0.35	2.22	2.68
12	0.89	0.72	0.78	0.32	0.29	0.26	0.77	4.08
13	0.31	0.39	0.39	0.21	0.33	0.24	1.16	2.44
14	0.54	1.21	3.68	5.72	2.09	1.52	3.06	11.5

Appendix 4i: Orthophosphate (mg/l) measurements at the 12 sampling locations of the Observatory study area

Orthophosphate (mg/l) – Observatory Study Area

Site	4-Jul	7-Jul	9-Jul	11-Jul	16-Jul	21-Jul	22-Jul	27-Jul
1	0.09	0.08	0.16	0.04	0.03	0.58	0.4	0.09
2	0.11	0.11	0.18	0.09	4.16	0.33	0.15	0
3	-	0.05	0.04	0.12	0.34	2.96	0.43	0.01
4	0.91	0.57	0.51	0.45	1.89	0.36	0.36	1.35
5	0.48	0.38	0.7	0.56	0.34	0.33	0.15	0.69
6	0.27	0.17	0.34	0.12	3.36	0.37	0.28	0.91
7	0.13	0.78	0.06	0.06	0.68	0.28	0.64	0.21
8	0.29	0.31	0.13	0.27	0.57	0.32	0.13	0.17
9	0.12	0.03	0.09	0.02	0.02	0.05	0.12	0.03
10	0.59	0.86	1.51	1.44	9.56	5.12	0.77	-
11	2.23	1.9	0.96	4.91	3.78	1.72	1.89	4.28
12	6.52	2.31	2.53	5.42	6.7	5.28	2.64	4.94
Site	1-Aug	6-Aug	12-Aug	16-Aug	20-Aug	22-Aug	26-Aug	1-Sep
1	0.63	0.35	0.37	0.77	0.21	0.17	0.31	0.07
2	0.06	0.1	0.14	0.29	0.08	0.63	0.38	0.67
3	0.3	0.54	0.47	0.19	0.3	0.29	0.64	1.82
4	0.39	0.38	0.35	0.4	0.76	0.55	0.46	0.49
5	0.18	0.75	0.4	0.47	0.25	0.02	0.35	0.11
6	0.34	0.35	0.64	0.09	0.12	0.17	0.29	0.23
7	0.62	0.24	0.2	0.19	0.38	0.29	0.32	0.94
8	0.27	0.14	0.54	0.19	0.2	0.42	0.17	0.52
9	0.32	2.26	0.37	0.04	0.26	0.21	0.26	0.35
10	6.72	7	1.68	1.65	0.7	1.03	1.13	0.75
11	19.6	0.57	0.25	0.74	0.4	0.71	5	19.4
12	13.8	15.2	15.7	3.96	0.66	2.46	0.42	7.8
Site	10-Sep	14-Sep	22-Sep	24-Sep	27-Sep	29-Sep	4-Oct	20-Oct
1	1.15	0.55	0.43	0.46	1.08	0.13	0.76	0.68
2	0.11	1.27	2.48	0.99	0.73	0.33	2.92	0.48
3	3.26	1.07	0.65	0.74	0.56	0.26	1.26	0.46
4	0.84	1.64	2.37	1.13	1.04	0.57	0.4	-
5	1.08	1.13	1.59	1.65	0.76	0.24	1.02	1.12
6	6.04	1.04	0.41	1.92	0.65	0.22	0.08	0.48
7	3.56	2.86	13.2	1.26	71.9667	1.32	1.96	12.6
8	0.64	1.09	0.36	0.51	0.64	0.31	2.56	1.04
9	0.74	0.86	-	0.27	0.32	0.14	0.23	1.12
10	2.46	3.48	2.81	1.12	1.62	0.71	2.28	3.12
11	0.07	2.38	6.96	0.15	12	0.59	2.48	5.6
12	3.68	3.19	6.92	6.04	4.4	1.09	4.76	16.3

Appendix 4j: Ammonia (mg/l) measurements at the 13 sampling locations of the Newlands study area

Ammonia (mg/l) – Newlands Study Area

Site	4-Jul	7-Jul	9-Jul	11-Jul	16-Jul	21-Jul	22-Jul	27-Jul
1	0.5967	0.7733	0.1333	0.47	1.9533	0.5633	0.5233	0.7033
2	0.2733	0.2367	0.4333	0.32	0.2633	0.11	0.38	0.39
3	0.1767	0.2333	0.1667	0.1667	0.2267	0.1467	0.0833	0.42
4	0.31	0.7833	0.57	0.3333	0.6	0.24	0.3767	0.8867
5	0.1733	0.18	0.2967	0.1567	0.33	0.0667	0.2867	0.1567
6	0.1167	0.2	0.08	0.0833	0.2	0.1133	0.1933	0.1733
7	0.2667	0.23	0.4	0.14	0.5967	0.1433	0.11	-
8	0.32	0.5633	0.33	0.2833	0.4833	0.2233	0.3367	0.39
9	0.18	0.1267	0.13	0.15	0.1633	0.09	0.1767	0.1633
11	0.4967	0.2867	0.1933	0.1533	0.1433	0.1633	0.22	0.1733
12	0.2267	0.3567	0.1633	0.13	0.2167	0.0967	0.2	0.1067
13	0.39	0.2167	0.1133	0.1033	0.2233	0.05	0.1767	0.2233
14	-	-	-	-	-	5.5367	0.0633	0.5733

Site	1-Aug	6-Aug	12-Aug	16-Aug	20-Aug	22-Aug	26-Aug	1-Sep
1	2.5	0.6266	0.1867	0.1567	0.0833	0.31	0.4267	1.3367
2	0.77	0.13	0.57	0.0767	0.2433	0.25	0.3833	0.34
3	0.4767	0.89	0.2267	0.06	0.14	0.2267	0.46	0.3367
4	0.9867	0.4367	0.6067	0.1433	0.3467	0.5667	0.6133	0.21
5	1.3567	1.2433	0.2033	0.15	0.0867	0.09	0.3633	0.1667
6	0.44	0.3133	0.1033	0.0233	0.0433	0.0933	0.3667	0.1067
7	0.2367	0.7633	0.65	0.1467	0.1233	0.2767	0.47	0.28
8	0.7167	0.4467	0.2267	0.2433	0.0933	0.2367	0.4167	0.3233
9	0.4967	0.2233	1.1167	0.1367	0.3233	0.05	0.3767	0.6267
11	0.2267	0.1967	0.3167	0.0667	0.13	0.1633	0.3367	0.21
12	0.9	0.1933	0.1467	0.1133	1.0133	0.37	0.6633	0.5667
13	0.4867	0.1667	0.1	0.1	0.0733	0.0867	0.41	-
14	3.4333	3.6833	0.1567	0.0267	1.73	5.8333	0.5833	0.5533

Site	10-Sep	14-Sep	22-Sep	24-Sep	27-Sep	29-Sep	4-Oct	20-Oct
1	0.4933	1.66	0.8667	0.5133	0.3833	0.46	4.4335	3.05
2	0.2967	0.6167	0.51	0.4633	0.0667	0.1267	0.5233	0.9633
3	0.2167	2	1.2667	0.41	0.1633	0.6533	1.21	-
4	0.36	1.36	0.6767	0.6533	0.2433	0.3633	1.15	3.6335
5	0.3467	0.54	-	-	-	-	-	-
6	0.2733	0.8067	2.0867	0.39	0.53	0.1533	0.3567	0.16
7	0.6167	2.65	1.6	0.46	0.1	0.0967	0.7833	3.8335
8	0.8733	0.53	1.66	0.8267	1.98	0.3767	1.4333	0.36
9	0.36	0.4667	0.39	0.5	0.1	0.0667	0.3533	1.2467
11	0.3733	0.6367	0.3933	0.4567	0.0133	0.08	0.6467	0.2633
12	2.2133	0.4967	0.64	0.5	0.0867	0.13	0.89	1.44
13	0.3967	0.5433	0.7433	0.42	0.07	0.2067	0.7067	1.6133
14	0.5367	1.9667	1.7767	2.95	1.37	1.5	1.2467	4.0665

Appendix 4k: Ammonia (mg/l) measurements at the 12 sampling locations of the Observatory study area

Ammonia (mg/l) – Observatory Study Area

Site	4-Jul	7-Jul	9-Jul	11-Jul	16-Jul	21-Jul	22-Jul	27-Jul
1	1.5067	0.4167	0.35	1.1267	0.31	0.46	0.0933	0.27
2	0.35	0.1033	0.4333	3.7833	0.73	0.24	0.23	2.265
3	-	0.1633	0.29	0.2067	0.4667	2.28	0.3633	0.2767
4	0.703	0.1733	0.4233	0.08	1.7067	0.2533	0.2533	1.7633
5	0.59	0.22	0.7	0.0767	0.2133	0.3433	0.2067	0.73
6	0.24	0.2633	0.4267	0.13	0.7633	0.36	0.0433	0.3733
7	0.63	0.4567	0.3	0.22	0.3933	0.1933	0.3267	0.2233
8	0.2767	0.3233	0.3233	0.0933	0.3867	0.4033	0.2867	0.34
9	0.12	0.2267	0.3367	0.0667	0.2933	0.1567	0.0933	0.0967
10	0.3	0.2067	0.1867	0.1667	1.0533	0.6167	0.1733	-
11	0.89	0.48	0.66	3.1333	1.4967	0.8	0.5267	2.4933
12	2.24	0.9367	0.6067	1.82	6.9167	1.1667	0.6267	1.74
Site	1-Aug	6-Aug	12-Aug	16-Aug	20-Aug	22-Aug	26-Aug	1-Sep
1	0.45	0.1133	0.1967	0.1367	0.0933	0.14	0.4367	1.345
2	1.2867	0.0967	0.1133	0.07	0.0333	0.1233	0.4633	0.2167
3	0.57	0.31	0.8267	0.0833	0.0867	0.06	0.4867	1.0967
4	0.7133	0.1233	0.2033	0.2533	0.1033	0.0767	0.52	0.2833
5	7.3833	0.32	0.0967	0.2	0.08	0.13	0.4867	1.12
6	0.38	0.19	0.0867	0.0567	0.1067	0.1367	0.37	0.2867
7	0.3733	0.1933	0.08	0.1233	0.0867	0.11	0.3867	0.3267
8	0.65	0.13	0.98	0.0267	0.0733	0.1367	0.46	0.4
9	0.61	0.0967	2.1733	0.05	0.0867	0.0833	0.39	0.2033
10	1.8033	0.5967	1.1567	2.3333	0.3067	0.4467	0.66	0.4067
11	10.2667	0.7033	0.51	0.3133	0.1733	0.2367	1.34	1.7
12	0.8233	6.5165	2.7167	1.4067	0.2	0.7633	0.47	5.3583
Site	10-Sep	14-Sep	22-Sep	24-Sep	27-Sep	29-Sep	4-Oct	20-Oct
1	0.8333	1.2	0.4633	0.4867	1.07	0.19	1.41	0.55
2	0.4233	0.6367	1.0733	0.5333	0.5633	0.1133	5.1667	0.22
3	1.0667	0.5867	0.4533	0.4767	0.17	0.1333	0.7567	0.3867
4	0.55	0.7367	0.35	0.5967	0.33	0.3867	0.7067	-
5	0.84	0.7467	0.28	0.8167	0.1133	0.2667	0.5667	0.3233
6	1.18	0.6933	0.46	0.5667	0.23	0.18	0.6967	0.1867
7	1.3167	1.0867	2.1333	0.4333	5.4767	1.5067	1.1967	0.8133
8	0.33	0.56	0.47	0.4867	0.1233	0.18	4.7335	0.5267
9	0.95	0.4067	-	0.4033	0.0967	0.1033	0.9333	3.05
10	1.23	2.0467	1.2	0.6367	0.4333	0.2667	1.33	1.3333
11	5.9167	2.05	8.3667	1.61	5.9626	0.32	4.55	2.0933
12	0.72	1.3533	1.48	0.8267	0.68	0.32	21.75	5.8325

Appendix 4l: Nitrate (mg/l) measurements at the 13 sampling locations of the Newlands study area

Nitrate (mg/l) – Newlands Study Area								
Site	4-Jul	7-Jul	9-Jul	11-Jul	16-Jul	21-Jul	22-Jul	27-Jul
1	0.9667	1.0333	0.6667	1	3	0.3	0.1667	0.3
2	0.7333	0.6333	0.3667	0.5	0.2	0.4667	0.4333	0.7
3	0.65	0.4667	0.7	0.3667	0.4	0.4667	0.5667	0.4
4	0.7333	0.6333	0.3667	0.6667	0.3667	0.3667	0.5	0.3667
5	1.3667	0.6333	0.4	0.4	0.4667	0.5	0.5667	0.6
6	1.1	0.8667	0.1667	0.4333	0.6	0.5333	0.5333	0.2667
7	0.9667	0.5	0.4333	0.2	0.3667	0.3	0.5	-
8	0.6	0.6333	0.3	0.2333	0.3333	0.3	0.4333	0.3
9	0.0667	0.6	0.1667	0.3333	0.2333	0.0667	0.3667	0
11	0.5333	0.4	0.5667	0.5	0.6	0.3667	0.5333	0.3
12	0.55	0.5333	0.6	0.3	0.5333	0.1333	0.4333	0.4667
13	0.3667	0.6	0.5	0.2	0.5667	0.4333	0.4667	0.3
14	-	-	-	-	-	0	0.5333	0.3
Site	1-Aug	6-Aug	12-Aug	16-Aug	20-Aug	22-Aug	26-Aug	1-Sep
1	3.2333	1	0.6333	0.4	0.5333	1.5667	0.1667	0.8333
2	0.4	0.4333	0.4667	0.3333	0.2667	0.4667	0.4333	0.4667
3	0.5	0.3333	0.6667	0.1333	0.4667	0.2667	0.1667	0.5667
4	0.6667	0.2	0.4	0.5	0.2333	0.4	0.3333	0.4
5	0.7	0.5667	0.6333	0.5	0.2333	0.4333	0.5333	0.0333
6	0.6667	0.4333	0.4	0.4667	0.6333	0.4333	0.2	0.3333
7	0.4333	0.4	0.4333	0.2333	0.7	0.5	0.5	0.3667
8	0.5667	0.3667	0.5333	0.3333	0.3667	0.4333	0.6	0.4333
9	0.5333	0.2333	0.6	0.3667	0.2333	0.6	0.3333	0.4
11	0.5	0.3667	0.2333	0.1667	0.1667	0.5667	0.5333	0.4333
12	0.2	0.4667	0.4667	0.4	0.1333	0.4	0.3667	0.3667
13	0.1	0.4333	0.4667	0.4	0.3667	0.5333	0.3333	
14	0	0	0.4667	0.4333	0	0	0	0.1667
Site	10-Sep	14-Sep	22-Sep	24-Sep	27-Sep	29-Sep	4-Oct	20-Oct
1	0.5667	2.5667	0.1333	0.4	0.8	0.7	3.55	0.3
2	0.5	0.4667	0.5333	0.5	0.4	0.55	0.4	0
3	0.3	0	0.6	0.4	0.4	0.3	0.15	-
4	0.2	0.1	0.7333	1.4	0.3	0.4	0.5	0.35
5	0.2667	1.2667	-	-	-	-	-	-
6	0.1667	0.0667	1.6333	0.8	0.4	0.4	0.4	0.4
7	0	0	1.1333	1.1	0.3	0.4	0.25	0
8	0	0.8667	0	0.9	0	0.25	0.1	0.15
9	1.1667	0.3667	0.8333	0.4	0.3	1.5	0.6	0
11	0.1333	0.3333	0.4333	0.4	0.45	0.4	0.3	0.15
12	0.5333	1.0333	0.3333	1.3	0.3	0.4	0.35	0
13	0.2333	1.4667	0.7667	1.1	0.5	0.35	0.35	0
14	0.3333	0	0.5667	3.1	0.5	0.05	1.05	0

Appendix 4m: Nitrate (mg/l) measurements at the 12 sampling locations of the Observatory study area

Nitrate (mg/l) – Observatory Study Area								
Site	4-Jul	7-Jul	9-Jul	11-Jul	16-Jul	21-Jul	22-Jul	27-Jul
1	0.1	0.4333	0.5333	0.4667	0.2333	0.5333	0.5	0.8333
2	1.3667	0.9	0.7	2.6	0.2333	0.3667	0.5	0.3667
3	-	0.8667	0.6333	0.5	0.5333	0.1667	0.4333	0.1333
4	1.2667	1.4667	0.6333	0.7667	0	0.5	0.5667	1.1
5	1.2333	1.0667	0.7333	0.6333	0.1	0.4333	0.5667	0.9
6	0.2333	1.1	0.6667	0.6333	0.3333	0.1667	0.6333	0.4667
7	0.9333	1.2667	0.6	0.5333	0.2	0.7	0.5667	0.3667
8	0.8333	1.1	0.7333	0.5667	0.7	0.5667	0.7333	0.8
9	1.15	0.4333	0.8	0.8	0.4	0.6333	0.4333	0.1333
10	0.7667	1	0.4	-	1.7	0.6667	0.6	-
11	0.7333	0.3333	0.3	0	0.2667	0.3	0	0
12	0	0.2	0.3	0	0.5	0	0.0667	0
Site	1-Aug	6-Aug	12-Aug	16-Aug	20-Aug	22-Aug	26-Aug	1-Sep
1	0.5	0.3	0.3667	0.6667	0.4333	0.3667	0.4333	0
2	0.4	0.4333	0.4667	0.4667	0.7667	0.6667	0.3333	0.4333
3	0.3	0.4	0.5667	0.3667	0.5	0.5333	0.5	0.1
4	0.3333	0.5333	0.5667	0.4667	0.6333	0.4333	0.6333	0.4667
5	8.0333	0.6667	0.4667	0.5667	0.5333	0.5	0.5333	2.8
6	0.4	0.4333	0.7333	0.6	0.5	0.4667	0.5	0.5333
7	0.4	0.3	0.5	0.5	0.1667	0.1333	0.3667	0.5
8	0.7	0.6333	0.5667	0.4333	0.2333	0.6333	0.6667	0.7
9	0.4	0.6333	0.6667	0.2667	0.5	0.4667	0.4	0.4333
10	2.4	0.9667	0.2667	0.4	0.4667	0.6333	0.5667	0.5333
11	1.1	0.0667	0.2	0.2	0.2667	0.2333	0.1667	0
12	0	0.4333	0.7333	0	0.5	0.1333	0.4667	0
Site	10-Sep	14-Sep	22-Sep	24-Sep	27-Sep	29-Sep	4-Oct	20-Oct
1	0.1333	0.5667	0.4333	0.9667	0.3	0.45	1.1	0.65
2	0.1667	0.6	1.7	0.467	0.7	0.85	1.1	0.2
3	0.2667	0.4667	0.5333	0.5	0.2	0.45	0.9	0.6
4	0.1667	0.6667	0.5333	0.5333	0.8	0.85	0.85	-
5	3.3333	1	0.3333	0.2667	0.5	0.55	1.25	0.65
6	0	0.4	0.9	0.5	0.7	0.65	0.9	0.5
7	0.1	0.4	5.3667	0.3333	3.9	0.75	0.15	0.1
8	0.4	0.3667	0.6333	0.6	0.4	0.65	0.7	0.15
9	0.2667	2.8		0.5667	0.4	0.65	0.55	0.5
10	0.7333	0.2	0.2333	0.3333	0.5	0.75	1.75	0.15
11	1.6333	0.7	0.8333	0	0	0.45	1.4	0
12	0	1.7	0.5667	0.25	0.05	0.35	0.45	3.1

Appendix 4n: Nitrite (mg/l) measurements at the 13 sampling locations of the Newlands study area

Nitrite (mg/l) – Newlands Study Area								
Site	4-Jul	7-Jul	9-Jul	11-Jul	16-Jul	21-Jul	22-Jul	27-Jul
1	0.01033	0.062	0.012	0.028	0.542	0.002	0.001	0.027
2	0.004	0	0.01	0.004	0.006	0.004	0.003	0.009
3	0.005	0.009	0.01	0.008	0.007	0.001	0.003	0.005
4	0.006	0.007	0.007	0.005	0.004	0.005	0.003	0.009
5	0.00767	0.003	0.005	0.009	0.011	0.007	0.011	0.017
6	0.004	0.008	0.007	0.004	0.012	0.004	0.004	0.004
7	0.00267	0.009	0.002	0.002	0.01	0.005	0.004	-
8	0.00633	0.002	0.012	0.003	0.012	0.005	0.01	0.018
9	0.00733	0.01	0.009	0.006	0.003	0.004	0.004	0.006
11	0.00667	0.004	0.004	0.004	0.004	0.002	0.001	0.001
12	0.00367	0.001	0.003	0.004	0.007	0.001	0.003	0.002
13	0.003	0.005	0.004	0.003	0.004	0.003	0.002	0
14	-	-	-	-	-	0.001	0.003	0.004
Site	1-Aug	6-Aug	12-Aug	16-Aug	20-Aug	22-Aug	26-Aug	1-Sep
1	0.554	0.058	0.004	0.004	0.007	0.042	0.014	0.072
2	0.007	0.005	0.004	0.003	0.003	0.003	0.002	0.003
3	0.002	0.004	0.003	0.004	0.003	0.003	0.003	0.009
4	0.019	0.008	0.004	0.005	0.005	0.004	0.004	0.003
5	0.063	0.01	0.004	0.004	0.007	0.007	0.009	0.005
6	0.003	0.002	0.005	0.003	0.004	0.004	0.005	0.003
7	0.006	0.004	0.004	0.002	0.002	0.004	0.006	0.004
8	0.009	0.004	0.003	0.004	0.003	0.005	0.003	0.003
9	0.004	0.003	0.005	0.004	0.008	0.006	0.004	0.009
11	0.002	0.002	0.004	0.005	0.002	0.005	0.001	0.002
12	0	0.002	0.002	0.001	0	0.005	0.004	0.002
13	0.002	0.002	0.001	0.001	0.003	0.003	0.004	-
14	0	0	0.005	0.003	0	0	0.005	0.003
Site	10-Sep	14-Sep	22-Sep	24-Sep	27-Sep	29-Sep	4-Oct	20-Oct
1	0.022	0.462	0.005	0.01	0.024	0.025	0.576	0.147
2	0.004	0.022	0.006	0.002	0.003	0.003	0.027	0.004
3	0.002	0	0.006	0.004	0.003	0.004	0.004	-
4	0.002	0.027	0.342	0.49	0.004	0.002	0.021	0.008
5	0.011	0.484	-	-	-	-	-	-
6	0.003	0.002	0.005	0.03	0.003	0.001	0.006	0.006
7	0.003	0	0.018	0.203	0.003	0.001	0.024	0.005
8	0.001	0.232	0.004	0.001	0.003	0.003	0	0.004
9	0.004	0.014	0.003	0.007	0.003	0.005	0.082	0.004
11	0.002	0.034	0.018	0.002	0.004	0.003	0.003	0.004
12	0.004	0.421	0.004	0.42	0.003	0.003	0.003	0
13	0.003	0.473	0.006	0.134	0.003	0.002	0.014	0.008
14	0	0.082	0.015	0.01	0.013	0.007	0.006	0.001

Appendix 4o: Nitrite (mg/l) measurements at the 12 sampling locations of the Observatory study area

Nitrite (mg/l) – Observatory Study Area								
Site	4-Jul	7-Jul	9-Jul	11-Jul	16-Jul	21-Jul	22-Jul	27-Jul
1	0	0.003	0.007	0.037	0.002	0.026	0.004	0.118
2	0.02433	0.013	0.025	1.304	0.004	0.002	0.015	0.004
3	-	0.01	0.021	0.005	0.007	0.008	0.003	0.002
4	0.023	0.025	0.021	0.014	0	0.006	0.016	0.047
5	0.02433	0.024	0.019	0.017	0.008	0.011	0.017	0.67
6	0.01333	0.017	0.007	0.007	0.01	0.013	0.005	0.2
7	0.01867	0.038	0.014	0.007	0.005	0.008	0.014	0.049
8	0.025	0.028	0.023	0.022	0.029	0.011	0.025	0.003
9	0.00633	0.003	0.009	0.005	0.003	0.003	0.009	0.078
10	0.00933	0.019	0.003	-	0.003	0.002	0.008	-
11	0.01167	0.031	0.007	0	0.007	0.006	0.005	0
12	0	0	0.001	0	0	0	0	0
Site	1-Aug	6-Aug	12-Aug	16-Aug	20-Aug	22-Aug	26-Aug	1-Sep
1	0.01	0.005	0.003	0.018	0.004	0.003	0.003	0.004
2	0.005	0.03	0.005	0.006	0.003	0.014	0.004	0.002
3	0.002	0.002	0.004	0.004	0.003	0.009	0.005	0.001
4	0.037	0.01	0.01	0.008	0.014	0.015	0.005	0.012
5	0.018	0.002	0.001	0.019	0.006	0.004	0.005	0.015
6	0.001	0.002	0.005	0.005	0.003	0.003	0.007	0.002
7	0.001	0.003	0.004	0.003	0.007	0.002	0.004	0.009
8	0.019	0.009	0.012	0.007	0.003	0.015	0.016	0.019
9	0.002	0.006	0.011	0.004	0.008	0.013	0.003	0.003
10	1.024	0.089	0.003	0.031	0.009	0.043	0.012	0.007
11	0.01	0.002	0.001	0.001	0.004	0.007	0.002	0.003
12	0	0.039	0	0	0.012	0.004	0.005	0
Site	10-Sep	14-Sep	22-Sep	24-Sep	27-Sep	29-Sep	4-Oct	20-Oct
1	0.003	0.003	0.005	0.003	0.01	0.005	0.079	0.005
2	0.001	0.11	0.004	0.013	0.013	0.012	0.061	0.004
3	0.004	0.017	0.006	0.004	0.004	0.006	0.026	0.006
4	0.002	0.004	0.004	0.037	0.009	0.027	0.049	-
5	0.003	0.006	0.004	0	0.007	0.012	0.178	0.087
6	0.001	0.046	0.004	0.006	0.005	0.014	0.039	0.004
7	0.004	0.007	0.006	0.002	0.024	0.035	0.006	0.016
8	0.01	0.007	0.002	0.024	0.01	0.014	0.046	0.003
9	0.003	0.567	-	0.004	0.004	0.01	0.056	0.005
10	0.13	0.519	0.032	0.006	0.02	0.009	0.179	0.006
11	0.063	0.003	0.012	0.001	0.002	0.017	0.012	0.001
12	0.002	0.507	0.002	0.002	0.015	0.015	0.155	0.021

Appendix 5: Water Quality - Descriptive Statistics

Appendix 5a: Descriptive statistics for the combined water quality data in Newlands and Observatory study areas

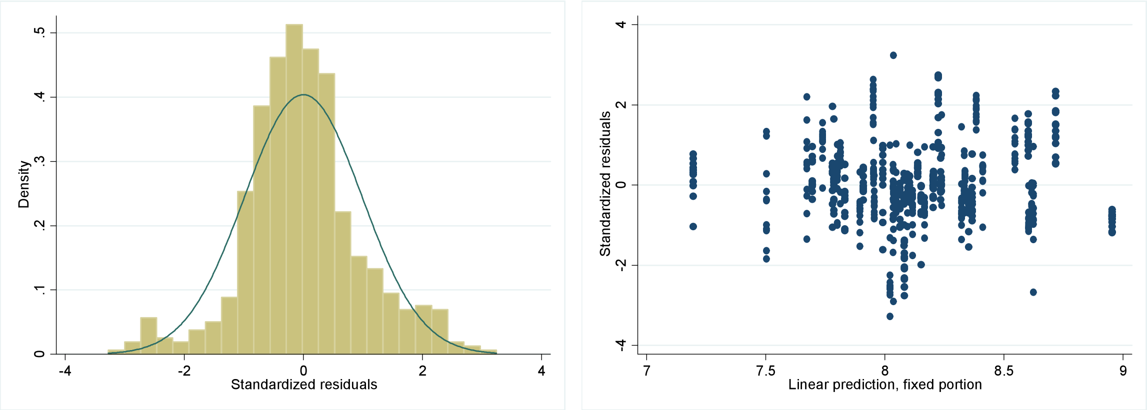
Descriptive statistics – Newlands and Observatory Study Areas (Combined)								
Variable	N	Min.	Max.	Mean	Std Dev.	Median	25th Percentile	75th Percentile
pH	585	3.20	12.80	8.14	0.84	8.10	7.70	8.40
TDS (ppm)	551	0.00	2150.00	86.19	123.67	50.00	50.00	100.00
EC (µS)	551	0.00	4300.00	172.04	246.59	100.00	100.00	200.00
Orthophosphate (mg/l)	582	0.00	71.97	1.30	3.77	0.40	0.20	0.94
Ammonia (mg/l)	582	0.01	21.75	0.75	1.43	0.37	0.18	0.70
Nitrate (mgl)	581	0.00	8.03	0.56	0.60	0.47	0.30	0.63
Nitrite (mg/l)	581	0.00	1.30	0.03	0.10	0.01	0.00	0.01

Appendix 5b: Descriptive statistics for water quality data separated by study area

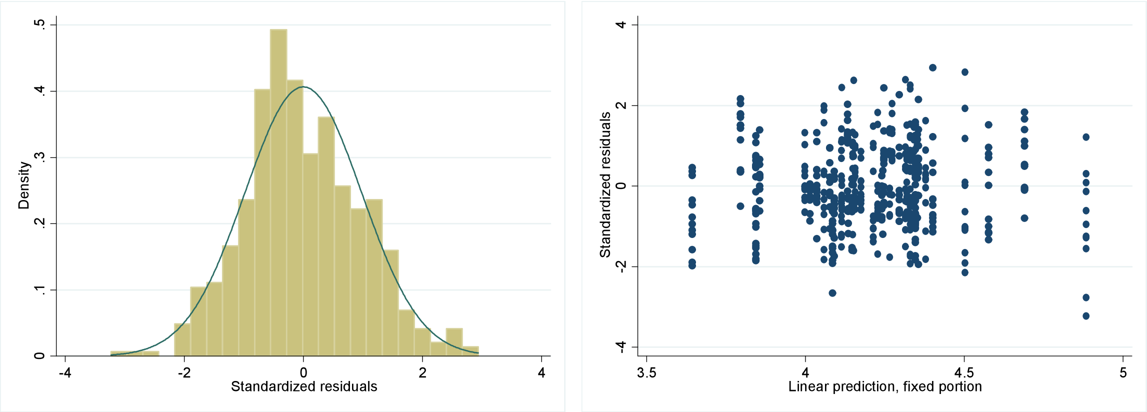
Descriptive Statistics – Per Area								
Variable	N	Min.	Max.	Mean	Std Dev.	Median	25th Percentile	75th Percentile
Newlands								
pH	300	5.90	12.50	8.18	0.80	8.10	7.80	8.40
TDS (ppm)	287	0.00	392.00	71.90	53.53	50.00	49.00	100.00
EC (µS)	287	0.00	795.00	143.18	107.35	100.00	98.00	200.00
Orthophosphate (mg/l)	298	0.00	13.50	0.77	1.46	0.33	0.17	0.66
Ammonia (mg/l)	298	0.01	5.83	0.58	0.81	0.34	0.16	0.60
Nitrate (mgl)	298	0.00	3.55	0.49	0.44	0.40	0.30	0.57
Nitrite (mg/l)	298	0.00	0.58	0.03	0.09	0.00	0.00	0.01
Observatory								
pH	285	3.20	12.80	8.09	0.88	8.10	7.70	8.50
TDS (ppm)	264	0.00	2150.00	101.72	168.53	57.50	50.00	100.00
EC (µS)	264	0.00	4300.00	203.42	335.75	116.00	100.00	200.00
Orthophosphate (mg/l)	284	0.00	71.97	1.86	5.14	0.56	0.26	1.48
Ammonia (mg/l)	284	0.03	21.75	0.94	1.85	0.42	0.21	0.83
Nitrate (mgl)	283	0.00	8.03	0.62	0.73	0.50	0.33	0.70
Nitrite (mg/l)	283	0.00	1.30	0.03	0.12	0.01	0.00	0.02

Appendix 6: Water Quality - Mixed Effect Regression Model Diagnostics

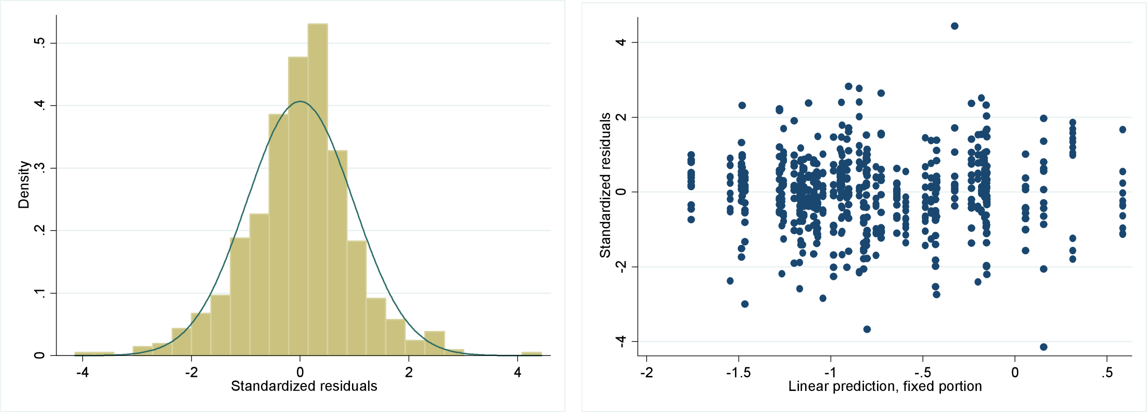
Appendix 6a: Model diagnostics for pH = $DC_D + RC_R + SC_S + I$



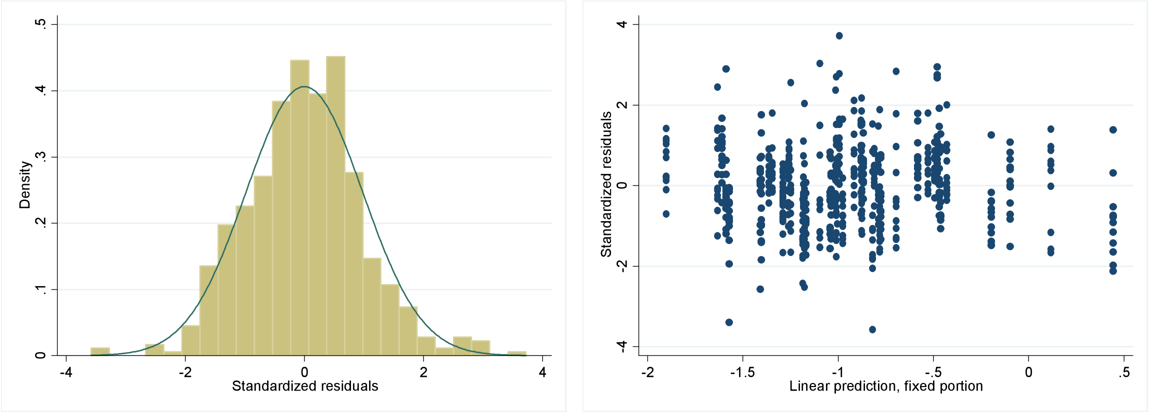
Appendix 6b: Model diagnostics for Ln(TDS) = $DC_D + RC_R + I$



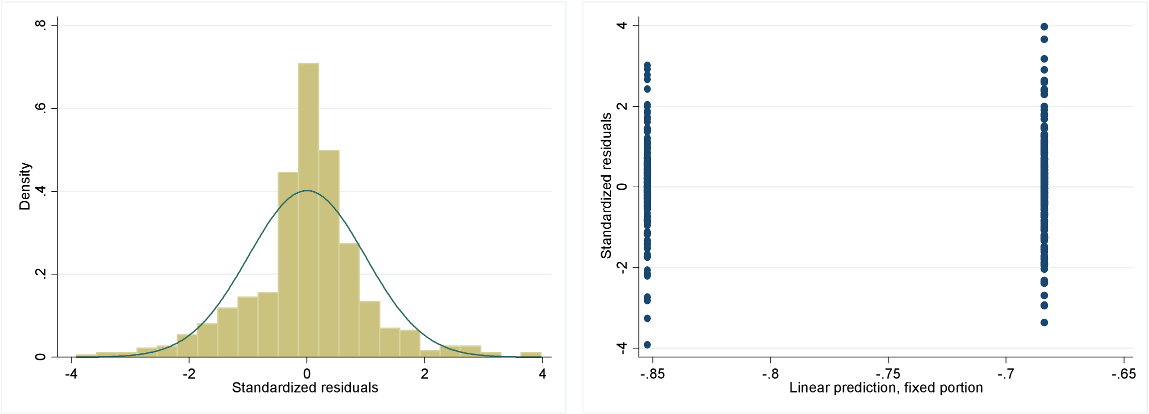
Appendix 6c: Model diagnostics for Ln(PO_4^{3-}) = $DC_D + RC_R + SC_S + I$



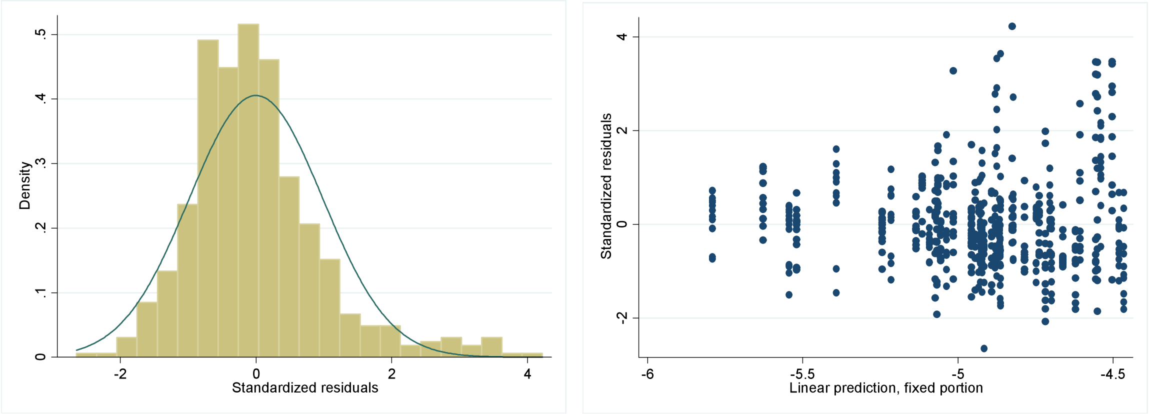
Appendix 6d: Model diagnostics for $\text{Ln}(NH_3\text{-}N) = DC_D + RC_R + SC_S + I$



Appendix 6e: Model diagnostics for $\text{Ln}(NO_3^-) = AC_A + I$



Appendix 6f: Model diagnostics for $\text{Ln}(NO_2^-) = DC_D + RC_R + SC_S + I$



Appendix 7: Water Quality - PCA

Appendix 7a: Rotation of principle components in Newlands PCA biplot

	PC1	PC2	PC3	PC4	PC5	PC6	PC7
pH	-0.048	0.168	0.821	-0.514	0.174	0.012	0.004
TDS	-0.508	-0.151	0.243	0.393	-0.004	0.085	0.705
EC	-0.510	-0.153	0.240	0.383	0.017	0.100	-0.708
Orthophosphate	-0.426	-0.155	-0.311	-0.562	-0.199	0.585	0.009
Ammonia	-0.486	-0.045	-0.248	-0.325	0.169	-0.753	-0.002
Nitrate	-0.177	0.681	0.034	0.053	-0.698	-0.117	-0.012
Nitrite	-0.173	0.661	-0.222	0.101	0.643	0.246	0.012

Appendix 7b: Rotation of principle components in Observatory PCA biplot

	PC1	PC2	PC3	PC4	PC5	PC6	PC7
pH	-0.119	0.083	0.778	0.523	-0.313	-0.048	0.001
TDS	0.571	-0.340	0.198	-0.065	0.062	0.096	0.708
EC	0.570	-0.341	0.201	-0.066	0.065	0.101	-0.706
Orthophosphate	0.302	0.369	-0.340	0.505	-0.115	0.623	0.000
Ammonia	0.428	0.261	-0.262	0.114	-0.450	-0.681	-0.004
Nitrate	0.220	0.580	0.237	0.018	0.719	-0.202	0.001
Nitrite	0.102	0.469	0.273	-0.670	-0.401	0.292	0.001

Appendix 8: Resident Survey - Results

Appendix 8a: Description of resident survey participation

	Newlands	Observatory	Total
Households approached for survey	94	272	366
Surveys completed	32	36	68
Households which could not be reached	6	90	96
Households which declined to participate	10	17	27
Households which did not respond	46	129	175
Participation rate	34.04%	13.24%	18.58%

Appendix 8b: Results obtained from resident survey responses. Long-answer questions have been categorised. The second column in each category (% of relevant sample) refers to the response when the sample size differs from the total in each area (Newlands N_N = 32; Observatory N_O = 36; Combined N_T = 68). The relevant sample size for such questions can be found in line with the question.

Question (Bold) and Answers (Regular Font)	**Newlands (N_N = 32)**		**Observatory (N_O = 36)**		**Areas Combined (N_T = 68)**	
	Total Responses (%)	**Total of Relevant Sample (%)**	**Total Responses (%)**	**Total of Relevant Sample (%)**	**Total Responses (%)**	**Total of Relevant Sample (%)**
Delivery Method						
Dropped off	46.88		50		48.53	
In person	53.13		50		51.47	
Gender						
Male	43.75		41.67		42.65	
Female	56.25		47.22		51.47	
Unknown	0		11.11		5.88	
How often do you visit the Liesbeek River?						
Daily	40.63		11.11		25	
Weekly	34.38		30.56		32.35	
Monthly	12.5		22.22		17.65	
Never/Rarely	12.5		36.11		25	
What is the condition of the Liesbeek River?						
Very good (5)	43.75		0		20.59	
Good (4)	46.88		30.56		38.24	
Neutral (3)	9.38		36.11		23.53	
Poor (2)	0		25		13.24	
Very poor (1)	0		5.56		2.94	
No answer	0		2.78		1.47	
Level of concern for the Liesbeek River?						
Very concerned (5)	46.88		55.56		51.47	

Concerned (4)	34.38	30.56	32.35
Neutral (3)	12.5	8.33	10.29
Not concerned (2)	6.25	5.56	5.88
Not concerned at all (1)	0	0	0
Who is the primary group responsible for local river pollution?			
Commercial properties	0	0	0
Vagrants	25	47.22	36.76
Non-residents	9.38	16.67	13.24
Residents	18.75	2.78	10.29
Industrial practices	9.38	16.67	13.24
Construction practices	34.38	11.11	22.06
Other (invasive plants)	0	0	0
Other (wind)	0	0	0
Who is among the top 3 groups responsible for local river pollution?			
Commercial properties	12.5	19.44	16.18
Vagrants	53.13	83.33	69.12
Non-residents	53.13	52.78	52.94
Residents	25	33.33	29.41
Industrial practices	12.5	25	19.12
Construction practices	71.88	30.56	50
Other (invasive plants)	0	0	0
Other (wind)	0	0	0
Who is among the top 5 groups responsible for local river pollution?			
Commercial properties	15.63	22.22	19.12
Vagrants	65.63	88.89	77.94
Non-residents	56.25	55.56	55.88
Residents	28.13	41.67	35.29
Industrial practices	15.63	27.78	22.06
Construction practices	71.88	36.11	52.94
Other (invasive plants)	0	5.56	2.94
Other (wind)	0	8.33	4.41
Sources that contribute to water in the Liesbeek River			
Runoff from natural landscapes	96.88	97.22	97.06
Wastewater effluent	12.5	19.44	16.18
Street runoff	93.75	88.89	91.18
Runoff from roofs, paved areas	59.38	69.44	64.71
Water from washing machine	12.5	8.33	10.29
Water from pool backwash	53.13	30.56	41.18
Water from car washing	37.5	30.56	33.82
Residential garden runoff	65.63	69.44	67.65
Water from kitchen & bathroom plumping	9.38	8.33	8.82
Other (Springs)	0	2.78	1.47
Which is the primary cause of local river pollution?			
Litter/rubbish (unintentional/small scale)	37.5	77.78	58.82
Illegal dumping (intentional)	25	8.33	16.18
Building/construction waste	21.88	2.78	11.76
Garden waste/runoff	3.13	5.56	4.41
Riverbank erosion	3.13	0	1.47
Sewage/inadequate sewage	3.13	5.56	4.41

Domestic animals	3.13	0	1.47
Impacts from cars	3.13	0	1.47
Which are among the top three causes of local river pollution?			
Litter/rubbish (unintentional/small scale)	81.25	94.44	88.24
Illegal dumping (intentional)	62.5	75	69.12
Building/construction waste	56.25	30.56	42.65
Garden waste/runoff	21.88	16.67	19.12
Riverbank erosion	37.5	16.67	26.47
Sewage/inadequate sewerage	6.25	38.89	23.53
Domestic animals	21.88	2.78	11.76
Impacts from cars	3.13	16.67	10.29
Which are among the top five causes of local river pollution?			
Litter/rubbish (unintentional/small scale)	90.63	97.22	94.12
Illegal dumping (intentional)	75	83.33	79.41
Building/construction waste	78.13	52.78	64.71
Garden waste/runoff	37.5	22.22	29.41
Riverbank erosion	65.63	44.44	54.41
Sewage/inadequate sewage	37.5	55.56	47.06
Domestic animals	40.63	16.67	27.94
Impacts from cars	15.63	33.33	25
Are drains an acceptable disposal method for materials other than stormwater?			
Yes	3.13	0	1.47
No	75	66.67	70.59
Depends on material	21.88	33.33	27.94
What type of stormwater drainage system is used locally?			
Separate pipe network	96.88	86.11	91.18
Combined pipe network	3.13	13.89	8.82
Who is primarily responsible for drainage management?			
Local government	96.88	94.44	95.59
National government	0	5.56	2.94
Residents	3.13	0	1.47
Property owners	0	0	0
Who (if any) holds a secondary role of responsibility?			
Local government	0	0	0
National government	3.13	2.78	2.94
Residents	28.13	19.44	23.53
Property owners	9.38	11.11	10.29
Who (if any) holds a tertiary role of responsibility?			
Local government	0	0	0
National government	0	0	0
Residents	3.13	5.56	4.41
Property owners	6.25	5.56	5.88
Where does stormwater go after entering a drain?			
Water treatment plant/sewage system	12.5	5.56	8.82
Local River	68.75	75	72.06
Directly to the Ocean	12.5	5.56	8.82
Other	0	0	0
Unsure	6.25	13.89	10.29

Who regularly cares for your garden?						
Myself/family member	31.25		80.56		57.35	
Family and gardener	28.13		8.33		17.65	
Gardener/estate manager/hired individual	40.63		8.33		23.53	
Nobody/NA	0		2.78		1.47	
Does the lawn get watered aside from natural rainfall?						
Yes	84.38		66.67		75	
No	9.38		16.67		13.24	
NA/unsure	6.25		16.67		11.76	
When does the lawn get watered?		**N_N = 27**		**N_O = 24**		**N_T = 51**
Unsure	3.13	3.7	0	0	1.47	1.96
Spring	40.63	48.15	58.33	87.5	50	66.67
Summer	81.25	96.3	63.89	95.83	72.06	96.08
Autumn	15.63	18.52	36.11	54.17	26.47	35.29
Winter	3.13	3.7	13.89	20.83	8.82	11.76
Is fertilizer used in the garden?						
Yes	81.25		63.89		72.06	
No	18.75		33.33		26.47	
NA/unsure	0		2.78		1.47	
When are fertilizers used?		**N_N = 26**		**N_O = 23**		**N_T = 49**
Unsure	6.25	7.69	5.56	8.7	5.88	8.16
Spring	62.5	76.92	38.89	60.87	50	69.39
Summer	50	61.54	38.89	60.87	44.12	61.22
Autumn	18.75	23.08	5.56	8.7	11.76	16.33
Winter	6.25	7.69	0	0	2.94	4.08
What type of fertilizer is used?		**N_N = 26**		**N_O = 23**		**N_T = 49**
Chemical	9.38	11.54	5.56	8.7	7.35	10.2
Natural (compost/manure)	53.13	65.38	52.78	82.61	52.94	73.47
Chemical and natural	18.75	23.08	5.56	8.7	11.76	16.33
Don’t use fertilizer or unsure	18.75	-	36.11	-	27.94	-
How do you decide how much fertilizer to apply?		**N_N = 26**		**N_O = 23**		**N_T = 49**
No answer	18.75	0	38.89	4.35	29.41	2.04
Professional services	6.25	7.69	0	0	2.94	4.08
Based on soil test	0	0	0	0	0	0
Calibrated spreader	3.13	3.85	0	0	1.47	2.04
Based on past experience	15.63	19.23	11.11	17.39	13.24	18.37
Follow instructions	34.38	42.31	33.33	52.17	33.82	46.94
Guess	21.88	26.92	16.67	26.09	19.12	26.53
Are pesticides used in your garden?						
Yes	40.63		19.44		29.41	
No	59.38		77.78		69.12	
NA/Unsure	0		2.78		1.47	
When are pesticides applied?		**N_N = 13**		**N_O = 7**		**N_T = 20**
Spring	0	0	2.78	14.29	1.47	5
Summer	3.13	7.69	0	0	1.47	5
Autumn	0	0	0	0	0	0
Winter	0	0	0	0	0	0
When pests appear	37.5	92.31	8.33	42.86	22.06	75
Unsure	0	0	0	0	0	0

Spring and summer	0	0	2.78	14.29	1.47	5
Spring and autumn	0	0	2.78	14.29	1.47	5
Autumn and winter	0	0	2.78	14.29	1.47	5
Don’t use pesticides or unsure	59.38	-	80.56	-	70.59	-
Are vehicles washed on the premises?						
Yes	81.25		66.67		77.94	
No	18.75		33.33		26.47	
NA/unsure	0		0		0	
Where does vehicle wash runoff go?		**$N_N = 26$**		**$N_O = 24$**		**$N_T = 50$**
Flows Into the street	65.63	80.77	52.78	79.17	58.82	80
Flows into the garden	15.63	19.23	8.33	12.5	11.76	16
I direct, collect, dispose of it	0	0	5.56	8.33	2.94	4
Does car oil get changed on the premises?						
Yes	3.13		2.78		2.94	
No	96.88		97.22		97.06	
NA/unsure	0		0		0	
How is pet waste managed?		**$N_N = 30$**		**$N_O = 26$**		**$N_T = 56$**
No animals	6.25	-	27.78	-	17.65	-
Left to decompose outside	18.75	20	19.44	26.92	19.12	23.21
Put on compost pile/pit	15.63	16.67	2.78	3.85	8.82	10.71
Picked up and put in rubbish	53.13	56.67	41.67	57.69	47.06	57.14
Buried by animal	6.25	6.67	8.33	11.54	7.35	8.93
What happens to swimming pool back wash?		**$N_N = 4$**		**$N_O = 27$**		**$N_T = 31$**
No swimming pool	15.63	-	88.89	-	54.41	-
Drains to Street	40.63	48.25	2.78	25	20.59	45.16
Drains to soil/garden area	12.5	14.81	8.33	75	10.29	22.58
Directed into Sewage System	21.88	25.93	0	0	10.29	22.58
Street and Sewerage system	6.25	7.41	0	0	2.94	6.45
Unsure	3.13	3.70	0	0	1.47	3.23
Have you had problems with stormwater drainage?						
Yes	46.88		52.78		50	
None	53.13		47.22		50	
Type of problem:		**$N_N = 15$**		**$N_O = 19$**		**$N_T = 34$**
Flooding of property	9.38	20	8.33	15.79	8.82	17.65
Road flooding/drain blockage	40.63	86.67	36.11	68.42	38.24	76.47
Theft of drain covers/pipes	0	0	5.56	10.53	2.94	5.88
Substrate inhibits infiltration	0	0	5.56	10.53	2.94	5.88
Action Taken:		**$N_N = 15$**		**$N_O = 19$**		**$N_T = 34$**
Removed blockage	21.88	46.67	25	47.37	23.53	47.06
Calls council	9.38	20	11.11	21.05	10.29	20.59
No action	15.63	33.33	11.11	21.05	13.24	26.47
Frequency:		**$N_N = 15$**		**$N_O = 19$**		**$N_T = 34$**
Once a year or more	31.25	66.67	38.89	73.68	35.29	70.59
Less than once a year	15.63	33.33	5.56	10.53	10.29	20.59
Unspecified	0	0	2.78	5.26	1.47	2.94
Have you observed intentional misuse of stormwater drains?						
Yes	12.5		38.89		26.47	
No	87.5		61.11		73.53	
Action observed:		**$N_N = 4$**		**$N_O = 14$**		**$N_T = 18$**
Pushing/washing debris into	12.5	100	27.78	71.43	20.59	77.78

drain						
Pouring directly into drain	6.25	50	5.56	14.29	5.88	22.22
Dumping rubbish	3.12	25	22.22	57.14	5.88	22.22
Action taken:		**N_N = 4**		**N_O = 14**		**N_T = 18**
Approached them	3.13	25	19.44	50	11.76	44.44
Contacted authority	0	0	0	0	0	0
Approached and contacted the authority	3.13	25	0	0	1.47	5.56
No action	6.25	50	19.44	50	13.24	50
Have you observed un-intentional misuse of stormwater drains?						
Yes	59.38		27.78		42.65	
No	40.63		72.22		57.35	
Action observed:		**N_N = 19**		**N_O = 10**		**N_T = 29**
Wash-off associated with construction or painting sites (sand/paint/concrete)	43.75	73.68	13.89	50	27.94	65.52
Street debris (litter, bags, clothing, dead squirrel)	9.38	15.79	13.89	50	11.76	27.59
Pool backwash	3.13	5.26	0	0	1.47	3.45
Soapy water	6.25	10.53	0	0	2.94	6.9
Engine oil from road	0	0	2.78	10	1.47	3.45
Action taken:		**N_N = 19**		**N_O = 10**		**N_T = 29**
No action	40.63	68.42	13.89	50	26.47	62.07
Approached responsible party	6.25	10.53	11.11	40	8.82	20.69
Managed it themselves	9.38	15.79	0	0	4.41	10.34
Contacted authority	3.13	5.26	2.78	10	2.94	6.9
Do you know whom to contact for stormwater drainage issues?						
Yes	59.38		66.67		63.23	
No	40.63		33.33		36.76	
What would you do if you saw a blocked or flooding drain?						
Clear it (myself/hired worker)	28.13		30.56		29.41	
Contact the authority	43.75		38.89		41.18	
Ignore it	6.25		5.56		5.88	
Clear it and contact authority	21.88		25		23.53	
Other	0		0		0	
What would you do if you saw intentional misuse of drains?						
Approach and ask to stop	34.38		47.22		41.18	
Contact the authority	34.38		8.33		20.59	
Ignore it	6.25		25		16.18	
Approach (if it is safe to do so) and contact authority	21.88		19.44		20.59	
No answer	3.13		0		1.47	
What is your length of residence at the current location?						
0-1 year	9.38		13.89		11.76	
2-5 years	25		38.89		32.35	
6-10 years	37.5		16.67		26.47	
11-20 years	21.88		13.89		17.65	
21+ years	3.13		16.67		10.29	
No answer	3.13		0		1.47	
Do you rent or own the property?						
Rent	6.25		25		16.18	

Own	93.75		75		83.82	
Do you collect stormwater on the premises?						
Yes	12.5		2.78		7.35	
No	59.38		61.11		60.29	
Not yet, but plan to	28.13		33.33		30.88	
No answer	0		2.78		1.47	
What do/would you use the harvested stormwater for?						
Garden	28.13		27.78		27.94	
Pool	12.5		0		5.88	
Household uses	3.13		27.78		2.94	
No answer	62.5		72.22		67.65	
Of those that do collect stormwater - why?		**N_N = 4**		**N_O = 1**		**N_T = 5**
Environmental/conservation reasons		25		100		40
Drought or water supply reasons		25		0		20
Economic reasons- cuts costs		75		0		60
For fun or personal reasons (i.e. hobbies, permaculture)		0		100		20
Of those that do not collect stormwater - why not?		**N_N = 19**		**N_O = 22**		**N_T = 41**
Economic reasons- not enough incentive or too expensive		15.79		0		7.32
Not enough space on the premises		15.79		36.36		26.83
Do not need/care to		21.05		22.73		21.95
Not enough time or haven't lived here long enough		5.26		0		2.44
Never thought to or no knowledge of it		0		9.09		4.88
Don't own the property or don't want to invest in it		0		18.18		9.76
No Answer		57.89		27.27		41.46
Of those that plan to collect stormwater- why?		**N_N = 9**		**N_O = 12**		**N_T = 21**
Environmental or conservation reasons		88.89		50		66.67
Drought or water supply reasons		11.11		0		4.76
Economic reasons - cuts costs		22.22		33.33		28.57
For fun or personal reasons (i.e. hobbies, permaculture)		11.11		0		4.76
Only gave reasons they have not begun yet, including limited space and time		11.11		25		19.05
No answer		0		25		14.29
How long have you been collecting stormwater?		**N_N = 4**		**N_O = 1**		**N_T = 5**
NA	87.5	-	97.22	-	92.65	0
0-1 year	0	0	0	0	0	0
2-4 years	6.25	50	2.78	100	4.41	60
5-7 years	3.13	25	0	0	1.47	20
8-10 years	0	0	0	0	0	0

11+ years	3.13	25	0	0	1.47	20
Do you have other concerns about local stormwater or the river?						
Yes	21.88		41.67		32.35	
None	78.13		58.33		67.65	
Other concerns:		**$N_N = 7$**		**$N_O = 15$**		**$N_T = 22$**
Road and subway flooding	3.13	14.29	8.33	20	5.88	18.18
Infrastructure is old, broken	3.13	14.29	5.56	13.33	4.41	13.64
Inadequate servicing and regulation by municipality	6.25	28.57	13.89	33.33	10.29	31.82
Frequent pool backwashing to stormwater drains	3.13	14.29	0	0	1.47	4.55
Not enough oversight of construction practices	0	0	5.56	13.33	2.94	9.09
Litter blockage of drains and misuse by street sweepers	0	0	2.78	6.67	1.47	4.55
Theft of drainage grids and pipes	0	0	5.56	13.33	2.94	9.09
Wasteful not to collect stormwater, too little awareness	3.13	14.29	5.56	13.33	4.41	13.64
Need to increase awareness of stormwater system to improve social responsibility	0	0	11.11	26.67	5.88	18.18
General environmentalist concerns	0	0	13.89	33.33	7.35	22.73
Litter in river (via wind/rain)	3.13	14.29	11.11	26.67	7.35	22.73
Litter in river (via dumping)	6.25	28.57	11.11	26.67	8.82	27.27
Safety along walking paths	0	0	8.33	20	4.41	13.64

Appendix 9: Resident Survey - Chi-Square Analyses

Appendix 9a: Chi-square analysis of resident perspective of contributors to local river pollution and length of residence

Length of Residence	Are vagrants in the top 5 groups responsible for local river pollution?		Total
	Yes	No	
0-1 year	4	4	8
2-5 years	16	6	22
6-10 years	17	1	18
11-20 years	8	4	12
21+ years	7	0	7
Total	52	15	67
$X^2 = 9.5940$, $p_{Fischers} = 0.039$, $p = 0.048$			

Appendix 9b: Chi-square analysis of resident perspective of contributors to local river pollution and frequency of Liesbeek River visits

Frequency of Liesbeek River visits	Are vagrants in the top 5 groups responsible for local river pollution?		Total
	Yes	No	
Frequent (daily or weekly)	34	5	39
Infrequent (monthly or rarely/never)	18	11	29
Total	52	16	68
$X^2 = 5.8285$, $p_{Fischers} = 0.022$, $p_{1\text{-sided Fischers}} = 0.017$, $p = 0.016$			

Appendix 9c: Chi-square analysis of resident perspective of contributors to local river pollution and frequency of Liesbeek River visits

Frequency of Liesbeek River visits	Are non-residents in the top 5 groups responsible for local river pollution?		Total
	Yes	No	
Frequent (daily or weekly)	25	14	39
Infrequent (monthly or rarely/never)	13	16	29
Total	38	30	68
$X^2 = 2.5064$, $p_{Fischers} = 0.142$, $p_{1\text{-sided Fischers}} = 0.091$, $p = 0.113$			

Appendix 9d: Chi-square analysis of resident perspective of contributors to local river pollution and frequency of Liesbeek River visits

Frequency of Liesbeek River visits	Are non-residents in the top 3 groups responsible for local river pollution?		Total
	Yes	No	
Frequent (daily or weekly)	24	15	39
Infrequent (monthly or rarely/never)	12	17	29
Total	36	32	68
$X^2 = 2.7131$, $p_{Fischers} = 0.141$, $p_{1\text{-sided Fischers}} = 0.080$, $p = 0.100$			

Appendix 9e: Chi-square analysis of resident perspective of local river pollution sources and frequency of visiting the Liesbeek River

Frequency of Liesbeek River visits	Are building and construction waste in the top 5 causes of local river pollution?		Total
	Yes	No	
Frequent (daily or weekly)	30	9	39
Infrequent (monthly or rarely/never)	13	16	29
Total	43	25	68
$X^2 = 7.3697$, $p_{Fischers} = 0.011$, $p_{1\text{-sided Fischers}} = 0.007$, $p = 0.007$			

Appendix 9f: Chi-square analysis of knowledge of the stormwater system design and knowledge of acceptable materials for stormwater drains

Water that enters a storm drain goes to…	Are storm drains an acceptable disposal method for anything other than rainwater?			Total
	Yes	No	Depends on material	
Water treatment plant/sewerage	1	4	1	6
Local river	0	38	11	49
Directly to the ocean	0	3	3	6
Unsure	0	3	4	7
Total	1	48	19	68
$X^2 = 15.7890$, $p_{Fischers} = 0.045$, $p = 0.015$				

Appendix 9g: Chi-square analysis of resident knowledge of water sources to the Liesbeek River

Does street runoff contribute water to the Liesbeek River?	Does car washing contribute water to the Liesbeek River?		Total
	Yes	No	
Yes	23	39	62
No	0	6	6
Total	23	45	68
$X^2 = 3.3634$, $p_{Fischers} = 0.089$, $p_{1\text{-sided Fischers}} = 0.074$, $p = 0.067$			

Appendix 9h: Chi-square analysis of Liesbeek River water sources and contributors to local river pollution

Are residents in the top 5 groups responsible for local river pollution?	Does residential garden runoff contribute water to the Liesbeek River?		Total
	Yes	No	
Yes	20	3	23
No	26	18	44
Total	46	21	67
$X^2 = 5.4502$, $p_{Fischers} = 0.026$, $p_{1\text{-sided Fischers}} = 0.017$, $p = 0.020$			

Appendix 9i: Chi-square analysis of Liesbeek River water sources and management of vehicle wash runoff

Does street runoff contribute water to the Liesbeek River?	What happens to vehicle washing runoff? (Of those that wash vehicle on the premises)			Total
	Flows into the street	Flows into a garden/soil area	I direct, collect and dispose of it	
Yes	38	7	1	46
No	2	1	1	4
Total	40	8	2	50
$X^2 = 5.5027$, $p_{Fischers} = 0.079$, $p = 0.064$				

Appendix 9j: Chi-square analysis of vehicle wash runoff management and resident perspective of responsibility for stormwater management

Who is primarily responsible for managing stormwater and its issues?	What happens to vehicle washing runoff? (Of those that wash vehicle on the premises)			Total
	Flows into the street	Flows into a garden/soil area	I direct, collect and dispose of it	
Local Government	39	8	1	48
National Government	1	0	1	2
Residents	0	0	0	0
Property Owners	0	0	0	0
Total	40	8	2	50
$X^2 = 11.5885$, $p_{Fischers} = 0.102$, $p = 0.003$				

Appendix 9k: Chi-square analysis of pet waste management and recognition of residential garden runoff as a source of water to the Liesbeek River

Does residential garden runoff contribute water to the Liesbeek River?	How is pet waste managed? (Of those that own pets)				Total
	Left outside	Put in compost	Picked up and put in rubbish	Buried by the animal	
Yes	9	3	26	1	39
No	4	3	6	3	16
Total	13	6	32	4	55
$X^2 = 7.0352$, $p_{Fischers} = 0.054$, $p = 0.071$					

Appendix 9l: Chi-square analysis of pet waste management and resident perspective of responsibility for local river pollution

Are residents in the top 3 groups responsible for local river pollution?	How is pet waste managed?					Total
	No pets	Left outside	Put in compost	Picked up and put in rubbish	Buried by the animal	
Yes	0	6	2	9	2	19
No	12	7	4	24	2	49
Total	12	13	6	33	4	68
$X^2 = 7.8554$, $p_{Fischers} = 0.049$, $p = 0.097$						

Appendix 9m: Chi-square analysis of pool backwash management and understanding of acceptable materials for disposal in stormwater drains

Are storm drains an acceptable disposal method for anything other than rainwater?	**How is pool backwash managed? (Of those that own pools)**				**Total**
	Drains to the street	**Drains to garden or soil area**	**Directed to the sewerage system**	**Unsure**	
Yes	0	1	0	0	1
No	15	2	5	0	22
Depends on material	2	3	2	1	8
Total	17	6	7	1	31
$X^2 = 11.6018$, $p_{Fischers} = 0.025$, $p = 0.071$					

Appendix 9n: Chi-square analysis of observed unintentional misuse and resident perspective of contributors to local river pollution

Have you observed intentional misuse of stormwater drains?	**Are residents in the top 5 groups responsible for local river pollution?**		**Total**
	Yes	**No**	
Yes	15	14	29
No	8	31	39
Total	23	45	68
$X^2 = 7.2386$, $p_{Fischers} = 0.010$, $p_{1\text{-sided Fischers}} = 0.007$, $p = 0.007$			

Appendix 9o: Chi-square analysis of observed unintentional misuse and resident perspective of contributors to local river pollution

Have you observed intentional misuse of stormwater drains?	**Are construction practices in the top 5 groups responsible for local river pollution?**		**Total**
	Yes	**No**	
Yes	20	9	29
No	15	24	39
Total	35	33	68
$X^2 = 6.1959$, $p_{Fischers} = 0.016$, $p_{1\text{-sided Fischers}} = 0.012$, $p = 0.013$			

Appendix 9p: Chi-square analysis of observed unintentional misuse of stormwater drains and resident perspective of the causes of local river pollution

Have you observed intentional misuse of stormwater drains?	**Is garden waste/runoff in the top 5 causes of local river pollution?**		**Total**
	Yes	**No**	
Yes	12	17	29
No	7	32	39
Total	19	49	68
$X^2 = 4.5351$, $p_{\text{Fischers}} = 0.055$, $p_{\text{1-sided Fischers}} = 0.032$, $p = 0.033$			

Appendix 9q: Chi-square analysis of observed unintentional misuse of stormwater drains and resident perspective of the causes of local river pollution

Have you observed intentional misuse of stormwater drains?	**Is building/construction waste in the top 3 causes of local river pollution?**		**Total**
	Yes	**No**	
Yes	16	13	29
No	12	27	39
Total	28	40	68
$X^2 = 4.0893$, $p_{\text{Fischers}} = 0.051$, $p_{\text{1-sided Fischers}} = 0.038$, $p = 0.043$			

Appendix 9r: Chi-square analysis of resident response to observed unintentional misuse of stormwater drains and knowledge of which municipal body to contact regarding stormwater issues

Do you know whom to contact for stormwater-related issues?	**Resident response to observed unintentional misuse of stormwater drains**				**Total**
	No action	**Approached responsible party**	**Managed it themselves**	**Contacted the authority**	
Yes	9	6	2	2	19
No	9	0	1	0	10
Total	18	6	3	2	29
$X^2 = 6.1307$, $p_{\text{Fischers}} = 0.098$, $p = 0.105$					

Appendix 9s: Chi-square analysis of resident response to unintentional misuse of stormwater drains and perspective of responsibility for stormwater management issues

Who holds secondary responsibility for management of stormwater issues?	Resident response to observed unintentional misuse of stormwater drains				Total
	No action	Approached responsible party	Managed it themselves	Contacted the authority	
National government	1	0	1	0	2
Residents	5	3	0	2	10
Property Owners	0	1	2	2	3
Total	6	4	3	2	15
$X^2 = 9.2917$, $p_{Fischers} = 0.096$, $p = 0.158$					

Appendix 9t: Chi-square analysis of resident responses to observed and hypothetical stormwater problems

Resident response to observed problems with stormwater drainage	Resident's hypothetical response to problem with stormwater drainage				Total
	Manage it	Manage it and contact the authority	Contact the authority	Contact the authority or ignore it	
Managed it themselves	9	4	3	0	16
Contacted the authority	1	4	2	0	7
Ignored it	3	1	4	1	9
Total	13	9	9	1	32
$X^2 = 9.2606$, $p_{Fischers} = 0156$, $p = 0.159$					

Appendix 9u: Chi-square analysis of resident responses to observed and hypothetical intentional misuse of a stormwater drain

Resident response to observed intentional misuse of stormwater drains	**Resident's hypothetical response to intentional misuse of stormwater drains**					**Total**
	Approach individual	**Approach and contact the authority**	**Contact the authority**	**Contact the authority or ignore it**	**Ignore it**	
Approached the individual	6	2	0	0	0	8
Approached and contacted the authority	0	0	1	0	0	1
Ignored it	0	2	1	1	9	9
Total	6	4	2	1	9	18
X^2 = 21.7500, $p_{Fischers}$ = 0.001, p = 0.005						

Appendix 9v: Chi-square analysis of resident's hypothetical response to a blocked stormwater drain and level of concern for the Liesbeek River

Resident concern for the health of the Liesbeek River	**Resident's hypothetical response to problem with stormwater drainage**					**Total**
	Manage it	**Manage it and contact the authority**	**Contact the authority**	**Contact the authority or ignore it**	**Ignore it**	
Disagree	2	1	0	0	1	4
Neutral	2	2	1	1	1	7
Agree	5	2	14	1	0	22
Strongly agree	11	11	13	0	0	35
Total	20	16	28	2	2	68
X^2 = 25.3870, $p_{Fischers}$ = 0.008, p = 0.013						

Appendix 9w: Chi-square analysis of resident's hypothetical response to a blocked stormwater drain and perspective of responsibility for stormwater management

Who is primarily responsible for managing stormwater and its issues?	Resident's hypothetical response to problem with stormwater drainage					Total
	Manage it	Manage it and contact the authority	Contact the authority	Contact the authority or ignore it	Ignore it	
Local Government	19	16	27	2	1	65
National Government	1	0	0	0	1	2
Total	20	16	27	2	2	67
$X^2 = 16.9304$, $p_{Fischers} = 0.068$, $p = 0.002$						

Appendix 9x: Chi-square analysis of resident's hypothetical response to misuse of a stormwater drain and perspective of responsibility for stormwater management

Who holds secondary responsibility for management of stormwater issues?	Resident's hypothetical response to intentional misuse of stormwater drains					Total
	Approach individual	Approach and contact the authority	Contact the authority	Contact the authority or ignore it	Ignore it	
National government	0	0	1	1	0	2
Residents	6	7	2	0	1	16
Property Owners	3	0	2	0	2	7
Total	9	7	5	1	3	25
$X^2 = 20.1488$, $p_{Fischers} = 0.028$, $p = 0.010$						