Ecological resilience and the interaction between the freshwater ecosystem services and built environment in the City of Tshwane

by

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Declaration

I, the undersigned, hereby confirmed that the attached treatise is my own work and that any sources are adequately acknowledged in the text and listed in the bibliography.

I accept the rules of the University of Pretoria and the consequences of transgressing them.

This treatise is submitted in partial fulfilment of the requirements for the degree of Masters in Landscape Architecture (Research) at the University of Pretoria. It has not been submitted before for any other degree or examination at any other University.

Signature of acceptance and confirmation

Emmarie Otto

Date

Abstract

Nature and humans are intrinsic parts of the same system called a social-ecological system (SES), wherein freshwater ecosystems form one of the most important bases of the survival of all life. Human activities, such as land use and overconsumption, impact on freshwater systems; and freshwater systems also impact on the urban systems through which they flow. Changes in one part of the system, be it human or ecological, will impact on the other. If a freshwater ecosystem's resilience is negatively affected and fails to retain its functional integrity, it will increase the vulnerability of the SES. Disregarding this connection can have a significant impact on the quality of an urban system.

Throughout its 159-year history (1855–2014), the City of Tshwane SES has moved through different eras of change which have altered the quality of the connection between the Apies River and the urban infrastructure through which it flows. These eras of change have been identified as: a) First era (1855–1909) Apies River as a natural system; b) Second era (1910–1970) Apies River becoming a hidden, polluted and disconnected freshwater system c) Third era (1971–2014) the era of attempts at beautification and to regenerate the Apies River freshwater system.

The main goal of this study is to understand how changes in the connection between the built infrastructure in the City of Tshwane and the Apies River have affected the resilience of the Apies River freshwater ecosystem as an integral part of the Tshwane SES. The study achieved this by identifying the different changes, the drivers of change, and the effects that these changes have had on the resilience of the Apies River as part of the Tshwane SES. This was carried out using the method of a historical narrative.

It was concluded that the Apies River gained specific resilience but lost its general resilience and therefore also lost its adaptive capacity, which is the capacity to deal with change. The main drivers behind the loss of general resilience of the Apies River systems were: a) the lack of a local government structure to supply proper infrastructure and service delivery to the people of Pretoria, followed by an inflexible and largely unresponsive local government system; and b) ecological ignorance, lacking the understanding of how freshwater ecosystems function in order to incorporate natural freshwater ecosystems as an integral and functional part of the urban infrastructure.

Keywords: Resilience, City of Tshwane, freshwater ecosystem services, Apies River, social-ecological system (SES).

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List of Acronyms/Definitions/Abbreviations

Abbreviations

CBD	Central Business District
DEA	Department of Environmental Affairs
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry (former name of DWA)
MEA	Millennium Ecosystem Assessment
NRF	National Research Foundation
SACN	South African Cities Network
SES	Social-ecological system
TEEB	The Economics of Ecosystems and Biodiversity
UN	United Nations
UNEP	United Nations Environment Program
WMA	Water Management Area

Definitions

Adaptive capacity	"The capacity of the actors in a system to manage the system's resilience is known as adaptability (also referred to as adaptive capacity). This might be by moving thresholds, moving the current state of the system away from or toward a threshold, or making a threshold more difficult or easy to reach." (Walker & Salt, 2006:119)
Canalised water course	"Hard surfaced river system." (Tshwane City Council, 2007:XV)
Catchment	"An area from which any rainfall will drain into the watercourse or watercourses or part of a watercourse, through surface flow to a common point or common points."(DWA, 2013:106)

Drainage basins and watersheds	"The term drainage basin is used for a larger area and a watershed for a specific area." (Steiner, 2008:14)
Ecosystem	"A community of all the organisms, such as plants, animals, fish and microbes, living in complex but balanced relationships with the physical features of their environment such as light, heat, moisture, wind, water, nutrients and minerals." (DWA, 2013:106)
Flood	"… a condition of flood exists when discharge of a river cannot be accommodated within the margins of its normal channel, so that the water spreads over adjoining ground upon which crops or forests are able to flourish." (Strahler & Strahler, 1973:331)
Floodplain	"The floodplain is the flat area adjoining the river channel constructed by the river in the present climate and overflowed at times of high discharge." (Dunne & Leopold, 1978:600)
Freshwater systems	"Freshwater systems consist of wetlands, lakes and rivers." (UNEP, 2005:14)
Natural water course	"Natural watercourse is a river system that is still in its natural state."(Tshwane City Council, 2007:XV)
Resilience	"The amount of change a system can undergo (its capacity to absorb disturbance) and remain within the same regime-essentially retaining the same function, structure, and feedbacks." (Walker & Salt, 2006:164)
Riparian zone	"Riparian zone is an important ecological link between the river and the terrestrial component of a catchment. In addition it provides a necessary buffer between the river itself and any potential impacts that might originate from within the catchment. " (River Health

	Program, 2005:16)
Social-ecological system (SES)	“Integrated system of ecosystems and human society with reciprocal feedback and interdependence. The concept emphasizes the humans-in-nature perspective.” (Folke, Carpenter, Walker, Scheffer, Chapin, & Rockström, 2010)
Spruit	The word *spruit* is an Afrikaans word meaning: ‘’A small watercourse, typically dry except during the rainy season.’’ (Oxford Dictionaries, 2015)
Threshold	“Thresholds are levels in underlying controlling slow variables after which feedbacks to the rest of the system change - crossing points that have the potential to alter the future of many of the systems upon which we depend upon.” (Walker & Salt, 2006:165)
Watercourse	Watercourse means - “(a) a river or spring; (b) a natural channel in which water flows regularly or intermittently; (c) a wetland, lake or dam into which, or from which, water flows; and (d) any collection of water which the Minister may, by notice in the Gazette, declare to be a watercourse, and a reference to a watercourse includes, where relevant, its bed and banks;” (RSA, 1998)
Water management area (WMA)	Water management area is “an area established as a management unit in the national water resource strategy within which a catchment management agency will conduct the protection, use, development, conservation, management and control of water resources;” (*ibid.*)

Wetland

“Land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil.” (*ibid.*)

CHAPTER 1 - INTRODUCTION TO THE STUDY

1.1 Introduction

Humans exist as an integral part of natural systems. When viewed in the context of intrinsically linked social-ecological systems (SES), as described by Folke, Carpenter, Walker, Scheffer, Chapin, and Rockström, (2010) and according to Folke (2003:2027), humans are responsible for shaping these natural systems over time. Freshwater ecosystem services are crucial to support human well-being, however, the value of the multi-dimensional functions of freshwater systems, for example habitat provision, nutrient cycling and purification, is not understood and not managed as part of the urban system. It is also acknowledged, that freshwater is not recognised in terms of its value as the bloodstream of the biosphere (*ibid.*).

The purpose of this study is to investigate how the disconnection between humans and freshwater ecosystem services in the urban context affects the resilience of the urban SES. The case of the Apies River in the City of Tshwane, South Africa, was used to explore this question, with the aim to: a) determine the reasons for the disconnection between the urban and freshwater system and b) determine how this can be managed better in future to create a positively resilient SES.

In order to address the purpose of the study, the major triggers causing change according to the freshwater system's historical timeline, within a specific section of the Apies River, are explored. This reveals the adaptive capacity of the freshwater ecosystem, which is its ability to cope with these changes. By studying how the freshwater system adapted to, or transformed itself, as a result of the disturbances inflicted upon the system, historical patterns became clear, as do the reasons for the psychological and ecological disconnection between the urban and freshwater system. Understanding the patterns of the system's adaptation and transformation facilitates the anticipation of future changes. This knowledge makes it possible to: a) improve the management of the freshwater system in future in order to strengthen the adaptive capacity of the freshwater ecosystem, and b) implement appropriate interventions to create a freshwater ecosystem which is better connected to the urban SES in order to promote positive resilience in the SES.

1.2 Background

1.2.1 The importance of freshwater systems for cities

Freshwater systems are an intrinsic ecosystem service necessary for the survival of both nature and humans (Falkenmark & Folke, 2003:1917). This important link between freshwater systems to support humans can be seen since the early civilisations when rivers played an important role in the establishment of human settlements, in that many major cities were established along river valleys and floodplains. These early civilisations settling along river banks, developed around 12000 years before present, when permanent settlements started to be established, farming was developed and rivers were used to irrigate crops and supply water and transport. However, the valuable ecosystem goods and services of the freshwater system can only continue to be provided to adjacent communities if the wetlands, river channels, reservoirs, biodiversity and interconnected ecosystems of the watershed are maintained intact. Examples of freshwater ecosystem goods and services benefitting human settlements are local drinking water, irrigation, and flood regulation. Flood regulation is particularly important as floods may increase in the future as a result of altered rainfall patterns following climate change (Secretariat of the Convention on Biological Diversity, 2012:10,34).

Nature and humans are inherent parts of the same system called a social-ecological system (SES) (Folke *et al.*, 2002b:437), wherein freshwater ecosystems form the basis of the survival of all life (Resilience Alliance, 2002a). The close connection between humans and freshwater ecosystems is the biggest influence on the state of freshwater ecosystems (Allan & Castillo, 2007:6). In the context of resilience thinking and to understand the dynamics of either the social or the ecological system, these systems must be viewed in relation to each other, with the understanding that social systems exist as an integral part within ecological systems (Walker & Salt, 2006:31). Because of this close link, changes which occur in the social system, impact on ecological systems and, similarly, changes that occur in the ecological systems affect and have an impact on the social system (*ibid.*). SESs, which are complex adaptive systems, characterised by non-linear behaviour and human activities, can unpredictably affect natural systems in a positive or negative way (Folke *et al*., 2002b:437). Should human activity degrade freshwater ecosystems to a point where natural systems are no longer supported, the social system will become vulnerable as well (*ibid.*). Vulnerable systems have a reduced resilience and a weakened capacity to adapt to change (Carpenter, Walker, Anderies & Abel, 2001:779).

1.2.2 The problem of deteriorated urban freshwater systems

Globally, freshwater ecosystems have been extensively transformed by the expansion of cities, so that the question is often asked: “Can you find the river that first made the city?” (McHarg,1992:20,21). Unless cities are designed and managed to incorporate freshwater ecosystems as an integral part of and service provider to the socio-economic urban system, their value will continue to be disconnected and lost to human well-being. The diversity and ecological integrity of watersheds should therefore be protected so that the vitality of freshwater ecosystem services can be maintained (UNESCO, 2003:16). Connecting freshwater ecosystems in an integrated manner with urban planning, contributes positively to human well-being and a resilient SES (Walker & Salt, 2006:148).

1.2.3 Apies River freshwater system in the City of Tshwane

The disconnection between humans and the freshwater systems they depend on, is explored in a study area situated in Pretoria, within the City of Tshwane, in the Gauteng province in South Africa, as indicated in Figure 1.

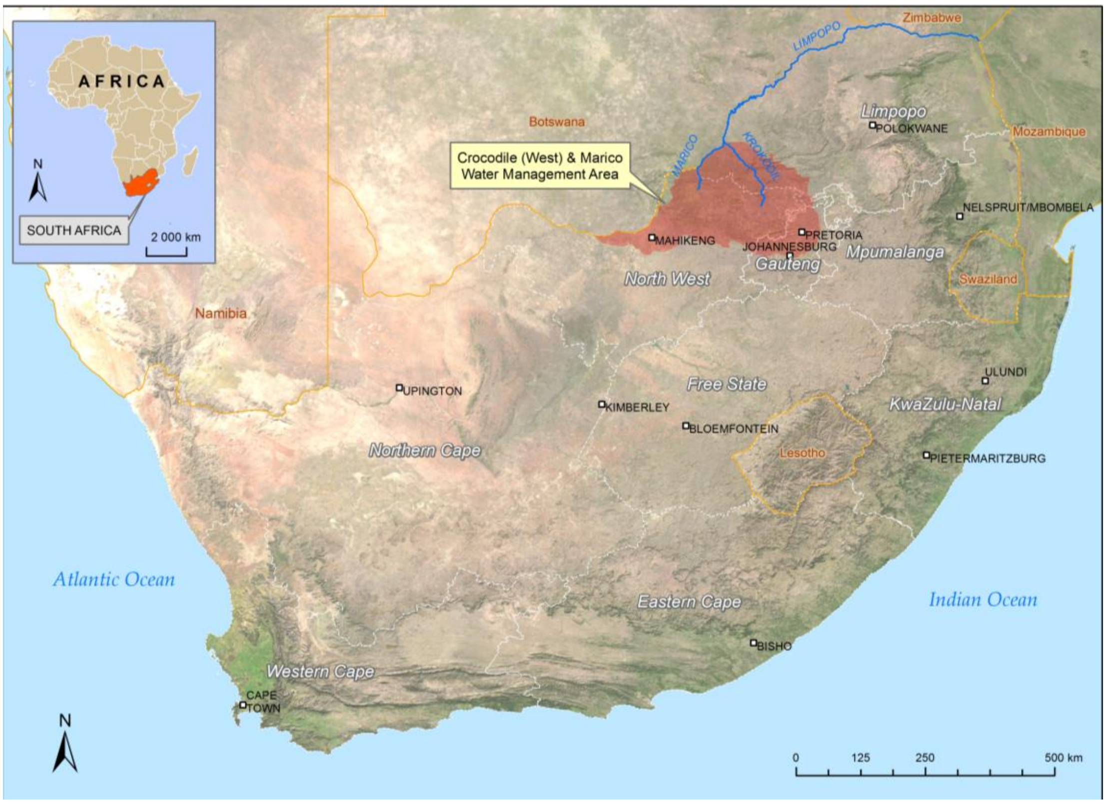


Figure 1: Map showing location of study area: Regional context (Compiled by:UP, 2015a)

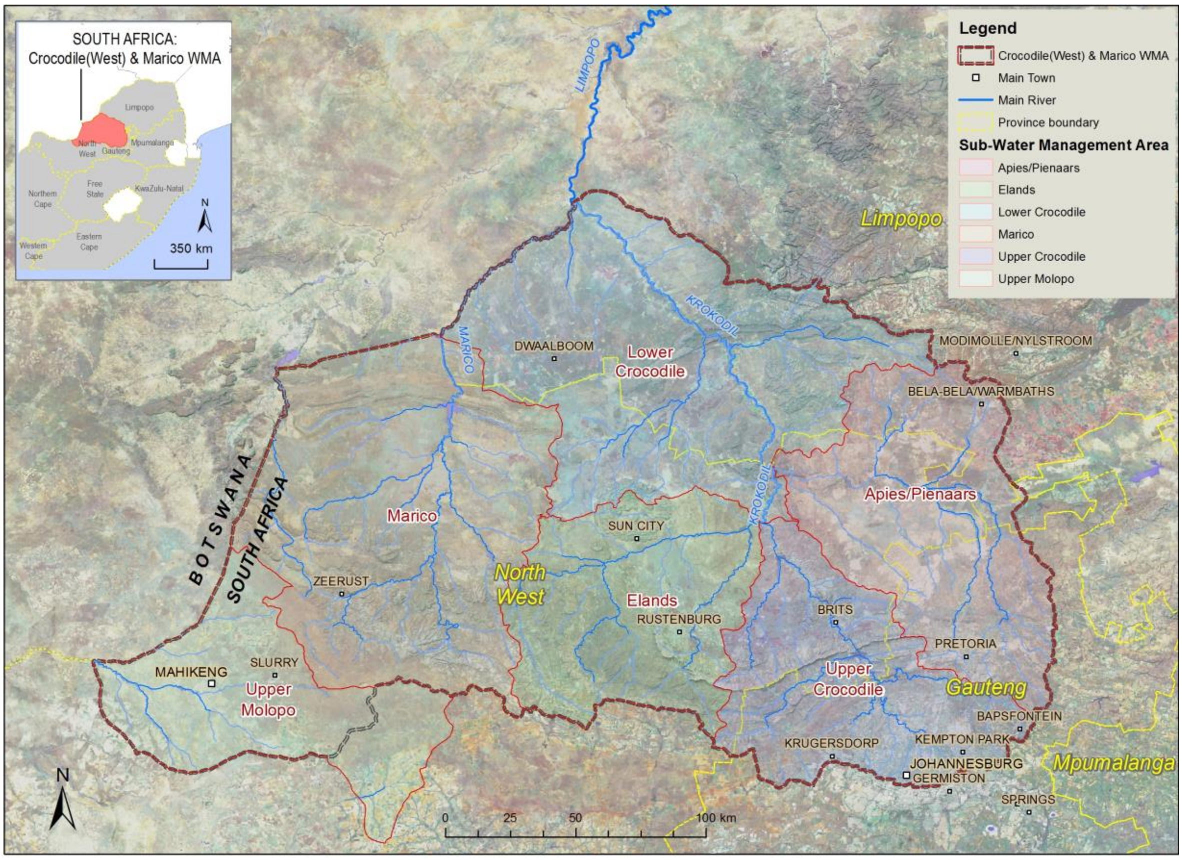


Figure 2: Map showing location of study area and the context within the Crocodile (west) and Marico WMA (Compiled by:UP, 2015b)

The study focused on a section of the Apies River flowing through the quaternary water management areas (WMAs) A23E and A23D as illustrated in Figure 3. The length of the Apies River, from where it enters the study area to where it leaves the study area, is 82,781.82 metres, and the length of the tributaries is 398,539.09 metres (University of Pretoria, 2014). The study area covers the part of the Apies River which flows through the central business district (CBD) of Pretoria, from where it flows northwards to enter the Bon Accord dam north of the city. The source of the Apies River is located south of Pretoria (south of Erasmus Park). From here, the river flows northwards and, throughout its course, according to Van der Waal and Associates (1999:54) 53 rivers and spruits feed the Apies River. The Apies River flows with a natural gradient allowing for a constant flow through the city whereafter it cuts through the three parallel ridges: Salvokop, Witwatersberg at Daspoort, and the Magaliesberg at the Wonderboompoort (Carruthers, 1990:29,47). The ridges comprise of weathering-resistant sandstone and quartzite, which typifies these east-west ridges (Andrews, 1985a:13; Dippenaar, 2013:37).

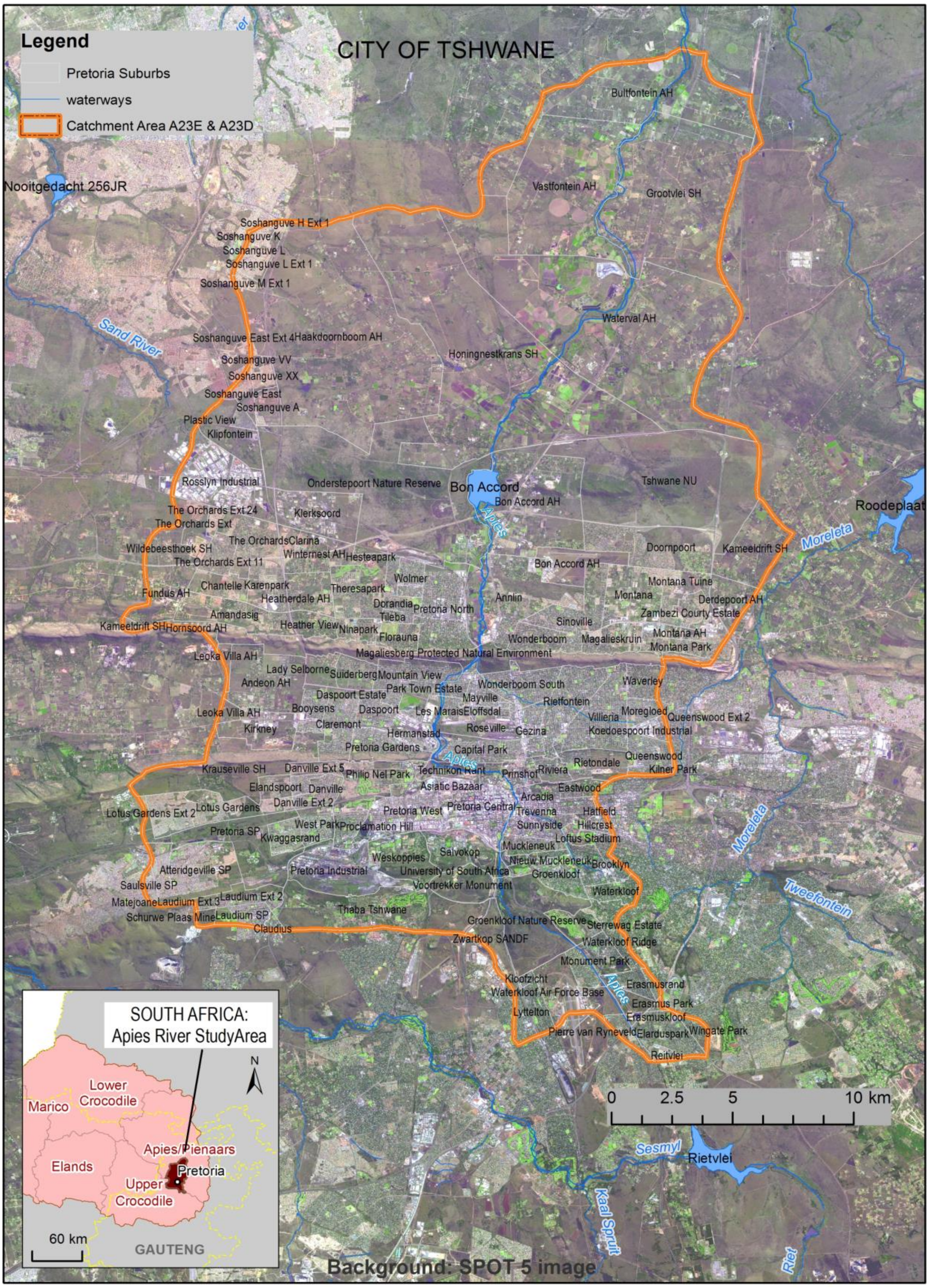


Figure 3: Map showing location of study area and the context within the Crocodile (west) and Marico WMA (Compiled by:UP, 2015c)

The City of Tshwane, which includes Pretoria, falls within the Crocodile (West) and Marico WMA, which is one of 19 WMAs in South Africa, and is divided into six sub-management areas, one of which is the Apies River/Pienaars River sub-management area within which the quaternary WMAs, A23E and A23D, which form the boundaries of the study area, are located (DWAF, 2004:D3.3). The location of the Crocodile (West) and Marico WMA is illustrated in Figure 2.

Water in the Apies River/Pienaars River WMA is not managed sustainably, with pollution and high consumption levels exceeding the water available locally (*ibid.*). The result is that the city is reliant on importing water from other WMAs in the country (SACN, 2011:91). Rainfall in the WMAs of the City of Tshwane is lost due to urban surface water runoff, resulting from impermeable surfaces and storm water drainage systems that divert water away (DWAF, 2004:D3.5) to the Limpopo River (*ibid.*D3.1).

Land use changes due to urbanisation in the study area have a) weakened and changed the connection of the Apies River's ecological components (the wetlands, the floodplain and the river basin) with each other, and b) changed the connection between the river and the built environment. These changes affect the resilience of the entire SES. The study uses narrative timelines to explore the causes and effects of these changes and the impact they have had on the resilience of the Apies River as part of the SES.

1.2.4 Levels of disconnection between built infrastructure and freshwater systems

> *Planting trees and lawn in a desert or burying a river in a sewer and filling in its floodplain are examples of urban form that obscures or opposes a city's deep structure. In contrast urban form that reveals and responds to deep structure is likely to be more functional, more economical and more resilient than design that disregards it.* (Spirn, 2011:18)

With the growth in population and the expansion of cities, a certain level of disconnection, or a dysfunctional connection has occurred, which has changed the quality of the relationship between cities and their freshwater systems. These disconnections can be described as:

a) Psychological disconnection: The psychological disconnection between cities and freshwater systems occurred in the twentieth century when cities were no longer in touch with the natural sources of freshwater, and societies became more concerned about meeting their needs for fuel and food, detaching themselves from nature (Grant, 2012:1-2). Urban infrastructure was further detached from nature when services in cities began to be based on engineered solutions instead of ecological solutions, according to Hough (1995:9). Water was channeled underground, piped and stored, and the natural sources and dynamics of the freshwater system became invisible to the urban dweller who only saw the end point — the tap. According to Hough (1995:31), keeping the natural processes of our freshwater life support system visible is critical for environmental awareness and responsible behavior. Cities and nature became disassociated in people's minds; cities, and open space in cities, were for people and their recreational needs while nature was part of the countryside, as if nature and its integrated system could not flourish within cities (*ibid.*15). In the process of trying to meet consumption needs, the very resources that support human well-being, the natural processes, became less important and critical ecosystem services were altered, diminished, degraded and encroached on by development (McHarg, 1992:vii; Secretariat of the Convention on Biological Diversity, 2012:26). Cities became a place for humans, and nature was regarded as something separate, as the areas beyond the city (Grant, 2012:1-2; Hough, 1995:10).

b) Physically dysfunctional connection: With the psychological disconnection between people and the freshwater resource in cities, a dysfunctional physical connection manifested. In the City of Tshwane, a change in the quality of the physical connection established between the Apies River and the built environment resulted when the river was put in a concrete channel. This change in the physical connection can be seen in that development encroached onto the floodplain and wetlands, destroying the essential components that keep the freshwater systems healthy and functional. Once the river no longer functioned as it should, the natural riverbed had to be straightened and modified into a concrete channel to avoid flooding and to control stormwater. The stream modification further degraded natural processes, and weakened the ecosystem benefits provided by the river of flood regulation, water purification, disease regulation and recreation and spiritual health. The channeled river caused erosion and pollution downstream (Hough, 1995:41) and changed the quality of the psychological benefits (the spiritual health aspect), which used to be derived from the river (Dunne & Leopold,1978:154,156)

When a city changes its connection with its ecosystems, in this particular case, with the natural freshwater system, it compromises the resilience of the city. As described by Spirn (2011:18), every city contains deeper structures, which consist of the underlying ecology and geology, which were responsible for the forming of the valleys and the rivers that are visible. Spirn further states that cities that are designed in harmony with these deep structures encourage resilient urban form and will save the city the energy and effort used to push against the deeper structures, which will continue to reassert themselves. Reinforcing the connection between the urban and freshwater systems can contribute towards the resilience of the Tshwane SES. Understanding what changed the connection between the city and the freshwater system could inform the understanding of similar disconnections with other ecosystem services in the urban context, in order to determine how best they can contribute to the capacity of the urban system to adapt to change.

This study examined the pressures that caused the change in connection between the freshwater systems and the city, and how that affected the resilience of the river. Spirn (2011:18), states that recognising the disturbances in the natural system may provide insight for better planning for resilient cities. Knowledge of how systems in a city interact with each other over time is essential to create resilient cities that are flexible and adaptable to change, which could either be a change in needs or conditions (*ibid.* 20). This will be explained further in the research problem.

1.3 Research problem

The problem that this study set out to investigate was the change in connection between freshwater ecosystem services and humans in the urban context, as a threat to the resilience of the SES, and what can be done to ensure better quality connections in future developments that can contribute towards creating a positive urban resilience. According to Walker and Salt (2006:148), the resilience of an SES is enhanced when the importance of ecosystem services is recognised and these services are connected to and integrated into urban planning, acknowledging the value of the ecosystem services as a contributor to human well-being.

Cities provide habitats for both humans and ecosystems, with the activities of humans being the main drivers of ecosystem change. Current urban growth undermines ecosystems services, as the form of growth is unresponsive to the value of natural processes and development is not sensitive to the existing natural features (Hough, 1995:6; McHarg, 1992:57,155). The underlying principles and the main determinant of the urban form are not based on natural science or ecological principles, but rather motivated by economic forces such as the availability of cheap energy (Hough, 1995:6,16).

Globally, freshwater ecosystems are considered to be the most vulnerable of all ecosystems (MEA, 2005a:553). It is confirmed that the habitats and species of inland water systems are in a poorer condition than those of grasslands, forest and coastal systems and are degraded to such an extent that 50% of the inland water habitats in the world is estimated to have been lost during the previous century (*ibid.*). This degradation of freshwater systems happens despite the dependence of human well-being and all the other ecosystem services on freshwater. The capacity of ecosystems to sustain freshwater provisioning services to humans has been weakened, mainly due to the impact of anthropogenic overuse and poor management (MEA, 2005a:168). Spirn (1984:129), emphasises that despite the fact that water is the essence of life and health and the largest imported resource into any city, cities continue to pollute this scarce resource.

Weak ecosystem networks are compromised systems, which do not function optimally and which cannot support human well-being. Because ecosystems and social systems are closely linked and part of the same system, this weakening will reduce the resilience of the SES, decreasing its ability to adapt to disturbances inflicted upon the system (such as natural disasters and climate change) and increasing the risk of system shift over a threshold and into a state with a new set of functions (Walker & Salt, 2006:141).

The research problem is expressed in the main research question and the three sub-questions which describe what needed to be investigated to achieve the purpose of the study.

1.4 Research questions

The main research question can be defined as: How does the change in the connection between humans and freshwater ecosystem services in the urban context affect the resilience of the urban SES?

In order to understand what caused the current state of a specific section of the Apies River system and the change in connection between the river system and the urban system through which it flows, and in order to explore how a specific section of the Apies River can be made more resilient in future so that it can contribute to the resilience of the city, it is necessary to understand the river's ability to absorb change. Change is brought about over time by press or slow disturbances or by pulse or quick disturbances, originating at different scales. It is necessary to know what caused the changes in the river system and what the response was to these changes, and what the patterns are of how the river adapted itself to disturbances over a period of time in history. It is therefore necessary to determine:

c) Sub-question 1 - What are the different press and pulse disturbances that triggered major change in the resilience of a specific section of the Apies River over a period of 159 years?
d) Sub-question 2 - What are the undercurrents (slow press disturbances) affecting changes in resilience over time of the specific section of the Apies River ?
e) Sub-question 3 - What effects do these changes have on the resilience of the services of the freshwater ecosystem of a specific section of the Apies River in the context of the urban SES?

The research question relates to the following goal and objectives.

1.5 Goal and objectives of the study

The main goal of the study was to understand how the change in the connection between the built infrastructure in the City of Tshwane and the Apies River freshwater ecosystem has affected the resilience of the Apies River as part of the Tshwane SES in the quaternary A23D and A23E watersheds. The secondary goal of the study was to develop a better understanding of what caused the dysfunctional connection or the change in connection between the Apies River and the built infrastructure.

In order to achieve these goals, the study aims to meet the following objectives:

f) Objective 1: To determine the resilience or the ability of the freshwater system to adapt to change through identifying the trigger events that caused major change in the system from one era to another, as evident in the historical profile.
a) Objective 2: To determine the undercurrents (press disturbances) of the system driving changes in resilience over time.
g) Objective 3: To identify the obvious patterns of the trigger events (pulse disturbances) which brought about change, based on the information in the historical timeline.
h) Objective 4: To determine the pattern of cross-scale interactions that was also relevant to the focal system.

The objectives are based on an informed assessment process outlined by the Resilience Alliance Workbook for practitioners, as set out in Resilience Alliance (2010:21).

The different systems, which were studied as part of the historical timeline, are set out in Table 1.

Table 1: The different systems to be studied as part of the historical timeline

Scale above the focal system	Larger scale system above the focal scale: The study describes the history and interaction over time of events at the larger scale, which had an impact on the focal system. Change in the larger system happens more slowly than in the smaller system.
Focal system	Focal system: The focal system is a section of the Apies River, comprising quaternary catchments A23E and A23D. The study presents historical information capturing the changes over time to this portion of the river, and its interaction with the systems above and below.
Scale below the focal scale	Smaller scale systems below the focal scale: The study describes the history and interaction over time of the smaller systems within the focal system. Change in the smaller systems usually happens faster than in the larger system.

Source: Adapted from Resilience Alliance (2010:18,19,20)

This analysis of the adaptive capacity of a section of the Apies River over time, was carried out based on the approach as set out by the Resilience Alliance (2010:19,21), and included:

a) Three spatial scales forming part of a historical profile (horizontal axis), which included important key historical disturbances. These are described in Table 1.

b) Different historical periods were defined as eras between historical regime shifting points related to the Apies River quaternary catchments A23E and A23D and the changes in resilience of the section of the Apies River.

c) Cross-scale events, which influenced the focal system (Apies River quaternary catchments A23E and A23D), are demonstrated. These caused the crossing of thresholds and changes in resilience due to the effects of disturbances to the focal system over a period of 159 years.

Figure 4 illustrates the focus of the historical timeline information. The aim was to capture significant changes in the system over time along with the dynamic interaction between the different scales. A historical timeline demonstrates regime shifts and changes in resilience over time, revealing the historical system dynamics, which shaped the current system and what drives these changes. Understanding what drives change can provide insights into what effects these drivers can have in future (Resilience Alliance, 2010:18,19).

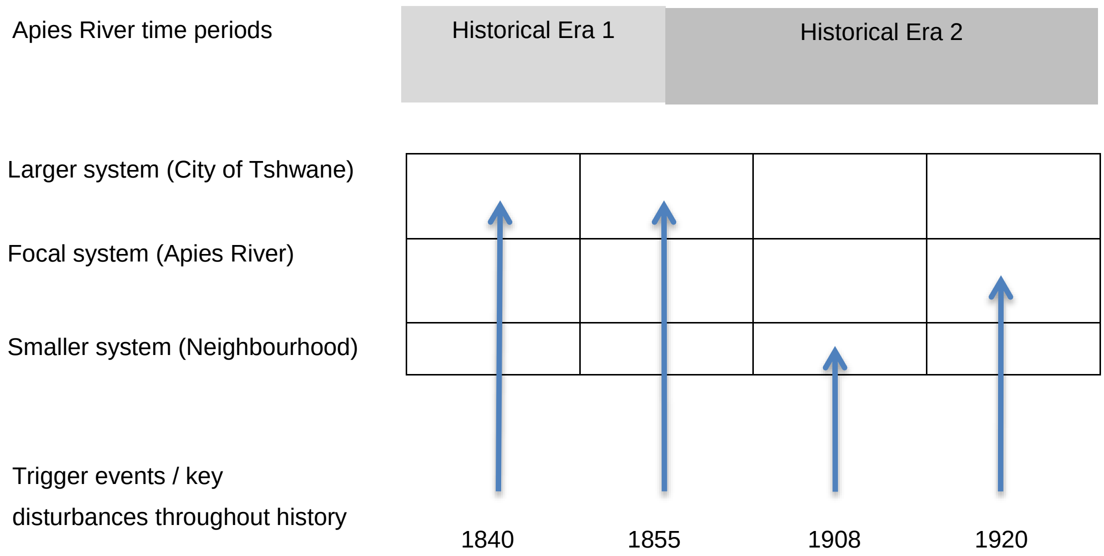


Figure 4: Illustration of the historical timeline for capturing significant changes at different scales in relation to the focal system (Source: Adapted from Resilience Alliance, 2010:19)

1.6 Expected contribution of the study

Knowing what is behind the changes which happened over time in a system (drivers of change), can provide a better understanding of how historical system dynamics have shaped the current state of the focal system, and what effects these drivers might have in the future (Resilience Alliance, 2010:18). In this way the study can inform appropriate management decisions and policy interventions that can benefit the adaptive capacity and positive resilience of urban freshwater ecosystem systems. This will lead to a better integrated SES in future and contribute towards the positive resilience of the city.

1.7 Research Design

1.7.1 Research approach

The research followed a qualitative approach, mainly consisting of historical research. The research involved an analysis of historical events and processes related to the interaction between the freshwater system and the built environment in order to extract patterns, which can be translated into cause and effect relationships.

1.7.2 Research methodology

The methodology of the research involved the construction of a narrative, which analyses and interprets a sequence of events, based on the Living Systems perspective, which embraces the Story of Place approach (Story of Place Institute, 2013). The Living Systems perspective focuses on the interconnection between systems rather than focusing on systems in isolation from each other (*ibid*.). The Story of Place approach involves the stitching together of different stories from history and research and, through synthesising these, finding the common thread that explains the dynamic interaction between different systems. The Story of Place approach reveals an identity, which makes every place unique and a contributor to the larger system (*ibid.*). The Story of Place provided a tool to better understand the complex relationships, which exist between freshwater ecosystems and the built environment, and reveal why and what occurred to change these complex relationships over time.

1.8 Assumptions, limitations and delimitations

1.8.1 Assumptions

The following concepts were assumed and were not debated:

The concept of resilience and the validity of resilience theory and its application to urban systems were accepted. The concept of resilience was considered in relation to how the river has changed over time, affecting its core purpose and function in the context of the SES. Resilience is understood to be: “the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure and feedbacks, and therefore identity, that is, the capacity to change in order to maintain the same identity.” (Folke *et al*., 2010).

For the purpose of this study it is assumed that a city is an SES where humans and nature are part of one system. The SES concept builds on the humans-in-nature perspective (*ibid.*). From this perspective, nature and humans are seen as functioning in one integrated system and the two have co-evolved throughout history with nature shaping the development of human society and human settlements shaping nature (Folke, Carpenter, Elmqvist, Gunderson, Holling, Walker, Bengtsson, Berkes, Colding, Danell, Falkenmark, Gordon, Kasperson, Kautsky, Kinzig, Levin, Mäler, Moberg, Ohlsson, Olsson, Ostrom, Reid, Rockström, Savenije & Svedin, 2002a:21).

1.8.2 Limitations

The first limitation of the research report is that, due to available time and funding, no new data has been generated and only available data on the Apies River were used. Data such as the percentage of the different states of the river (modified river, natural river and canalised river) are not available for the Apies River and such data were generated using aerial photos. Verification thereof has not been done.

The second limitation is the lack of information on the economic value of ecosystem services. This information would have been valuable to explain how the freshwater ecosystem services are recognised and valued/ under-valued within the city in terms of their functions, something that is important to recognise in planning for resilience. However, this information is not available for the City of Tshwane‘s freshwater ecosystem services.

1.8.3 Delimitations

The following delimitations will apply to the study:

a) Pretoria renamed to Tshwane: In December 2000 the Pretoria municipality as well as other municipalities which was situated outside its boundaries were combined as the City of Tshwane. During this time a recommendation was put forward to change the name of the municipality of Pretoria to Tshwane, which was approved by the South African Geographical Names Council. In 2005 it was voted that the name change should continue and during this time some media started to use Tshwane in their communications and writings as a public backing for the proposed name change. However, due to controversy about the little evidence of the origin of the name Tshwane the name change was not done. By 2007 with not yet approval by the relevant Minister the process of name change was withdrawn. Plans were however put forward to change all road signs related to the City of Pretoria to Tshwane, evoking much resistance from many groups. Then in 2010 the name Tshwane was published in the Government Gazette to register it as a place name, however this registration was withdrawn too late and could not be removed form the Gazette. The withdrawal was published soon after the Government gazette was published. After a renewed process in 2012, the name of the City of Pretoria was officially changed in 2015, to the

City of Tshwane. The city centre remained to be called Pretoria (Wikipedia, 2015). As part of this study, the early history refers to Pretoria and the later history refers to Tshwane.

b) Change of street names in Pretoria: 27 Street names were changed in 2012. The new street names were also referred to as part of this study.

c) Historical timeline: The first delimitation is the time period. The study explored the disturbances which challenged the resilience of the system, from the establishment of Pretoria in 1855 up until 2014. This time period is defined in order to determine the interaction of land use change and freshwater ecosystem services over a period of 159 years, since the establishment of Pretoria as a town.

d) Geographical: The second delimitation is the boundaries of the study area of the freshwater system. The study area is limited to the section of the Apies River and its tributaries which falls within the quaternary water catchment areas A23E and A23D, which form part of the Apies River / Pienaars River sub-management area within the larger Crocodile (West) and Marico Water Management Area (see Figure 2). The reason for choosing this section of the river is that it includes the section of the river as an urban freshwater system, that flows through the city and which was exposed to intense land use change over time, affecting the resilience of the river and then a section where it meanders through the Wonderboompoort towards the Bon Accord dam to provide water for irrigation. This area also covers the location where the first farm settlements were established and the first plots for Pretoria were set out, at the time of the establishment of Pretoria in 1855.

e) Processes: The third delimitation is the freshwater ecosystem services. Although all seventeen ecosystem services, as described in MEA (2005a) and MEA (2005b), exist in the City of Tshwane, interconnected and related to each other in terms of functions, only the freshwater ecosystem service will be described. Freshwater is seen as one of the most essential ecosystem services as it provides: supporting services, provisioning services, regulating services and cultural services and forms the basis for all the other ecosystem services which support human well-being (MEA, 2005a:554,575,576).

f) Evaluating the impact of the system: Only the impact on the resilience of the Apies River freshwater system will be evaluated and not the resilience of the SES. It is assumed that the functional integrity of the freshwater system is important for the resilience of the SES (Biggs, Schlüter, Biggs, Bohensky, BurnSilver, Cundill, Dakos, Daw, Evans, Kotschy, Leitch, Meek, Quinlan, Raudsepp-Hearne, Robards, Schoon, Schultz & West, 2012:426; Folke, 2003:2028).

g) SES resilience: This is resilience of the interconnected systems in which man and ecosystems exist (Folke *et al*., 2010). Social systems exist within and as part of the natural system, called an SES. The integration, or disconnection, which is found in the SES in terms of the urban freshwater system in the City of Tshwane, is explored as part of this study.

h) Freshwater ecosystem services: These include all the aspects of provisioning services, regulating services, cultural services and supporting services which freshwater ecosystems provide in support of human well-being, according to the MEA (2005a) and how these relate to resilient cities.

i) The principles of resilience that were included in the analysis of the resilience of the Apies River have been limited to: tightness of feedback; ecological variability; diversity; flexibility and the integration of ecosystem services into urban planning. Due to a limitation of time to conduct the research, only these four functional aspects of resilience were considered (Walker & Salt, 2006:145-149).

1.9 Conclusion

The problem that this study set out to investigate was the change in connection between freshwater ecosystem services and humans in the urban context, as a threat to the resilience of the SES, and what can be done to ensure better quality connections in future developments that can contribute towards creating a positive urban resilience

The goal of this study was to understand how the change in the connection between the built infrastructure in the City of Tshwane and the Apies River freshwater ecosystem affects the resilience of the Apies River as part of the Tshwane SES. The secondary goal of the study was to develop a better understanding of what caused the change in connection between the Apies River and the built infrastructure.

This leads to the main research question of the study: How does the change in connection between humans and freshwater ecosystem services in the urban context affect the resilience of the urban SES?

It is expected that the study would inform appropriate management decisions and policy interventions that can benefit the adaptive capacity and positive resilience of urban freshwater ecosystem systems. This will lead to a better integrated SES in future and contribute towards the positive resilience of the city.

The analysis of the adaptive capacity of the specific quaternary water catchments A23D and A23E of the Apies River was carried out in the context of a historical timeline depicting important events and historical periods which was defined between shifting points of change in resilience (where a threshold was crossed) and which revealed patterns that can inform future resilience practice.

CHAPTER 2 - THEORETICAL BASIS

1.1 Introduction

This study focuses on resilience in the SES context, consisting of interactive urban and ecological systems. The sufficient and consistent provision of ecosystem services to support human well-being is a growing challenge. In order to meet the demands of urbanisation, population growth and increased consumption, the need for provisioning services such as freshwater and food production has increased. The extraction of, storage and transfer of water in water stressed areas, for human needs are constantly placing a compromise and pressure on water supply for ecosystems (Allan & Castillo, 2007:12). There is a growing need to ensure that the ecosystem services that support social-ecological systems are resilient. The resilience of ecosystem services can be defined as "… the capacity of the SES to sustain a desired set of ES [ecosystem services] in the face of disturbance and on-going changes in SES." (Biggs *et al*., 2012:423)

This chapter discusses the theoretical constructs underpinning this study, including the concept of an SES; resilience; ecosystem services and how they relate to resilience; and specifically freshwater systems within the context of urban resilience.

1.2 Social-ecological system (SES)

Social-ecological systems (SES) can be described as '' Integrated system of ecosystems and human society with reciprocal feedback and interdependence. The concept emphasizes the humans-in-nature perspective. (Folke *et al.,* 2010)

Although not always recognised as such, urban systems function within and as part of the natural system, called the social-ecological system (SES). This connection is evident in that nature provides ecosystem services to humans, and forms the foundation for the social and economic development in the city. "We all depend on nature for our well-being. Ecosystems provide us with food, fresh water, fuel, fibre, fresh air and shelter." (TEEB, 2010:14). It is therefore clear that human well-being cannot exist without nature, and "cities depend on nature." (TEEB, 2010:7). According to Gotts (2007:2) ecological and social-ecological systems form a set of interconnected nested adaptive cycles, consisting of larger, slower cycles limiting the smaller, faster cycles to maintain the integrity of the system. This is called the panarchy. This is also illustrated in Figure 7. The different systems include cultural systems, political systems, socio-economic systems, ecological systems and technological systems, which all form part of the "humans-in-nature perspective" (Resilience Alliance, 2010:6). In terms of resilience, each one of these systems functions in its own state, which is constantly driven by the dynamics of change.

In the interactive SES, humans and ecosystems co-exist and when they are closely connected through the planning and development systems in the city, it supports positive resilience. Natural and urban systems are either connected, recognising each other as part of an interlinked system creating positive resilience, or the connection is lacking or dysfunctional creating resilience in a negative system state.

According to Walker and Salt, (2006:122), ecological and social systems cannot be managed in isolation as they exist within the same system, with dynamic feedbacks between them which must be taken into account.

1.3 The concept of resilience

1.3.1 What is resilience?

"Resilience thinking is a way of looking at the world. It's about seeing systems, linkages, thresholds, and cycles in the things that are important to us and in the things that drive them." (Walker & Salt, 2006:114).

The term "resilience" is derived from the verb "*resilire"* which meant "leaping back" in the Latin of the seventeenth century (Oxford Dictionaries, 2013). It was during the 1970s that the concept of resilience was applied to ecological systems by C.S. Holling. More recently, the concept has evolved to include resilience in the context of urban systems as SESs, where humans and the urban systems exist within nature in a closely linked and interactive way (Folke, *et al.,* 2010). Within the context of an SES, resilience can be described as "… the capacity of a system to absorb disturbances, undergo change, and still retain essentially the same function, structure, and feedbacks – the same identity" (Walker & Salt, 2006:62).

In the late 1990s, the concept of resilience was applied to other disciplines, besides the ecological, when it was mainstreamed in the social sciences. Anderies (2014:131-133), for example, explored resilience in terms of resilient communities and infrastructure, and Hassler and Kohler (2014:120,124) described resilience in the ecological, social, engineering and organisational disciplines. These approaches recognise the concept of resilience as applicable to both people (individuals) and systems (such as ecology). This is also supported by Zolli and Healy who define resilience in terms of ecology and sociology as: "… the capacity of a system, enterprise, or a person to maintain its core purpose and integrity in the face of dramatically changed circumstances" (2012:7).

A system's functional integrity can be maintained, after disturbances or shocks to the system, either through the system a) bouncing back to its original state, or b) adapting itself without crossing a threshold by absorbing change, or c) by transforming itself which involves crossing a threshold and reorganising itself into a new state. These can be described as follows:

i) Bouncing back: Bouncing back is often used in the context of "engineered resilience" according to Walker and Salt (2006:62,63). The term is used to describe how fast a system can return to a state of equilibrium, as a measure of a system's stability, and "engineered resilience" is not concerned with thresholds.
j) Adapting to change: This is described by the Resilience Alliance (2010:51) as: "The capacity of a system to absorb disturbances and reorganize while undergoing change so as to retain essentially the same function, structure, identity, and feedbacks." Another interpretation which describes resilience in the context of adapting to change is "complex, self-organising, unpredictable and responsive to spatial and temporal changes." (Rottle & Yocom, 2010:72). According to Walker and Salt (2006:63), "ecological resilience" describes a system's capacity to absorb perturbations and still function in the same way, and provides an indication of how much pressure a system can sustain before it loses its functional integrity. Ecological resilience, as opposed to engineered resilience, according to Walker and Salt (2006: 63,93), requires knowledge and understanding of the thresholds in a system, which represent the transition between alternate states of a system, in order to manage these thresholds in advance.
k) Transformability: Gunderson and Holling (2001:27), describe this as ecosystem resilience which embraces persistence, adaptability, variability and unpredictability and which allows for the system to change into another regime while maintaining its existing functions.

Resilience, in the context of ecosystems, is viewed in terms of dynamic equilibrium, which means that although ecosystems function in a state of stability that is maintained through constant adjustment through interval changes and interactions, the state of the ecosystem can be changed with the impact of disturbances such as storms, nutrient loading etc. These disturbances can force the ecosystem past a threshold, whereafter it crosses a tipping point into another state, depriving the ecosystem of its ability to function and to provide the necessary ecosystem services. However, the risk of crossing thresholds in a system is reduced when the ecosystem is resilient (Rottle & Yocom, 2010:72). The resilience of an ecosystem can therefore be measured, according to Gunderson and Holling (2001:27-28), by the amount of disturbance that the system's variables and processes that control the behaviour in the system, can absorb before the ecosystem shifts into a different state, with different structural and functional properties (Resilience Alliance, 2010:5). According to Walker and Salt (2006:63), resilience is about retaining the capacity to recover and less about the speed with which the system bounces back.

The only way to build resilience and a system's adaptive capacity is to understand the system's regimes and possible thresholds, so that a system can be either managed to cross a threshold into another regime or not if it is not desirable. By managing the crossing of a threshold, the system's ability to cope with external shock can be increased (Walker & Salt, 2006:118). The further away a system is from a threshold, the more resilient a system is and the closer a system is to a threshold the more easily the system is pushed across the threshold into another regime and the more vulnerable the system is (Walker & Salt, 2006:63).

According to Walker and Salt (2006:12), resilient SESs are adaptable, able to absorb changes in the larger dynamic systems of which they form a part, and able to retain their functions. Resilient SESs are also more flexible in terms of various uses and more tolerant of errors in management. Resilience thinking can be described as the acceptance of change and disturbance, rather than the rejection, resistance to or restriction of change (*ibid*.147).

In order to understand the resilience of a system it is necessary to know a) which key variables are driving a system; b) whether the system is moving closer to a threshold, and if so, what management decisions can be taken to avoid the system moving closer to the threshold; c) what the undercurrents of the system are; and d) what connections exist between the scales below and above the system of concern and the system itself (*ibid.*)? The resilience of a system depends on the distance to a threshold, and when thresholds are not identified and understood in advance, a system can cross the threshold unknowingly, and according to Walker and Salt (2006:74), once the threshold is crossed, the dynamics of the state of the system change.

According to Peres and du Plessis (2014:4), resilience is not a goal but is rather a characteristic of a system's state and functionality and therefore a value neutral concept which is neither positive nor negative; systems can be highly resilient while supporting negative press disturbances such as rapid urbanisation, pollution in rivers and climate change.

The state of a system is therefore either positive or negative and for the purpose of this study "positive resilience" will refer to a positive state of the system and "negative resilience" will refer to a negative state of resilience in the system. When a river is canalised it will function in a negative state of resilience in terms of the river's diminished natural systems and some of the services provided to man, but will be highly resilient in terms of transporting stormwater out of the city which can then be described as "negative resilient" in the context of the living system.

1.3.2 General and specific resilience

Specific resilience focuses on specific aspects of a system, which involves the identification of key variables that can alter the resilience of a system, causing it to cross a threshold into another regime. Focusing on specific resilience carries the risk of attending to the resilience of one part of a system while failing to realise the implications for the resilience of another part of the system. Specific resilience deals with the question of "resilience of what to what" and focuses on a specific known variable in the system. Focusing on specific resilience may compromise the capacity of the system to deal with unpredictable disturbances (Walker & Salt, 2006:120,121). To give an illustrative example, if you canalise a river in order to improve stormwater management and flood control, you will affect the resilience of another part of the system, e.g. the biodiversity of the riparian corridors, according to Carpenter *et al.* (2001:779), which then affects the ability of the freshwater system to supply provisioning services (Pedersen Zari, 2012:59).

General resilience, on the other hand, builds the capacity of systems to deal with unforeseen disturbances and circumstances. General resilience is supported by diversity (both functional diversity and response diversity), modularity and redundancy. Modularity refers to loose connectedness among the components of a system, while the components themselves are strongly connected internally. This allows some components to function despite pressures on the other components in the system. Tightness of feedback refers to how quickly pressures on one part of the system are experienced and reacted to, in the rest of the system (Walker & Salt, 2006:121).

In the resilient cities debate there is a strong link with disaster management and reducing the city's risk and vulnerability to disasters such as storms, floods, droughts, heat waves and landslides. This is labeled as urban disaster resilience where resilience is described as: '… the ability of a system, community or society exposed to hazards to resist, absorb, accommodate and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures.' (The World Bank, 2012:3).

This specific focus on preparing for disasters, to reduce risk and to recover from disasters to create safer cities, deals with pulse disturbances therefore focusing on creating specific resilience of the city to disasters. This does not address the underlying press disturbances, which exists in the city and fails to consider general resilience.

1.3.3 Characteristics of resilience

The resilience of an SES, or its adaptive capacity, is identified by the degree of a) diversity, b) ecological variability, c) modularity, d) slow variables, e) innovation, f) social capital, g) tightness of feedback, h) overlap of governance and i) ecosystem services that exist or are recognised in the system (Walker & Salt, 2006:145-148).

These characteristics of resilience are further explained below:

a) Diversity: Diversity refers to the ability to respond to disturbances in more than one way. The more response diverse an SES is, the more resilient the system is, as the system has a variety of responses to choose from to deal with disturbances. Diversity would promote resilience in all the various systems, such as the ecological, the landscape, the social and economic systems (Walker & Salt, 2006:145). For SESs, there are two types of responses, which are important according to Anderies (2014:135). There is functional diversity, which influences system performance, and response diversity, which influences resilience. It is further stated that diversity includes three properties: variety (indication of the different elements), balance (how many of each) and disparity (how the various elements differ from each other) (Stirling, 2007:715). In this context, diversity in an SES is seen to include elements such as species, landscape patches and cultures that are represented in terms of biodiversity, spatial heterogeneity and institutional diversity. Biggs *et al.* (2012:425) propose that redundancy is closely related to diversity as redundancy means that ecosystem elements which are destroyed or degraded and fail to function can be replaced by other ecosystem elements that provide a backup, just like insurance would do, enabling the continued functioning of the system. Redundancy is therefore where there is more than one element that can perform the same function and each can act on behalf of the other to ensure continued functioning of the system. Response diversity is also referred to as functional redundancy (Walker, Gunderson, Kinzig, Folke, Carpenter, & Schultz, 2006).

b) Ecological variability: Ecological variability refers to the dynamic changes which occur naturally in nature, such as the flooding of rivers in the rainfall season and the reduced flow during dryer seasons. Ecological variability would be maintained within a resilient system, rather than reduced or controlled. Controlling flood levels of a water system or prohibiting natural systems from freely maintaining their integrity would undermine their resilience (Walker & Salt, 2006:146).

c) Modularity: Modularity or a degree of modularity is necessary to maintain resilience in a system. An over-connected system easily transfers shock, which then moves through the system quickly and affects the whole system. If the system has a degree of modularity, the shock does not spread so far or so rapidly (ibid.). According to Zolli & Healy, (2012:11) the modularity in a resilient system consists of simple internal modular structures with components that can easily plug into each other and unplug from each other much like ‘’Lego blocks’’ and which allows a system to be reconfigured when disturbances emerge, preventing the effect of the disturbance in one part of the system to spill throughout the entire whole. This ensures that the system can adapt by expanding or downscaling when the time is right.

d) Slow variables: Although many variables are involved in effecting change in an SES, a few slow moving variables with associated thresholds mostly drive change in a system, and can move the system past a threshold such that the system now functions in a different way. Returning to a previous state after crossing a threshold is, most of the time, difficult or even impossible (*ibid.*). A resilient system would acknowledge significant, slow, regulated variables, which over time can push a system closer to a threshold. When the slow variables in an SES and how they can affect the system’s position relative to thresholds are understood, it is much easier to manage the resilience of a system. In order to maintain the system in a desired state, it is necessary to absorb disturbances and postpone or avoid the system crossing a threshold and entering into another system state. Acknowledging the key slow variables of a system can also make it possible to shift a system out of an undesired state (*ibid.*). In order to strengthen the resilience of a system it is important to understand the variables that drive the system, where the thresholds reside along these variables, and how much disturbance would move the system across a particular threshold (Walker & Salt, 2006:52). A system's resilience gets reduced and its vulnerability increases when the variables and their thresholds are ignored in the interests of becoming more efficient at business as usual. A more efficient system is not a sustainable system (*ibid.*). In the context of an SES, once a threshold has been crossed, the rules and functioning of the new regime affect both the social and the ecological dimension of the system (*ibid.*).

e) Innovation: Resilience embrace innovation. According to Folke (2006:253), resilient SESs allow the opportunity for disturbance to create renewal and innovation. This means that there is recognition of the importance of increasing knowledge, of learning through trial and error, of being open to transformation and change, and of the importance of locally developed systems (Walker & Salt, 2006:147).

f) Social capital: It is important in a resilient system to acknowledge social capital, which includes trust, well-established social networks, flexible leadership and the capacity to adapt. This social capital would, in a collective manner, strengthen the ability of an SES to respond to change and deal with disturbances in the system (*ibid.*).

g) Tightness of feedback: Tightness of feedback, together with diversity and modularity, are characteristics that are present in general resilience. Tightness of feedback is an indication of how quickly a change in one part of the system is recognised and reacted to in other parts of the system. The tighter and shorter the feedback time the more resilient the system is and the less likely it is that the system will cross a critical threshold. The longer the feedback time the more likely it is that the system will cross a threshold before the risks are detected, according to (*ibid*.121). Thresholds are suspected where there are changes in feedback, and thresholds can be determined by identifying which feedback in a system is likely to change under particular circumstances (*ibid.*).

h) Flexibility: Resilience requires governance structures which are flexible and have a high degree of response diversity. This is made possible through redundancy in institutions. Resilient social-ecological structures also have a combination of private and state property with interrelated access rights (Walker & Salt, 2006:148). According to Brand and Jax (2007) the concept of resilience itself, can be described as "flexibility over the long term".

i) Ecosystem services: Resilience is supported when development proposals recognise ecosystem services as valuable benefits to society (*ibid.*). Ecosystem services, in the context of SESs as complex adaptive systems, can be made more resilient, according to Biggs *et al.* (2012:424), when learning and experimentation is allowed for in the SES and participation and polycentric governance systems exist. Seven principles, which contribute to ecosystem resilience, are set out in **Figure 5**. The figure describes how the principles of diversity and redundancy, connectivity, slow variables and feedback could enhance the resilience of an SES, and ecosystem services as part of the SES.

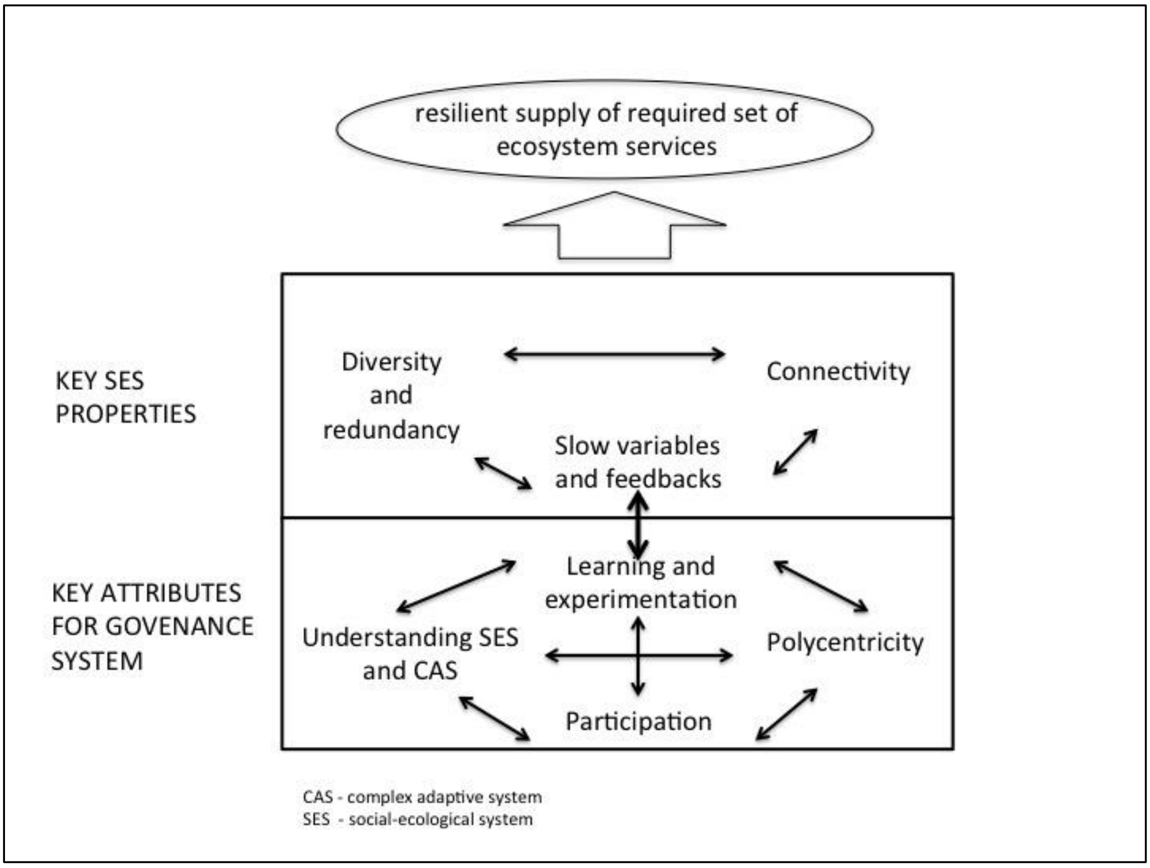


Figure 5: Seven principles related to SES management, which could enhance ecosystem resilience (Source: Adapted from Biggs *et al.,* 2012:424)

1.4 System dynamics of an SES

The previous section dealt with the characteristics of resilience. This section considers the dynamics of a system and its multiple states. Key concepts here are:

l) The concept of stable and unstable regimes which are found in the adaptive cycle; and
m) The interaction and dynamics between the multiple states of a system as found in the panarchy.

These concepts will be discussed next.

1.4.1 Adaptive capacity

The resilience of a system depends on the system's ability to adapt to change, and this depends on the system's response diversity. Greater response diversity makes the system stronger and increases the system's ability to adapt as the system has more options to respond to perturbations (Walker & Salt, 2006:164). The adaptive capacity of a system is the ability to reorganise in such a way as to minimise loss and enhance the positive resilience of a system (*ibid.* 154). The resilience of a system or its adaptive capacity is therefore the ability of a system to absorb change and to adapt to constant pressures by retaining its current functional integrity, despite disturbances.

Systems are dynamic and undergo change over time. Change can either be quick and abrupt or slow and gradual. Resilience is sometimes seen as the distance between a current system state and that critical threshold which affects transition and shifts the system from one state into another (Resilience Alliance, 2010:7). Resilience builds flexibility and adaptive capacity rather than building stable optimal production for short-term gains (Momberg & Simonsen, n.d.7).
Systems constantly move between the four phases of change of the adaptive cycle (Resilience Alliance, 2002b). The four phases, as illustrated in Figure 6, can be described as: the rapid growth phase (r) where resources are abundant; the conservation or the maintenance phase (k) where resources are few and unavailable, conserved and locked up in structures; the release phase (Ω), where resources are available and released; then the release phase quickly moves into a phase of reorganisation and renewal where innovation is unlocked (α), which rapidly opens the path for another growth phase. The growth and conservation phases happen over a relatively long period and are predictable, whereas the release and reorganisation phases happen more rapidly and are more chaotic (Resilience Alliance, 2010:7; Walker & Salt, 2006:81).

1.4.2 What is necessary to build the adaptive capacity of a system?

The adaptive capacity of a system, as described in Table 2, depends on the capacity to: a) learn how to live with transformation and unpredictability; b) learn how to support diversity in order to allow the system to restructure and regenerate; c) combine different types of knowledge and learning and; d) create opportunities for self-organising and regeneration (Berkes, Colding, & Folke, 2002:345,355).

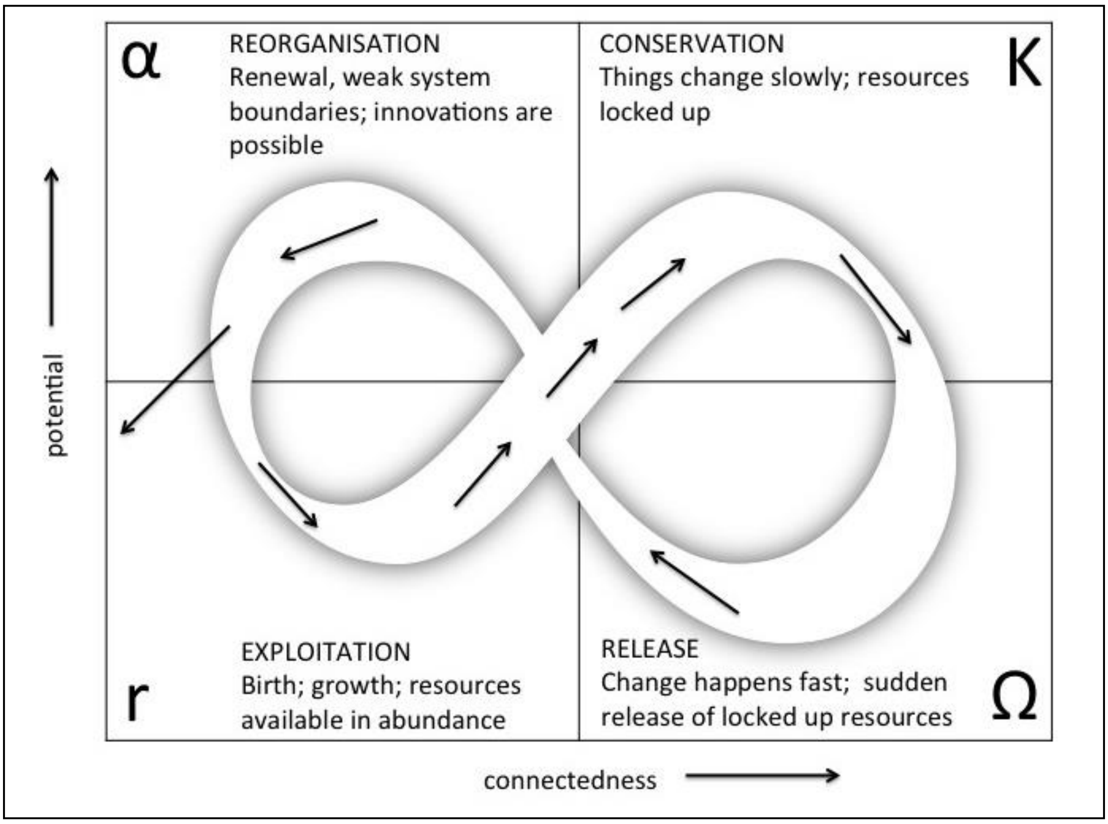


Figure 6: The adaptive cycle with the various phases (Source: Adapted from Resilience Alliance, 2002b; Walker and Salt, 2006:81)

Table 2: Building resilience and adaptive capacity in social-ecological systems

Learning to live with change and uncertainty	Evoking disturbances Learning from crisis Expecting the unexpected
Nurturing diversity for reorganisation and renewal	Nurturing ecological memory Sustaining social memory Enhancing social-ecological memory
Combining different types of knowledge and learning	Combining experiential and experimental knowledge Expanding from knowledge of structure to knowledge of function Building process of knowledge into institutions Fostering complementarity of different knowledge systems
Create opportunity for self-organisation	Reorganising the interplay between diversity and disturbance Dealing with cross-scale dynamics Matching scales of ecosystems and governance Accounting for external drives

Source: Adopted from Berkes *et al*. (2002:355)

1.4.3 Press and pulse disturbances affecting the adaptive capacity of a system

Disturbances to a system, affecting its ability to function and challenging its adaptive capacity, can be either slow (press) or instant (pulse). Understanding the dynamics of press and pulse disturbances in an SES will make it easier to understand negative ecosystem states (Collins, Carpenter, Swinton, Orenstein, Childers, Gragson, Grimm, Grove, Harlan, Kaye, Knapp, Kofinas, Magnuson, McDowell, Melack, Ogden, Robertson, Smith & Whitmer, 2011:351).

Ecosystems are constantly exposed to pressures, which bring change. Change can happen slowly or abruptly. Slow changes happen as a result of pressures, which occur over a long time, such as climate, nutrient loading, exploitation and habitat fragmentation. Natural systems respond gradually to these pressures. According to Scheffer, Carpenter, Foley, Folke and Walker (2001:591), slow press disturbances are easier to manage and modify than abrupt pressures. Abrupt pressures include stochastic events such as hurricanes and droughts, which usually happen unexpectedly, and can bring about a shift in state. Abrupt pressures are difficult to control and predict (*ibid*.).

Press disturbances are barely noticeable pressures on a system which occur cumulatively and gradually over a long period of time, while pulse disturbances occur as a short-term single event (Resilience Alliance, 2010:15, 16). Although many variables affect a system's state, there are always a few key variables that control the system and these are often the slow moving variables (Walker and Salt, 2006:63).

Press disturbances are more easily managed because they can be predicted, monitored and modified because they happen over a long period of time. Examples include land use change, climate change, changes in human values, increased resource consumption, changes in policies, and nutrient stocks (Collins *et al.*, 2011:352,353). Press disturbances on freshwater systems are mainly caused by human activities and may include sedimentation, the barrier effects of dams, canalisation and heavy metal pollution (Lake, 2000:574).

In contrast to press disturbances, pulse disturbances happen quickly and unannounced. These random events are more difficult to manage. They can negatively affect the adaptive capacity of a system, reduce resilience and even trigger a shift into another state, changing the resilience of the system. Pulse disturbances affecting freshwater systems include hurricanes, floods and droughts (*ibid.*).

Press and pulse disturbances can occur at a higher or lower scale to that of the focal system with responses and reactions travelling through the various scales of the system. How the different scales of a system interact with each other will be discussed in the next section on the panarchy.

1.4.4 The panarchy

The panarchy is also called the cross-scale and dynamic interactions in an SES (Resilience Alliance, 2002b). All systems function at multiple scales of space and time and these interactions across scales are important in determining the undercurrents of the system at any particular scale (Gunderson & Holling, 2001).

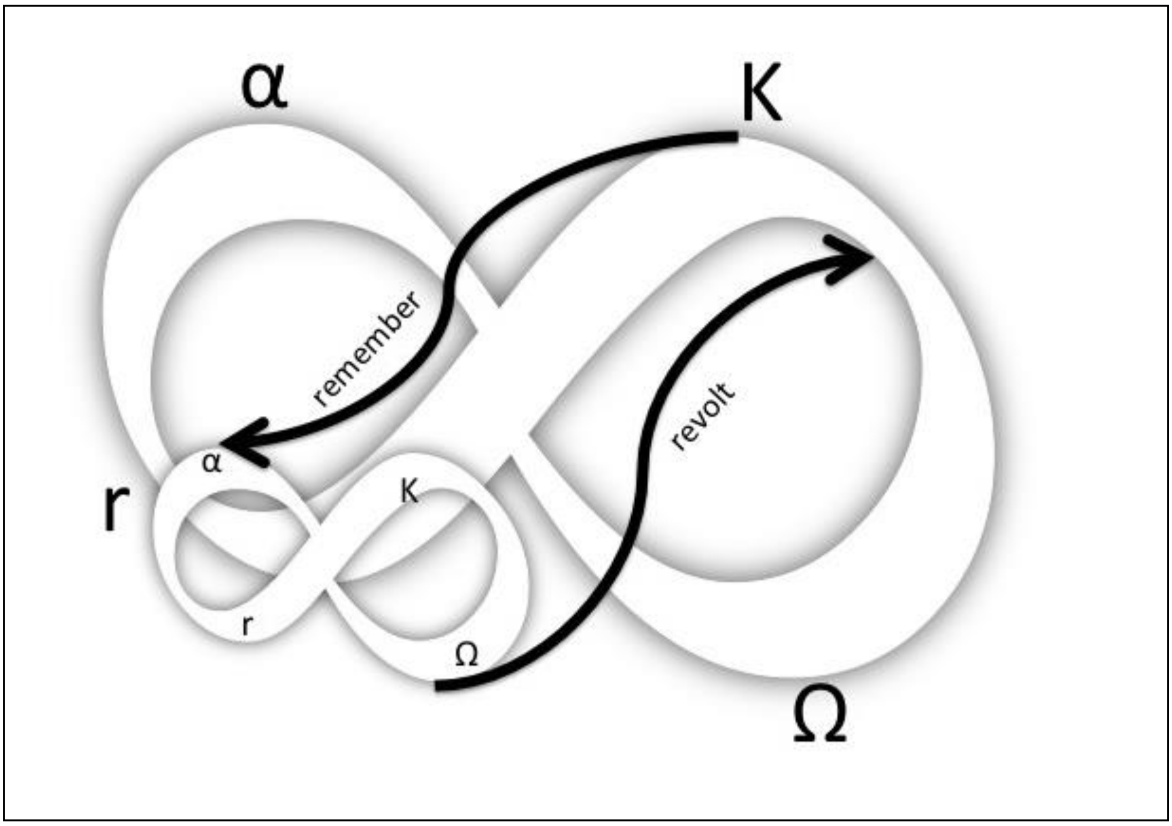


Figure 7: Panarchy containing the nested adaptive cycles, with interactions between the scales (Source: Adapted from Resilience Alliance, 2002b)

In terms of a freshwater system, the panarchy, or the nested sets of the adaptive cycles, as illustrated in Figure 7, can be described as the hierarchy of a system, which can have either a physical or spatial characteristic. In relation to rivers, the panarchy can be described as the organisation of rivers, with small streams, which drain to tributaries, and tributaries, which drain to the main stem of the river. This system contains sub-systems, which are spatially contained within a larger system organisation and this is referred to as the “nested” system (Rottle & Yocom, 2010:43).

1.5 Ecosystem services

People and cities depend on nature’s goods and services, also referred to as ecosystem services, which are the foundation upon which social and economic development depends (Alcamo *et al*., 2003:1). Ecosystem services are defined as: “… the benefits people obtain from ecosystems.” (*ibid*. v). Ecosystem services embrace approximately twenty different ecological goods and services. They are grouped into four main categories: a) Provisioning services: food, water, timber, fibre, natural medicines, pharmaceuticals, genetic resources and biochemicals; b) Regulating services: climate regulation, air quality regulation, water regulation, erosion regulation, water purification and waste treatment, disease and pest regulation, pollination and natural hazard regulation, such as flood regulation; c) Cultural services: spiritual and religious values, aesthetic values, ecotourism and recreation; and d) Supporting services: soil formation, photosynthesis, and nutrient cycling (MEA, 2005b:vi; TEEB, 2010:18,19). In Figure 8 ecosystem services and their link to human well-being are set out schematically.

Falkenmark and Folke (2003:1919) and Nellemann (2009:33), state that freshwater ecosystem services are the foundation upon which the functioning of all natural and social systems depend, and, according to Hough (1995:39), freshwater ecosystems are the most essential supporting system of the city. Spirn (1984:138) states that ‘‘without water, a city cannot survive’’. Freshwater ecosystems form the basis of food security by supporting the ecosystem services for food production (Nellemann, 2009:33). This study will focus and expand on freshwater ecosystem services, its functional integrity and how it contributes to resilience in the City of Tshwane.

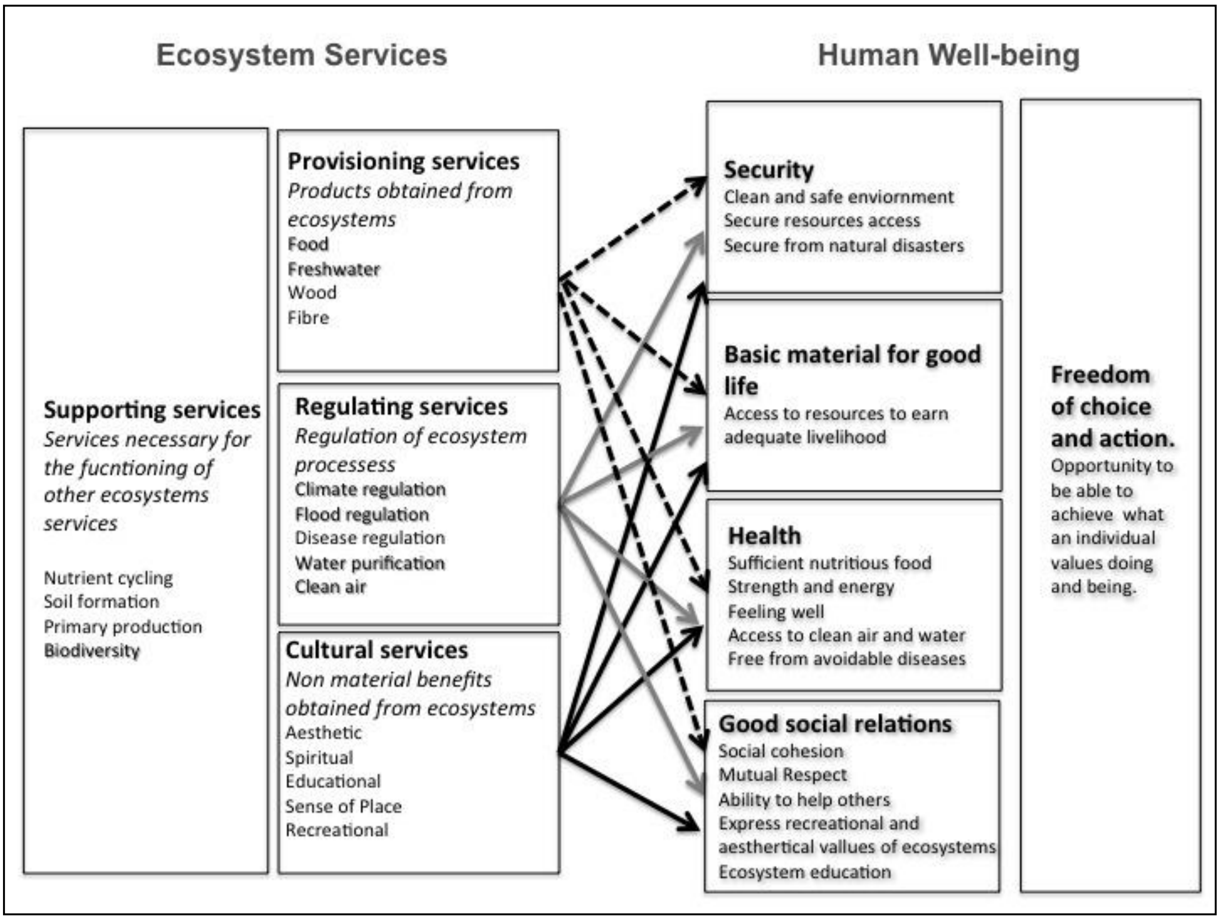


Figure 8: Ecosystem services and their link to human well-being (Source: Adapted from Alcamo *et.al.,* 2003:50)

1.6 Urban freshwater systems

1.6.1 Introduction

> *Rivers, lakes, wetlands and their connecting groundwaters are literally the "sinks" into which landscapes drain. Far from being isolated bodies or conduits, freshwater ecosystems are tightly linked to the watersheds or catchments of which they are a part, and they are greatly influenced by human modifications of land and water. The stream network is important to the continuum of river processes. Dynamic patterns of flow that are maintained within the natural range of variation will promote the integrity and sustainability of freshwater aquatic systems*. (Baron, Poff, Angermeier, Dahm, Gleick, Hairston, Jackson, Johnston, Richter & Steinman, 2003:1)

Nature is one big connected system with changes in one section of the system affecting the working of the entire system, according to McHarg (1992:56) and Nel, Driver, Strydom, Maherry, Petersen, Hill, Roux, Nienaber, van Deventer, Swartz, and Smith-Adao (2011:4). It is therefore necessary to understand the larger context of any river, considering the watershed and the bioregion (Hough, 1995:24). Rivers provide continuous ecological corridors, valuable in already fragmented landscapes (Nel *et al.,* 2011:4).

The following section will sketch the general history of urban freshwater systems and the connection between freshwater systems and human settlements. This is followed by what is meant by the functional integrity of freshwater ecosystems, at the challenges facing urban freshwater systems and lastly at what can be done to create more resilient and connected urban freshwater systems.

1.6.2 History of urban freshwater systems

Since early civilisation, rivers, with their multi-dimensional, life-giving qualities, have played an important role in determining where people would settle. Rivers not only provide provisioning and regulating services, but are also a source of spiritual and cultural connection (MEA, 2005b:168,554). The human dependence on rivers is evident in that most of the major cities in the world were built along river valleys and their floodplains. However, during the past three centuries, destruction of the environment has resulted in a disregard of the critical role that freshwater play in the survival of man (McHarg, 1992:vii). Failure to value the services that freshwater ecosystems provide has caused a change in connection between humans and this critical resource.

The disconnection between nature and cities was evident during the Industrial Revolution, when rivers became polluted sewers carrying disease and causing health hazards in cities, which resulted in many rivers being covered and buried underground, often merged with the sewer systems. Some rivers are still underground, such as the Rivière Saint-Pierre in Montreal, while Brescia, in Italy, has a network of medieval rivers flowing underneath it. These stories are captured in a film entitled *Lost Rivers* (Icarus Films, 2012) which also describes attempts that are now being made to “daylight” hidden rivers around the globe.

Watersheds changed as cities expanded and human demands increased, causing river basins to become overburdened and their ecological integrity to become degraded. River basins started to change with a decrease in forest and vegetation cover, which weakened rainwater infiltration, altering the flow rate of the river and the water temperature. As cities expanded, natural water management and regulating processes were diminished. Wetlands were removed to make way for development, resulting in flooding, making rivers a hazard rather than an attribute. The loss of wetlands also resulted in the loss of water storage and water purification which nature provided at no cost (Hough, 1995:73). To mediate this, rivers were modified and contained in concrete channels in an attempt to manage the hydrological system and avoid flooding in the city. Stream modification caused a further change in connection between the natural infrastructure and the city, resulting in modern cities being developed without recognising the functions of natural systems. This created costly management issues over the decades which followed, as engineered solutions attempted to control pollution and peak flows of rivers, replacing functions previously provided by the natural freshwater system (Hough, 1995:56).

The importance of managing freshwater systems in the broader context of a watershed is increasingly acknowledged. A watershed contains many interconnected ecosystem services that interact with each other, and a change in one part of the system creates change in another part of the system (McHarg, 1992:56). Awareness of the fragility of natural systems, of the interconnectedness of living systems, and of the physical processes which shape the landscape, has also increased (Hough, 1995:5). Planners are realising the benefits of “designing with nature” respecting that nature provides services to man. Such services are provided most effectively when nature is conserved (McHarg, 1992:57) and natural systems are seen as integral parts of infrastructure services in the city, called “green infrastructure”. Ecological urbanism builds on this ethos by recognising that our cities are part of nature: “… cities are habitats; cities are ecosystems; urban ecosystems are dynamic and interconnected; every city has a deep, enduring context; urban design is a tool of human adaptation.” (Spirn, 2011:6)

Watersheds that function in an ecological way are able to provide drinking water and irrigation to adjacent settlements, reducing the effects of climate change where rainfall patterns are affected (Secretariat of the Convention on Biological Diversity, 2012:34), making localised water provision possible from the catchment within which the city lies. However, this is only possible if wetlands and river channels are kept intact and maintained (*ibid.* 10).

Managing rivers in the context of their watershed is not a new approach; it has existed for many centuries in countries such as Greece and Switzerland. Similarly, communities in ancient China valued the ecological process in water catchments and did tree restoration within the catchment to enhance the natural purification process provided by forests, thereby strengthening the health of the river system by improving erosion control and water quality (Folke, 2003:2031).

Designing with ecosystems and recognising their valuable services does not only add quality of life to a city but also provides financial benefit, something that has been recognised in both Kenya and New York City (Secretariat of the Convention on Biological Diversity, 2012:10). Ecosystem services that clean and store water in the catchment areas of two of Kenya's main rivers contribute green infrastructure services to the value of US $20 million annually (*ibid.*). Similarly, in New York City, investment in natural assets, which included the purification of its degraded rivers, lakes and reservoirs in the Delaware Catskill water system, (polluted as a result of homes, golf courses and agriculture), saved billions of USD. A natural water purification system of forests was used which filtered water through tree roots and soil at no cost. These forests also provide aesthetic value to the area and a steady supply and flow of water, which alleviates flooding and soil erosion, provides habitat for wildlife and assists with carbon sequestration and mitigation of climate change (Turner & Daily, 2008:31). New York City opted for sustainable land management practices which included a) encouraging farmers to reduce the use of agrochemicals; b) ensuring that sewage treatment plants are well managed in support of a healthy watershed, c) avoiding landscape fragmentation and parcelization, which weakens forests which require large areas to be economically viable, and d) avoiding land use change from forests to crops or housing as this will weaken water purification function and increase runoff and nutrient load. In this way New York avoided the building of expensive, engineered water purification plants and invested in its natural assets (UN-HABITAT, 2012:37,39).

Recently, for environmental reasons and forced by the effects of climate change, cities have had to reconsider their hidden underground piped rivers (Icarus Films, 2012). There are many such rivers, one of which is the Saw Mill River in the City of Yonkers. Buried underground for the past 90 years, it has been regenerated into a natural park and river running through the inner city. There is also the Cheonggyechon River in Seoul, which has been regenerated, and in Toronto and London opportunities are being considered to improve the environmental condition of the underground rivers (ICI Radio Canada, 2014).

1.6.3 The functions of freshwater ecosystems

Freshwater ecosystem functions play a role in the overall resilience of the city. Once the diverse set of functions are interfered with, degraded or lost, the freshwater system loses its functional integrity, altering the services that it provides in support of human well-being and other ecosystems and the building of positive resilience.

This diverse set of functions of freshwater ecosystems are listed in Table 3.

Table 3: Functions of freshwater ecosystem

Functions of freshwater ecosystem services	
Categories of ecosystem service	**Ecosystem services**
Provisioning services	Food (fish, game, fruit, grains) Water for non-consumptive use (power generation, transport and navigation) Freshwater (quality and quantity) for consumptive use (storage and retention of water for domestic, industrial and agricultural use) Fibre and fuel (logs, fuel wood, peat, fodder) Biochemical (extraction of materials from biota) Genetic materials (medicine, genes for resistance to plant pathogens, ornamental species etc.) Biodiversity (species and gene pool)
Regulating services	Climate regulation (sink for greenhouse gases, influencing temperature and precipitation and other climate process and chemical composition of the atmosphere) Hydrological flows (groundwater recharge and discharge, storage of water for agriculture/industry) Maintenance of water quality through pollution control and detoxification (retention, recovery and removal of excess nutrients and pollution through natural filtration and water treatment) Erosion (retention of soils) Natural hazards (buffering of flood flows controlling floods, storm protection)
Cultural services	Spiritual and inspirational (personal feelings and well-being from free flowing rivers) Recreation (river rafting, fishing etc.) Tourism (river viewing) Aesthetic (appreciation of natural features) Educational (opportunities for formal and informal education and training)
Supporting services	Soil formation (sediment retention and accumulation of organic matter) Nutrient cycling (storage recycling, processing and acquisition of nutrients, role in maintenance of flood plain fertility) Pollination (support for pollinators) Mitigation of climate change (mangroves and floodplains as physical buffers) Ecosystem resilience

Sources: Adapted from MEA, 2005a:554 & MEA, 2005c:216

1.6.4 Issues affecting the functional integrity and resilience of urban freshwater ecosystems

> *Ecosystems include people, and rivers have always been magnets for human settlement, providing water for drinking and to grow crops, harvestable resources, transportation and hydropower. In ways both subtle and obvious, almost all running waters today show some evidence of modification due to human activities.* (Allan & Castillo, 2007:6).

The biggest driver of change in freshwater systems is population growth and urbanisation, which, through the activities of development and land use change, cause: pollution and degradation of the ecological functioning of the water system; over-extraction of local water supply; and stream modification (Allan, 2004:263; Folke *et al.*, 2002a:21-22; Hough, 1995:39; Strayer, Beighley, Thompson, Brooks, Nilsson, Pinay & Naiman, 2003:408). The second driver of degradation of freshwater systems is that they are not understood and valued for their multiple functions as part of a dynamic landscape in a catchment, and their functional role as the bloodstream of the biosphere is not appreciated, a role which is crucial to the resilience of the SES (Folke, 2003: 2027,2028).

The effects of disturbances of freshwater systems are the decline of major drainage basins in terms of the weakened ecosystem functioning of wetlands, rivers, lakes and marshes, due to habitat loss, water abstraction and pollution (nutrients, sedimentation, salt and toxins), which compromises ecosystem services for human well-being (MEA, 2005a:14). Additionally, according to Spirn (1984:130-141), urbanisation causes an increase in flooding. Human impacts further include canalising water, impounding it, pumping up groundwater, and transferring water between catchments. Then there are also changes in vegetation cover where natural forests make way for plantations and agricultural land. Urbanisation affects 20-90% of the permeability of the land, affecting the flow of smaller rivers with high discharge during the rainy season (Tricart, 1999:337).

Drivers of change to freshwater systems, issues that compromise the resilient functioning of freshwater systems and their effects, are presented in Figure 9 and described further below:

a) Transformation of natural habitat and vegetation: Vegetation cover plays an important role in the hydrological cycle. Alterations in the natural cover along streams and on adjacent land can have a severe impact on the flood peak and the quality of the water. According to Dunne and Leopold (1978:154,156), the impacts of altering and clearing the indigenous and natural vegetation cover along streams to increase water yields, and the clearing of vegetation on land for crops or development, can cause an increase in sedimentation downstream. It can also have a negative aesthetic affect (*ibid.*). Changing land use and vegetation cover alters the hydrological cycle and affects the water collection capability of the channel by altering the quantity of water, the speed with which it travels and the location where the water enters the channel (Dunne & Leopold, 1978:590).

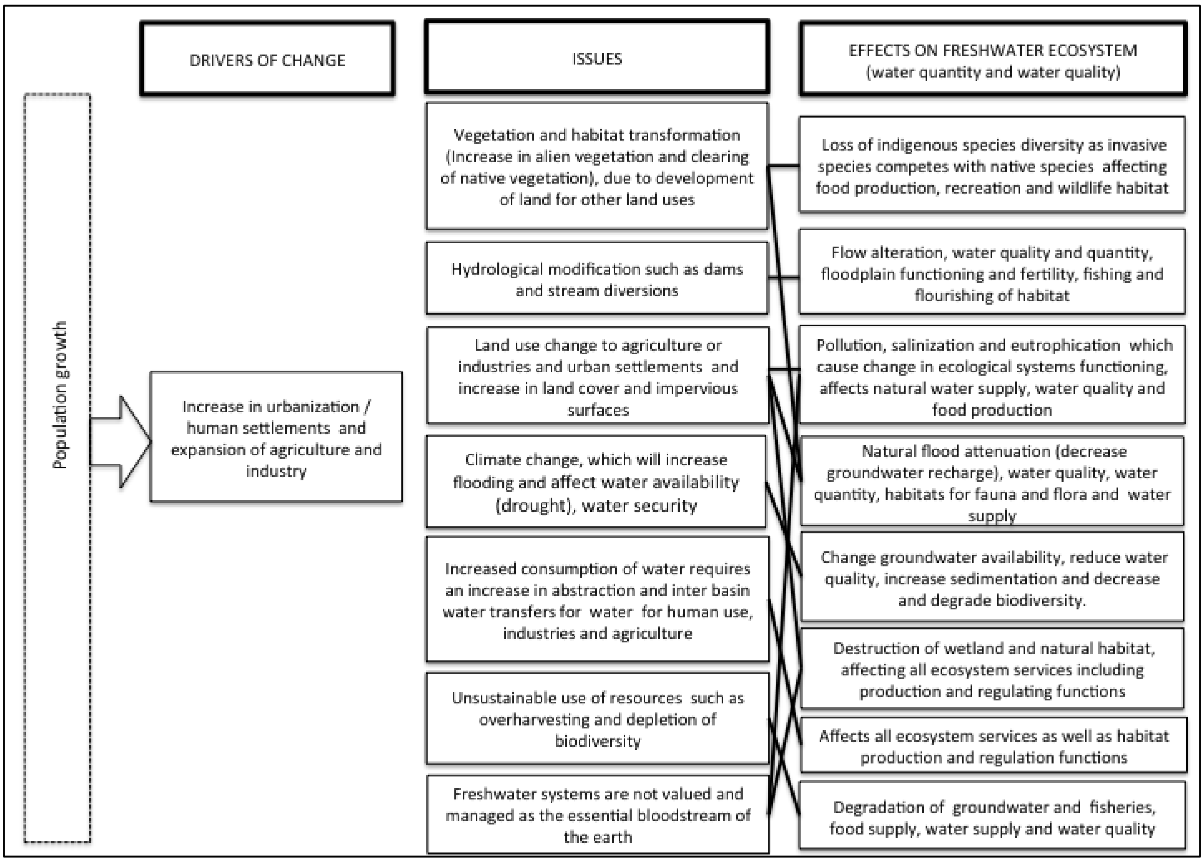


Figure 9: Issues effecting change in freshwater systems (Sources: This figure was compiled by the author drawing on information from: MEA, 2005a:14,553, 576; Nel et al., 2011:5,6; Prasad, Ranghieri, Shah, Trohanis, Kessler and Sinha, 2009:37; Secretariat of the Convention on Biological Diversity, 2012:34; UNESCO, 2003:14)

The invasion of alien plants transforming the natural habitat of a watershed impacts negatively on the functioning of the freshwater systems. One of the negative effects is that invasive plants can have an increase in fire potential, causing soil damage and erosion, which affects water quality. Invasive species also use more water than indigenous vegetation, consuming an estimated 7% of the total runoff per year in South Africa, affecting groundwater reserves, reducing the flow of rivers and impacting substantial on the freshwater habitat (Chamier, Schachtschneider, le Maitre, Ashton &

Van Wilgen, 2012:345). The reduced flow of the rivers increase the loading of pollution and nutrients in the water as a result of decreased dilution capacity (*ibid.*346).

Degradation and modification of riverbanks results in the decline of vegetation, affects the filtering capacity of the stream and reduces plant and animal habitat (Nel *et al*., 2011:6). Loss of riparian vegetation, runoff over exposed surfaces and return flows from industry all cause thermal pollution, increasing water temperature (Grant, 2012:44). Some land use changes have a greater impact on the quality and the quantity of water; agriculture is regarded as one of the biggest causes of wetland loss globally (MEA, 2005a:14,553), threatening the water quality and quantity of a watershed and the future availability of water (UNESCO, 2003:13).

b) Hydrological modifications: Hydrological modifications include canalisation of streams, hardening of stream banks, construction of dams and reservoirs and construction of stream barriers such as bridges and culverts. Obstructions to river flow, in an attempt to support agriculture and water storage in catchments, have caused serious fragmentation in 40% of the world's river systems (MEA, 2005a:14). Fragmentation disrupts the natural flow of water, increases erosion and sedimentation and destroys freshwater habitats (New York State Department of Environmental Conservation, 2015). Dams are also recognised globally as incurring social and environmental costs according to Allan and Castillo (2007:12). This is also true in South Africa where, according to Nel *et al*. (2011:5), dams, and the transfer of water between catchments, are major contributors to destruction of freshwater ecosystems, through altering the natural flow of rivers.

The introduction of storm water systems in cities, which are installed to convey storm water from streets, has increased the volume of water, and together with increased overland flow, can overwhelm streams and rivers causing peak flooding and reducing the lag time of water runoff. Storm water systems also prohibit the recharge of the water table as a result of water diversion (Dunne & Leopold 1978:275-277; Strahler & Strahler, 1973: 335, 336).

In an attempt to manage the increase in stormwater runoff, natural channels are straightened and deepened, and lined with concrete to ensure fast and effective hydrological action of taking the water quickly downstream (Dunne & Leopold, 1978:275-277). Another modification is the clearing of vegetation from the stream to increase the speed of the water in the channel, to prevent it from rising in the area and spilling over its banks; instead, the water is discharged promptly (Dunne & Leopold, 1978:403). This result in flooding downstream when large amounts of water are discharged in a short period of time. By making the channel deep and straight and with the resultant increase in stream velocity, erosion is caused where the water leaves the lined channel. There is then also a build-up of sedimentation further downstream once the velocity of the water is reduced due the increase in the stream's roughness coefficient and the flow is spread out wider and shallower. In some cases the drainage of natural wetlands occurs when the river channel is deepened (Dunne & Leopold, 1978:404).

Cities have hidden natural systems from the city dweller with engineered structures such as stormwater pipes which drain water from sidewalks, channel it away underground to purification plants and pump it back again to the city, where it emerges from taps. The source of the water, where it originates and how it functions is invisible to the city dweller (Hough, 1995:48).

c) Land use change from natural vegetation to agriculture, industries and urban settlements: Urban land use change affects freshwater ecosystems in the following way: it alters the streamflow; it reduces groundwater recharge; it increases pollution; and it affects all aspect of stream ecosystems (such as nitrate flux, aquatic and riparian vegetation and fauna species richness) (Strayer *et al*., 2003:408). In addition, as stated by Allan (2004:262): it increases sedimentation; it causes nutrient enrichment; it increases contaminant pollution; it causes hydrological alteration; and it causes the clearing of riparian vegetation and the opening up of canopies. These changes are mainly due to the fact that urbanisation replaces previously permeable soil with hard surfaces, and natural streams become canalised sewer systems (Hough, 1995:39).

Developments in floodplains have a huge impact on the health of freshwater systems because the activities closest to the river, in the floodplain and the riparian zone, have a greater impact on the water ecosystem than the landscape elements further away in the watershed (Strayer *et al*., 2003:409).

Urbanisation increases the extent of non-permeable surfaces which changes the flow conditions of streams. Impermeable surfaces consist of paved parking areas, driveways, walkways and roofs in built-up areas. They restrict rainwater from permeating into the lower layers of the soil causing an increase in overland flow to streams and rivers resulting in flood peaks during storms (Strahler & Strahler, 1973:335-336; Dunne & Leopold, 1978:275-277).

Impermeable surfaces increase the quantity and speed of overland flow of water which is diverted into stormwater canals and sewers. The stormwater canals and sewers then transfer large quantities of water in a short space of time to streams, rivers and dams, causing flash flooding downstream (Spirn, 1984:130-134). Flash flooding causes erosion resulting in poor water quality and diminishing groundwater and stream recharge (Hough, 1995:41). It is estimated that cities with up to 90% impervious ground surfaces can lose up to 83% of rainfall to stormwater runoff, which is channelled out of the city. By way of comparison, the runoff in forested landscapes is 13% (Secretariat of the Convention on Biological Diversity, 2012:11).

Hard surfaces in urban areas prohibit the recharge of groundwater through filtration of the soil layers, which is necessary to ensure adequate base flow of the river to sustain the flow in drier seasons. This creates drier and warmer cities due to reduced humidity, and increases the temperature creating a heat island effect (Grant, 2012:34,44,82,93). High overland flow and the installation of stormwater systems which divert stormwater from streets, adds volume to the amount of water, overpowering the stream's capacity to transport the water (Dunne & Leopold, 1978:275-277; Strahler & Strahler, 1973:335,336). Stream hydrology is affected as wetland areas decline and engineered drainage systems (ditches and subsurface drains) are installed. This increases the flow of stormwater and causes erosion and disturbance of habitat along streams (Allan, 2004:265).

Pollution of freshwater systems places a burden on the natural purification functions of freshwater ecosystems (to purify and reduce pollutants, to balance nutrient levels and to provide a buffer against natural disasters). These functions are in decline globally (MEA, 2005a:6). The burden of pollution of freshwater systems can be seen as cities continue to neglect water conservation, allow toxins to accumulate in runoff, divert water out of the city, overuse chemical fertilisers and pesticides which filter into the water system, and place industries and waste disposals sites in the vicinity of underground aquifer recharge areas, placing a burden on the functions of aquifers (Spirn, 1984:141). This creates a threat to freshwater ecosystems, affecting the biological quality, and undermines the health of communities (Nel *et al*., 2011:5).

Poor quality return flows from industries and agriculture affect the quality of water far beyond the boundary of the city (UNESCO, 2003:20). Agriculture changes the supply of sediments and increases concentrations of nutrients and contaminants, which in turn can cause fragmentation and degradation of habitat and an increase in sedimentation (Allan & Castillo, 2007:12). Sedimentation causes deterioration of the quality of water systems (Hough, 1995:42). It is found that sedimentation is 1,000 times higher in streams that run through cultivated land than in streams running through forested landscapes (Hough, 1995:35). High peak flows in rivers result in erosion which cause sedimentation and nutrient loading in freshwater systems (Hough, 1995:42). Sedimentation and nutrient loading reduce vegetation in river channels (Allan & Castillo, 2007:12), which in turn cause stream bank destabilisation as the interaction between the river and its land margin is weakened. Sedimentation causes eutrophication which is due to an unnatural enrichment of phosphorus and nitrogen in the water. Eutrophication depletes the oxygen in the water and causes anoxia, where there is no oxygen in the water. It causes unpleasant odours, increases algal blooms, causes the depletion of biodiversity in the freshwater system, and reduces the recreational value of the freshwater system (UNEP, n.d.).

The impact of land use on the quality of freshwater systems has been determined by empirical studies to influence ecological response variables in the freshwater system (Strayer *et al*., 2003:414). Table 4 is a summary of some of these land use impacts and the effect that they have on the ecological integrity of the freshwater system.

d) Increased consumption of water and overharvesting of freshwater natural resources: Increased consumption of water affects freshwater systems. Water is consumed by both humans and ecosystems, and when there is a shortage of freshwater due to the overharvesting of natural freshwater resources to meet human needs, it is often the supply of water for the functioning of natural ecosystems that is compromised (Allan & Castillo, 2007:12). With a world population of more than seven billion, the supply of water is in decline and the quality of freshwater ecosystems is deteriorating. It is predicted that the current mismanagement of water will escalate (UNESCO, 2003:10), which will make it even more difficult to meet human and ecosystem needs (MEA, 2005a:6) with 1.6 billion people already experiencing water scarcity currently (Boelee, Chiramba & Khaka, 2011:7). Globally, it is indicated that agriculture is the biggest consumer of water, using more than six times the amount of water that domestic water consumption does, with industry using more than 1.5 times the amount that is used for human consumption (World Bank, 2013:62), as indicated in **Figure 10**.

The use of water is also exacerbated by the loss of water through leaks in subsurface pipes (Spirn, 1984:141) and by the growth in human population, which generates an increased demand for water to meet the needs of higher industrial output (Folke *et al.,* 2002a:22).

Table 4: Land use impact and effect on the ecological integrity of freshwater systems

Impact of land use	**Effect**
High percentage of cultivated lands	High nitrate flux, low fish species richness and high % of aquatic plants.
High percentage of pasture agricultural lands	High fish species richness and low nitrate flux.
Wetlands	High fish species richness, low percentage of non-native fish species and high aquatic plant species richness.
Forested land	Negative nitrate flux, increases in non-native fish species, and linked positively to riparian plant cover.
The presence of open water	Negative effect on nitrate flux
Urban land cover	Positively linked with the proportion of exotic fish species and riparian canopy cover and negatively linked with macro-invertebrate species richness.

Source: Adapted from Strayer *et al*., 2003:414

e) Climate change: The eighth issue affecting freshwater systems is climate change, which affects rainfall patterns and temperature (Nel *et al.,* 2011:6).

f) Freshwater systems are not managed as the essential bloodstream of the earth: Freshwater systems are negatively affected if they are not managed within the context of the ecosystems of a larger river basin. The boundaries of cities are not determined according to the boundaries of river basins and the availability of water, but are rather guided by administrative boundaries. This places a strain on the natural availability of water and it creates competition between the different uses in a watershed (natural ecosystems and human needs) and then between the different administrations which share the same watershed or aquifer (UNESCO, 2003:25).

The disconnection between freshwater systems and cities is further complicated if the patterns of human settlement reject the existing natural drainage network upon which human settlements are built. Cities should rather honour the role of freshwater systems within the biosphere as the lifeblood that sustains both natural and human systems (Falkenmark & Folke, 2003:1917; Spirn, 1984:10,130). Freshwater, the most valuable resource for life, should be kept as an uncontaminated source of drinking water. Instead, freshwater has deteriorated into contaminated rivers with sewage sediments and waste, and water management creates disasters with extremes of floods and drought (Spirn, 1984:129).

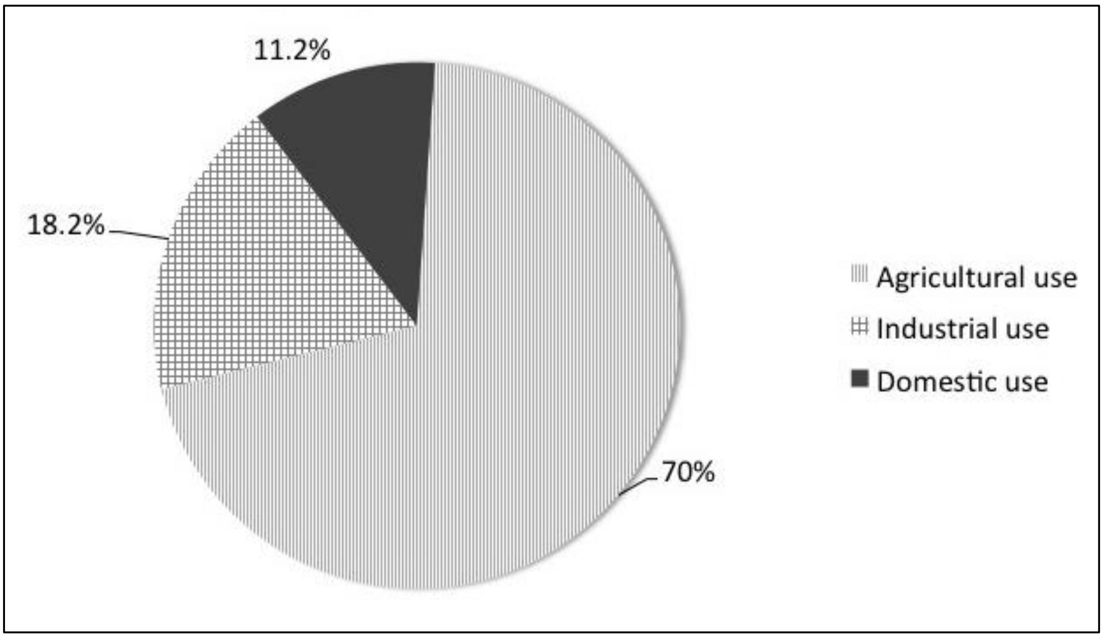


Figure 10: Competing global water use based on 2011 data (Source: World Bank, 2013: 62)

Following is a list of some initiatives that aim to create cities which are connected and integrated with the natural systems and the processes surrounding them.

1.6.5 Responses to create urban freshwater systems connected to the urban fabric

Resilient cities benefit from freshwater ecosystem services only if urban development proposals understand and integrate freshwater ecosystems as a valued contributor to human well-being (Rottle & Yocom, 2010:48; TEEB, 2010:106; Walker & Salt, 2006:148).

However, this approach of integrating cities with natural systems is not a priority in a market-driven economy (Walker & Salt, 2006:148).

In order to plan for more resilient cities and to reduce the vulnerability of urban environments to disturbances, cities need to enhance their ability to deal with challenges and perturbations. This can be done by: a) increasing the supply of water, b) developing proper flood management, c) improving planning and control of housing and industrial developments, d) supplying sanitation, e) controlling the abstraction of water and f) minimising pollution effluent (UNESCO, 2003:16). Planning for proper flood management can be done if: a) urban settlement patterns respond to and link with natural drainage systems, b) the density of impervious surfaces is reduced; and c) drainage and flood control systems are acknowledged (Spirn, 1984:130).

Urban development changes the face of the landscape, affecting the way in which water flows and is distributed. This can be changed by acknowledging and managing the urban hydrological system as part of an interconnected "green infrastructure" network consisting of a collection of ecosystems services in the city, beneficial to the environment and humans. Green infrastructure, in the context of hydrological systems, includes the management of urban stormwater and wastewater by using natural systems that encourage groundwater recharge and healthy aquatic habitats, and includes the development of rain gardens, and the use of wetland systems, bio-filtration swales, and green roofs (Rottle & Yocom, 2010:50).

Cities can learn from nature when developing urban hydrological systems, by: a) connecting with existing natural systems and incorporating them as part of the built infrastructure and/or b) regenerating existing stormwater systems or designing new stormwater systems in the city, which mimic the processes of natural water systems based on the good example which nature provides of how to deal with rainwater. Nature provides storage of water in floodplains and lakes, avoiding flooding and creating a more equal flow of water over a longer time; vegetated soil and woodlands facilitate water infiltration, filtration of water and recharge of groundwater supply.

These natural patterns of infiltration and storage can be applied in the design of urban stormwater drainage through: a) providing water retention facilities in urban developments to control stormwater runoff — onsite storm water management; b) creating permanent water storage ponds; c) creating temporary storage such as playing fields, cemeteries and parks that can accommodate additional water in extreme cases; and d) creating wetlands for biological treatment of wastewater, enhancing the quality of water runoff and controlling stream flows (Hough, 1995:77-78).

Table 5: Regenerative design inputs to strengthen functions of freshwater in the city

Ecosystem services for the built environment	**Design approaches to strengthen the functions of freshwater in the city**	**Positive environmental impacts**
Supporting ecosystem service: **Habitat provision**	Urban forests, re-vegetation; natural open space corridors; green roofs and green belts	Increased biodiversity; Increased water and soil quality; Reduced water and soil pollution; Reduced stormwater peak flows; and Ecosystems that is more adaptable to change such as ecosystem change and climate change.
Supporting ecosystem service: **Nutrient cycling to increase health of ecosystems and human well-being**	Recycling and reuse; industrial ecology; composting.	Reduced waste and consumption patterns, which drive the need for production and which increase ecosystem disturbance and waste.
Regulating services: Purification to be strengthened	Green roofs and green facades; improved filtration; urban forests; increase wetlands (constructed); composting techniques, phyto- and bio-remediation.	Increased terrestrial productivity; Reduced water pollution; Reduced eutrophication and; Remediation of polluted sites.
Provisioning service of freshwater to be strengthened	Rainwater harvesting and storage; water recycling; water wise landscapes; increased permeable surfaces; water conservation design.	Reduced water pollution; Creation of a healthier riparian system; Alleviation of the urban heat island effect; Increased quality of water; and Enhancement of the health of living systems.

Source: Adapted from Pedersen Zari, 2012:59

By regenerating freshwater ecosystem services through better planning and design, many of the natural systems in and around cities can be revived, creating healthier and more resilient cities. Both regulating and provisioning services are very relevant to the built environment and through regenerative design, the effect of the built environment on ecosystem services can be reduced (Pedersen Zari, 2012:60).

Table 5 presents regenerative design inputs to strengthen the functions of freshwater in the city.

In order for freshwater systems to contribute to the resilience of the SES, these freshwater ecosystems need to be healthy. The following section will expand on what is required to maintain healthy freshwater systems.

1.6.6 Resilient and healthy urban freshwater ecosystems

> *Resilient ecosystems, which have a rich biodiversity, are more likely to withstand disturbance and sudden shocks such as fires, droughts and floods and alien species invasion. Resilient areas are also better able to regulate climate, a critical ecosystem function* (European Union, 2010).

In order for freshwater ecosystem services to maintain their functional integrity and deliver continuous goods and services to humans, they need to be healthy and resilient, so that they can adapt to pressures and continue to function despite disturbances. For the freshwater system to be healthy, it is essential to protect its ecological integrity through watershed management, and minimising disturbances to the ecology (UNESCO, 2003:16). In the context of the SES, there is a direct correlation between the resilience of freshwater ecosystems and human well-being (MEA, 2005a:2) where: “Healthy natural systems regulate our climate, protect against hazards, meet energy needs, prevent soil erosion, and offer opportunities for breath-taking recreation, cultural inspiration and spiritual fulfilment.” (TEEB, 2010:6).

Freshwater recharges rivers and lakes and provides moisture for forests and plants in its dynamic movement through the landscape (Folke, 2003:2029). In order for freshwater systems to provide this life-supporting function, they need to be able to tolerate change and perturbations inflicted upon them and still maintain their functions. According to Allan (2004:260), the degree of a) ecological integrity, b) stream condition and c) river health is an indication of the status of the hydrological system and how it will respond to human disturbances, i.e. its capacity to be resilient. Figure 11 presents principles that support healthy freshwater ecosystems to maintain optimal resilience, sustain functional integrity and continue to supply freshwater services for human well-being.

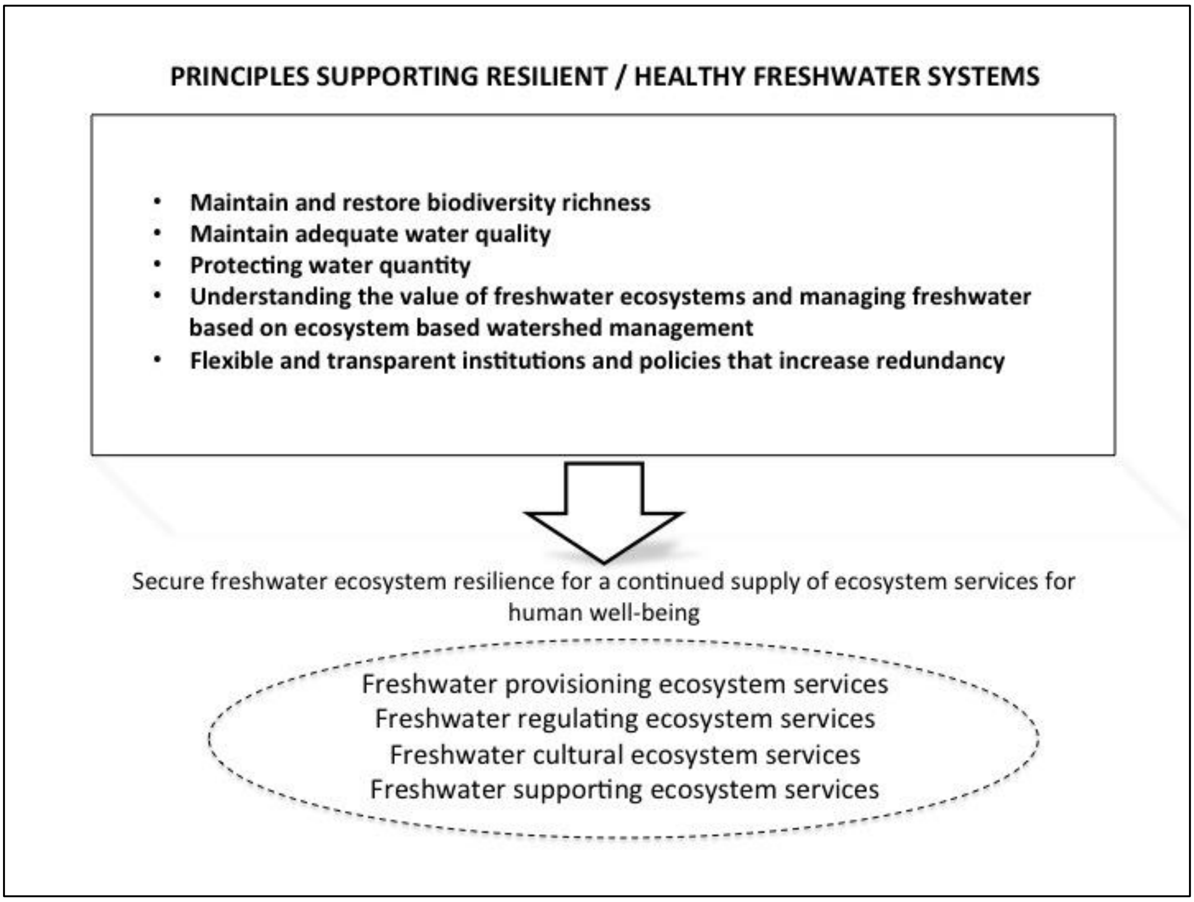


Figure 11: Principles supporting resilient/healthy freshwater systems (Source: Compiled by the author from information drawn from Biggs et al., 2012:440; Falkenmark, 2003:2037; Folke et al., 2002a:17,33,36; Folke, 2003:2027; Hough,1995:34; Nel et al., 2011:4; Resilience Alliance, 2002a; Spirn, 1984:131-132; Steiner, 2008:14; and UNESCO, 2003:13,16.)

Biodiversity richness is one indicator of health and resilience in freshwater ecosystems (UNESCO, 2003:13). Biodiversity provides for functional redundancy (see section 2.3.3). Functional redundancy makes ecosystems resilient by providing the capacity to act when there is change and to adapt when necessary (Hough, 1995:23; Resilience Alliance, 2002a; Rottle & Yocom, 2010:56; Stanford University, 2012). A strong biodiversity consists of different species/ecological processes and variety within species (TEEB, 2010:14) which allows for backup and duplication of functions and is an indicator of the health of ecosystems (Hough, 1995:23; Rottle & Yocom, 2010:56).

High functional redundancy (which can include species richness or biodiversity) in freshwater ecosystems is very important for ensuring the continuation of ecological processes, during times of environmental stress, such as primary production, decomposition and nutrient cycling (Baron *et al.,* 2003:7). Connectivity among water bodies is important as it allows for species to migrate to other water bodies with more favourable conditions when there is environmental stress (*ibid.* 7).

Freshwater systems require a range of natural variations or disturbances to maintain their functional integrity and resilience (Baron *et al.,* 2003:3). Freshwater ecosystems are dynamic systems functioning in constant change, highly unpredictable and far from equilibrium (Levin, 1999; Baron *et al.*, 2003:3). In order to keep freshwater ecosystems healthy and avoid a loss of species and ecosystem services in wetlands, rivers and lakes, it is important to accommodate this dynamic changing system and allow for: a) the natural dynamic patterns of water flow, b) adequate input of sediment and organic matter, c) heat and light fluctuation within the natural ranges but not beyond the natural range or at a constant level, d) clean water and e) diverse aquatic animals and natural vegetation (Baron *et al.,* 2003:12). Dams constructed as part of a river system affect the biodiversity because they change the flow patterns which affects the natural flow variation rates, keeping the river to a low flow rate through the seasons which affects fish species and riparian vegetation (*ibid*.5).

Adequate water quality is one of the principles that support resilient/healthy freshwater systems. The quality of water can be protected by a healthy riparian system, healthy tributaries and functional wetlands, because all of these support the sustainability of rivers and alleviate the impact of land-based activities on the freshwater system (Nel *et al.,* 2011:4). Toxic pollution should be avoided (Resilience Alliance, 2002a).

Protection of water quantity is another principle that supports resilient/healthy freshwater systems. Freshwater should be protected and groundwater should be allowed to recharge, providing rivers with water in dry seasons (Nel *et al.,* 2011:4).

Understanding the functioning and value of freshwater ecosystems and applying ecosystem-based watershed management is another necessary principle to support resilient/healthy freshwater systems. It is important to understand how the hydrological system functions and how it can enhance the resilience of freshwater ecosystems (UNESCO, 2003:13), realising that the freshwater system exists within a larger ecological context and watershed and that all the precipitation which falls in a drainage basin exits the basin at one single point, such as a river or a reservoir, where the water continues its path towards the ocean (Grant, 2012:84). Valuing freshwater systems for their central role as the bloodstream of the biosphere (Folke, 2003:2027), is an important consideration when planning cities. As Viktor Schauberger described it many years ago in a biography by Cobbald (2009:50), "I regard water as the blood of the earth, its internal process, while not identical to that of our blood, is nonetheless very similar." To apply this in planning, the planning boundaries of cities should correspond with the natural boundaries of a watershed instead of political boundaries (Steiner, 2008:14; Baron *et al.,* 2003:1). This would make it possible to use the natural features which exist in the landscape, such as storage and flood control structures, for managing the freshwater systems of the city, providing a much more cost-effective and long-term solution than built structures (Steiner, 2008:14). One of the ways in which this can be done is by keeping the floodplains free from development in order for the river and the floodplain, which is a unit designed by nature to manage floods, to do this to the benefit of the city (Spirn,1984:131-132). An example of this is the Charles River water basin in downtown Boston where wetlands were kept free from development and used as a natural storage area to retain floodwater and release it gradually over time (Spirn, 1984:154-157).

An understanding of the hydrological system of a watershed provides clarity on the composition and functioning of the freshwater system and its tight connection to the watershed which it drains. Water flows in three dimensions: a) from upstream to downstream, b) from the stream channels it moves to the floodplains and riparian wetlands, and c) surface water filters down to groundwater. Because of this three-dimensional pattern of flow, materials in the floodplain eventually end up in the rivers and lakes and other freshwater systems. This is why freshwater systems are so greatly affected by the anthropogenic activities in the watershed and cannot be seen as separate from them (Baron*, et al.*, 2003:3).

There is a constant competition in water catchments between ecological and human needs (Falkenmark, 2003:2040). It will be easier to balance human freshwater needs with ecological needs if the benefits to humans of healthy freshwater systems are better appreciated (Allan & Castillo, 2007:12). One way of creating a balance is through the catchment-based ecosystem approach which aims to ensure the integration of water, land use and ecosystems as dynamic changing systems, finding a balance and compromise in human behaviour with the aim of securing ecosystem resilience and so a continued supply of ecosystem services for human well-being (Falkenmark, 2003:2037).

The resilience of a hydrological system is affected by the surrounding area’s capacity for water infiltration, water storage, and nutrient cycling and vegetation structures. Allan (2004:272), states that hydrological responses to increases in urban land and impervious surfaces are usually nonlinear. Even natural landscapes can also change from one state

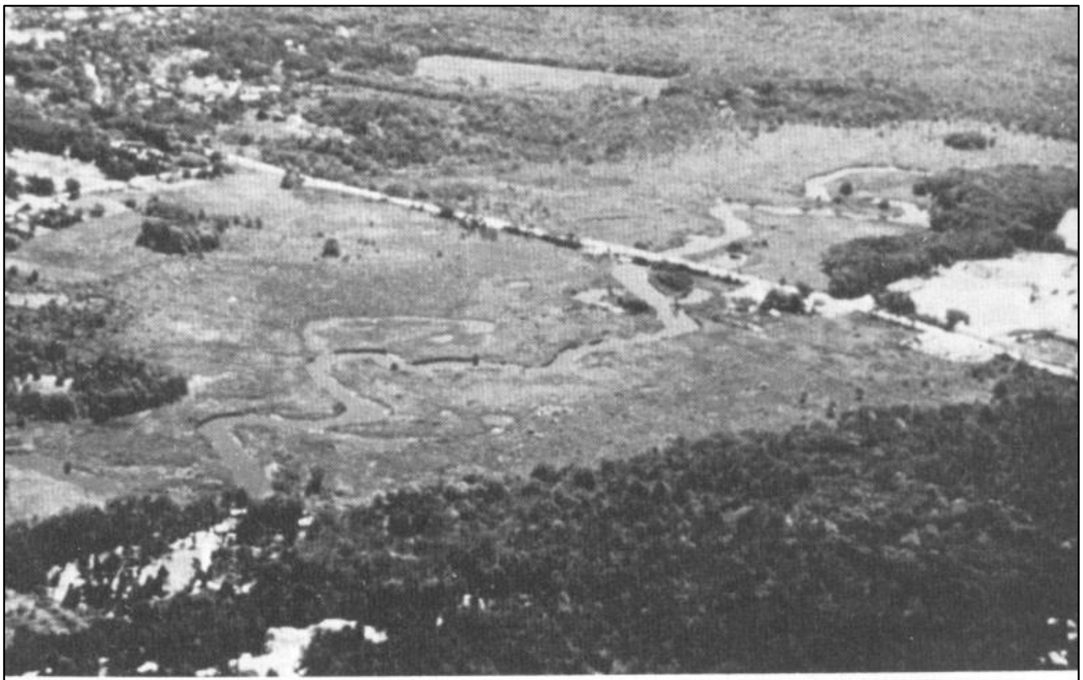


FIGURE 7.6(a)
Natural valley storage area in summer, with both the Charles River and adjacent wetlands clearly visible.

FIGURE 7.6(b)
The same area after spring floods, the river channel and wetlands now a single entity. Wetlands not only provide overflow space, but also absorb floodwaters. Had these wetlands been built upon, this water would have flooded downtown Boston.

Figure 12: The Charles River valley in Boston and floodwater attenuation (Source: Spirn,1984:156)

to another over a period of time, as stated by Folke *et al.* (2002a:29), as a result of disturbances such as weather, fire, human encroachment and overgrazing. According to Steiner, (2008:14) and Spirn (1984:154) it is therefore important for planning to take into account the dynamics of larger watershed areas when planning urban drainage systems and flood control, in order to prevent erosion and protect the water quality By incorporating the natural processes in the catchment as part of the planning, the freshwater system can contribute to keeping the freshwater ecosystem healthy, maintaining water temperature and avoiding sedimentation (Hough, 1995:34). According to Spirn (1984:156) preserving natural processes in a catchment as part of an SES, can also act as a flood regulating mechanism and a natural water storage area during wet seasons, as illustrated in the city of Boston where the wetlands and the river system still function as part of an interconnected unit, as illustrated in Figure 12.

Lastly, further necessary principles to support healthy and resilient freshwater systems relate to governance and management. Flexible, open and transparent institutions are needed as well as a strategic approach and policies that promote the management of freshwater ecosystems in a multi-sectoral way (Nel *et al.,* 2011:4,14; Resilience Alliance, 2002a). Perverse subsidies that encourage unsustainable use of resources, and a focus on production and increased efficiencies need to be avoided as they decrease redundancy making the system more vulnerable and weakening its adaptive capacity (Resilience Alliance, 2002a).

1.7 Conclusion

It can be concluded that humans exists within nature, called the social-ecological system (SES) where humans and nature are intrinsically linked (Resilience Alliance, 2010:6). It is because humans and nature exists as part of the same system in a dynamic and interactive way as described by Walker and Salt (2006:122) that neither social or ecological systems can be viewed in isolation.

Within the SES, the connection between freshwater and human settlements has played an important role in the establishment of civilisations as far as 12000 years before present when agriculture became a practice and permanent settlements formed along the major rivers. Around 2000 years ago the importance of nature for the benefit of human well-being was highlighted by Hippocrates when he drew the link between sickness and health and the forces of nature and that nature should be respected and not degraded (McHarg, 1992:vii). However, civilisations over the past 300 years through industrialisation and urbanisation and despite warning signals from nature, caused extensive degraded and polluted natural systems (*ibid*.). This ecological destruction has been intensified over the past 50 years [1955-2005] when humans altered ecosystems with more intensity and destruction than in any equivalent period of time in anthropological history, essentially to meet growing demands for food, water, timber, fibre, and fuel (MEA, 2005b:1). It is during this same time in history as noted by McHarg (1992:vii), that since the 1940's the importance of ecosystems has been recognised again and processes for regenerative design and reconnecting with nature in the urban context have been revived.

The concept of resilience in SES supports the recognition of ecosystem services as part of planning and development. The resilience of a system depends on the distance to a threshold, and when thresholds are not identified and understood in advance, a system can cross the threshold unknowingly, once the threshold is crossed the dynamics of the state of the system changes, according to Walker and Salt (2006:74). This study will aim to identify the thresholds in the history of the Apies River as part of the SES.

The resilience of an SES, or its adaptive capacity, is identified by the degree of: diversity; ecological variability; modularity; connectedness; slow variables; innovation; social capital; tightness of feedback; overlap of governance; and ecosystem services that exist or are recognised in the system (Gunderson & Holling, 2001; Walker & Salt, 2006:145-148).

Five of these qualities of resilience that have been discussed in this theoretical background: tightness of feedback; ecological variability; diversity; flexibility; and the integration of ecosystem services into urban planning, formed the basis of the analysis in this study. Using this framework, the study set out to identify:

n) The principles of resilience present or lacking in the Apies River system. The analysis also differentiated between specific and general resilience in this system.
o) Pulse and press disturbances, which impacted on the state of the Apies River system.
p) The effect of these disturbances on the adaptive capacity of the Apies River as the focal system.

Resilient freshwater systems contribute to the positive resilience of an SES. Freshwater ecosystems can only be resilient if they are healthy and bio-diverse and so able to sustain perturbations while continuing to provide the necessary services upon which an SES depends. Resilient freshwater systems are created by maintaining biodiversity, avoiding toxic pollution, creating flexible and open institutions, increasing subsidies that encourage sustainable use of resources and increasing redundancy (Resilience Alliance, 2002a).

The functional integrity of freshwater ecosystems contributes to the positive resilience of the SES by a) enhancing human health and well-being by creating citizens that are less stressed, are healthier and more productive (Secretariat of the Convention on Biological Diversity, 2012:11,30); b), providing regulating services to the city at a lower cost than conventional services (Hough, 1995:2; Secretariat of the Convention on Biological Diversity, 2012:11; TEEB, 2010:7; Hough,1995:41). Healthy freshwater ecosystems reduce the vulnerability of cities by providing buffers against natural disasters, making the city better able to respond to issues such as climate change (Secretariat of the Convention on Biological Diversity, 2012:34)

The resilience of a freshwater system relates to the amount of disturbance that the system can absorb before it shifts into a different state (Gunderson & Holling, 2001:27-28; Resilience Alliance, 2010:5). The resilience and health of freshwater systems are mainly undermined by population growth and urbanisation. These cause a) pollution and degradation of the freshwater ecological functioning, b) over-extraction of local water supply, and c) stream modification (Allan, 2004:263; Folke *et al.,* 2002a:8-9; Hough, 1995:39; Strayer *et al.,* 2003:408). Secondly, water systems are compromised because they are not managed and valued as a system with diverse functional roles and a part of bigger ecological systems (Folke *et al.,* 2002a:17, 23).

It can be concluded that in order to design cities, which connect with nature, freshwater systems should be recognised as dynamic systems interacting with other ecosystems and land use. Both Hough (1995:24) and McHarg (1992:56) stress that nature is one big connected system and cannot be viewed in isolated parts, and that changes in one section of the system will affect the working of the entire system. Consequently, in the context of an SES, the breakdown in resilience of the freshwater ecosystem can weaken the resilience of the social system (MEA, 2005a:2).

CHAPTER 3 - RESEARCH DESIGN AND METHODOLOGY

1.8 Introduction

The goal of the study was to carry out an analysis of the adaptive capacity of the Apies River. This required gathering information about important historical events in the Apies River system over a period of 159 years. The aim was to capture historical shifting points (trigger events) and cross-scale events which affected the Apies River, and to demonstrate the crossing of thresholds and changes (Resilience Alliance, 2010:19,21) in resilience over the time period. Given this goal, the study followed a historical-comparative research approach as contained within the qualitative research paradigm.

1.9 Qualitative research

According to Neuman (2012:23), a qualitative research approach includes a) field research and b) historical-comparative research. This study analysed historical change over time in the freshwater system in Tshwane and so adopted a historical-comparative research approach.

1.10 Historical-comparative research

1.10.1 Defining the relevance of a historical-comparative research approach to this study

Historical-comparative research was chosen as the best method for this study because it is a broad approach which makes comparisons over time using a multilayer historical timeline, permitting an in-depth understanding of the related theories and it allows aspects to not only be examined in a past historical era but also across different aspects or eras as explained by Neuman (2012:23,322). This is relevant as the study compared aspects of resilience in the Apies River across different historical eras.

Similarly to field research, the historical-comparative research approach does theory building/testing at the same time as data collection, refining the research question as the research process unfolds (Neuman, 2012:23). This is the approach which was followed in this research document and which made it possible to understand how the freshwater system changed over time, what made it change and how these systems can be made more resilient in future.

Another reason why the historical-comparative research approach was chosen is that it is effective in addressing big overarching questions such as in this study: how does a change in connection between humans and freshwater ecosystem services in the urban context affect the resilience of the urban SES? Historical-comparative research also allows for the extraction of unique similarities and features (*ibid.*), and this is also relevant to this study.

The historical-comparative research approach allows foresight into trends and events, which can assist current decision-making, according to Neuman (2012:322), this is relevant for this study which required insight into future management of freshwater resources to contribute to resilience.

1.10.2 Process to conduct a historical-comparative research

Conducting a historical-comparative research study includes the following steps: firstly, conceptualising the object of inquiry by obtaining, for example, initial information about the historical event and, secondly, theorising and formulating what you want to study (Neuman, 2012:329). After gathering the foundational knowledge and initial concepts, the bibliographic study of the historical-comparative research could focus, for example, on specific events and on specific aspects of these events over time (Neuman, 2012:330).

According to Neuman (2012:331), during the process of gathering data, the relevance of the information to the research question/s needs to be taken into consideration as well as the accuracy and strength of the information. In the process, the focus of the research can also shift which may alter the relevance of evidence gathered (*ibid.*).

Secondly, once evidence and data have been captured, they need to be organised through a primary analysis, identifying general themes, and after this the evidence, based on theoretical assessment, needs to be organised as stated by Neuman (2012:332). Thirdly, as the process unfolds, the evidence gathered needs to be synthesised and this is done by refining ideas, creating new theories and developing general explanatory examples (*ibid.*). During the synthesis there are patterns of similarity and patterns that highlight differences that start to emerge, as well as hidden connections and causal forces, according to Neuman (2012:332). After the synthesis is completed, the report is written, which collates all the evidence, arguments and conclusions into a clear and logical story with a persuasive picture (*ibid.*).

1.10.3 Data required for historical-comparative research

The data and evidence that can be used as part of a historical-comparative research approach include: a) statistics and documents such as photographs, maps, academic articles, books and newspaper articles; b) interviews; and c) observations (Neuman, 2012:23).

There are four different types of historical data, as described by Neuman (2012:333): a) primary sources; b) secondary sources; c) running records; and d) memoirs. Secondary sources include the writings of specialist historians who gained their information from primary sources, and are the main source of data on which historical-comparative research relies.

1.11 Analysing qualitative data using the narrative

Data analysis can be described as the process of extracting patterns or generalisations from empirical details in order to present general statements about the world (Neuman, 2012:352).

There are four ways of analysing qualitative data, which include: a) the narrative; b) ideal types; c) successive approximation; and d) the illustrative method (Neuman, 2012:360). This study applied the narrative approach in the analysis of the data.

The difference between qualitative and quantitative data analysis is that qualitative data analysis includes a range of approaches, and so is less uniform and more diverse than quantitative data analysis. Quantitative data analysis includes the application of statistics to assess numerical information, and the use of charts and formulas (*ibid.*). For the purpose of analysing the adaptive capacity of the Apies River according to a historical-comparative research approach the latter is not relevant.

The qualitative research approach which was used involved the use of narrative to analyse qualitative data, based on the approach by Neuman (2012:360). Changes over time in the Apies River were ascertained from documented historical data, and the information was collated and interpreted to specific themes and concepts linked to resilience theory which assisted in the building of and understanding of the overarching theory of the adaptive capacity of the Apies River.

The word “narrative”, according to Oxford Dictionaries (2014), means: “a spoken or written account of connected events; a story.’’ A story, according to Mang and Reed (2012:29) is described as “… a coherent organization of information, and of the relationships and connections between discrete pieces of information and different types of information.’’

The plot of a narrative has a specific beginning, a middle and an end, and in between, the plot contains a specific scope and boundary (University of Maryland, 2014). It is important to decide what the focus of the plot will be as this will determine what information to include that will contribute to the storyline (*ibid.*). There are various plotlines that can be used in a narrative. They include: a) a quest, which is a journey in search of an outcome; b) agonistic conflict which includes a struggle between forces; c) a climax plotline which portrays the building of tension, followed by the relief of the tension (University of Maryland, 2014). The narrative in this study used the journey in search of an outcome as the plotline, as it searched for the reasons for the changes in the Apies River system and the disconnection between the built infrastructure and the freshwater system.

The narrative can also be called a *“natural history* or *realist tale* approach.’’ (Neuman, 2012:360). The narrative approach, as described by Neuman (*ibid.*), took the perspective of telling a story as a sequence of unfolding events, focussing more on a description of what occurred historically than on intellectually abstract theory.

The Apies River narrative applied an analysis of the data approach, typical of the narrative approach as described by Neuman (2012:360), where the actual details of the historical events were captured in chronological order as the events unfold. In the narrative approach, data largely tell the story requiring little analysis and rearrangement of data into different concepts and themes. The narrative approach is about telling the story of naturally unfolding events that occurred. The analysis of the data in a narrative involves, for example, organising and grouping people and events, telling a story which portrays a descriptive picture and contributes to a larger picture and rationalisation (*ibid.* 360, 361).

In a narrative, the data, according to Neuman (2012:360), do not relate strongly to themes, concepts and abstract theories, but relies mostly on the way that data is combined and arranged to depict the story of events. This process makes very little use of interpretation by the writer and abstract thoughts, but rather depicts the actual views and the context of the specific historical events in time, by conveying a genuine sense of the intricacies and circumstances (*ibid.*). The narrative tells the story and depicts two or more historical events in causal and chronological sequence in a way which strengthens intrigue and anticipation (*ibid.*361).

Neuman (2012:361) highlights the positive aspect of the narrative approach which includes: depicting concrete details of events in a full and encompassing manner; the chronological ordering of occurrences; the opportunity to capture many facets of complex events; an appreciation of how different events influence and interact with one another; and an empathetic link to the story as revealed by the data.

The negative features of the narrative approach include that the narrative approach: can be too complex; repeats contradictions and variations of events researched; does not allow generalisation which is necessary for data organisation; limits the use of collective concepts that link to other studies; limits the opportunity for an in-depth examination due to the minimalist analysis; provides an emotional interaction rather than scientific reasoning (*ibid.*).

The content of a narrative includes: a) a summary of the whole story; b) a context describing the specific period, place and circumstances; c) multifaceted events and the relationships between the events; d) an emotional assessment of the importance and value of the narrative; e) a resolution of what occurred after a dynamic high point; and f) an indication that the narrative is concluded (*ibid.* 361).

The value of using narrative to convey a deeper understanding of a place can also be seen in the approach of Mang and Reed (2012:30), who explain that through constructing a "Story of Place'', communities start to develop a meaningful connection and understanding of a place, which evokes a deeper connection and care, making day-to-day changes possible. Secondly, the Story of Place also reveals knowledge of how living systems work and how humans and nature can be aligned to co-exist in a more beneficial manner; and thirdly, the Story of Place provides a platform for communities to co-evolve with their environment in a sustainable manner on an on-going basis.

The value of a story to understanding the context of a place is also reflected by Spirn (2008b), when she refers to the language of landscape: "My eye is drawn to the stories landscapes tell and to the significant details of their narrative." In order to understand the current pressures affecting a system and to understand the resilience of a system, we need to understand where the system originated, how the current state of a natural system came about and what shaped the current system. Historical narrative helps us to unveil the path to the present, and provides knowledge of how to create a more resilient future

The research sourced data through personal interviews, academic journals and websites containing the history of the Apies River in the context of the City of Tshwane. The information and historical maps and photographs were mainly sourced from:

a) A desktop study of policies and spatial plans (including cadastral and land use maps) of the City of Tshwane and national government.
b) Aerial photographs and geographical information system (GIS) maps from the Department of Rural Development and Land Reform (DRDLR): National Geo-spatial Information (NGI); The Unit for Geoinformation and Mapping, Department of Geography, Geoinformatics & Meteorology, University of Pretoria and Google Earth images.
c) Photographs and newspaper articles from the City of Tshwane's library archives.
d) Information on the historical water system, from the Water Research Commission (WRC).
e) The history of the first settlements and the settlement patterns, from historical journals, history websites and the African Room at the University of Pretoria library.
f) Information on the water catchment area of Tshwane from the national Department of Water and Sanitation.
g) Many artists worked in Pretoria in the early years after the establishment of Pretoria and inspiration was drawn from the paintings of some of these artists such as Baines, Wenning and Pierneef who lived and worked in Pretoria.

1.12 Conclusion

The study applied a historical-comparative research method, which is mostly an explanatory approach, which means that it allows for the description of events and cases in terms of a specific theory (Neuman, 2012:23). This was relevant to the study, which used the presence or absence of the principles of resilience to discuss the changes which happened in the Apies River system over time. Historical-comparative research can also be used to question existing justifications and provide new insights, which makes historical-comparative research well suited to the building of new ideas and theories (Neuman, 2012:322). This is relevant as the focus of the study was to provide insight into how future management of the Apies River freshwater system, can be adjusted to contribute to resilience.

The study used a narrative approach, which tell, in a chronological order, the events which occurred over a period in history, and how the Apies River freshwater system interacted with and changed over time in the context of the built environment in Tshwane. The data was analysed and arranged according to the pulse and press disturbances of the Apies River, relating these events to the principles of resilience and describing the impact of these changes on the adaptive capacity of the system. The narrative plotline used a journey approach in search of an outcome; this outcome was a deeper understanding of why the Apies River was disconnected from the built infrastructure of Tshwane.

CHAPTER 4 - HISTORICAL NARRATIVE

1.1 Introduction

This chapter will look at a section of the Apies River as the focal system and will explore the global, regional and local context of the river. It will also look at the natural systems which form a unit with the Apies River such as its tributaries and wetlands. It will further discuss the state and health of the Apies River.

Thereafter, a historical overview of three different eras of the Apies River will be presented. The different historical eras of the Apies River have been defined, according to the Resilience Alliance (2010:19,20) approach, as eras existing between historical transition points which defined a change in the resilience of the Apies River. The historical eras which were identified are:

a) First era: The Apies River as a natural system (1855–1909), covering 54 years of history;
b) Second era: The Apies River as a modified system with a change in the connection between the river and the urban system (1910–1970), covering 60 years of history; and
c) Third era: The era characterised by failed regeneration attempts (1971–2014), covering 43 years of history.

1.2 Background to the Apies River

1.2.1 The Apies River as the focal system: global, regional and national context

Globally, freshwater systems cannot meet human and ecosystem demands any more, a trend that will worsen should current consumption patterns persist (MEA, 2005a:6). This trend is also evident in South Africa, and what makes it even more challenging is that South Africa is a semi-arid country, with an average annual rainfall of 450 mm for the whole country, well below the global annual average of 860 mm (DWAF, 2004:15).

The combined flow of all the rivers in South Africa is less than half that of the Zambezi River, one of the closest large rivers in southern Africa (*ibid.*). The scarce freshwater systems in South Africa are under pressure with 57% of the river ecosystems and 65% of South Africa's wetland ecosystems in danger (Nel *et al.,* 2011:iii). South Africa has also limited groundwater resources with 80% of its groundwater reserves unavailable due to geologically hard rock structures and groundwater is under pressure from an increase in pollution and decrease in yield (DWAF, 2004:15).

Figure 13 shows the water management areas (WMA) in South Africa with water transfers taking place between the various catchments to meet water consumption requirements. The map shows the Crocodile West and Marico WMA, where the Apies River lies. A total of 700 million m^3 per annum of water is transferred into the catchment from the Upper Vaal WMA and the Olifants WMA, and 10 million m^3 per annum is transferred out of the WMA, into the Limpopo WMA and Botswana (DEA, 2007).

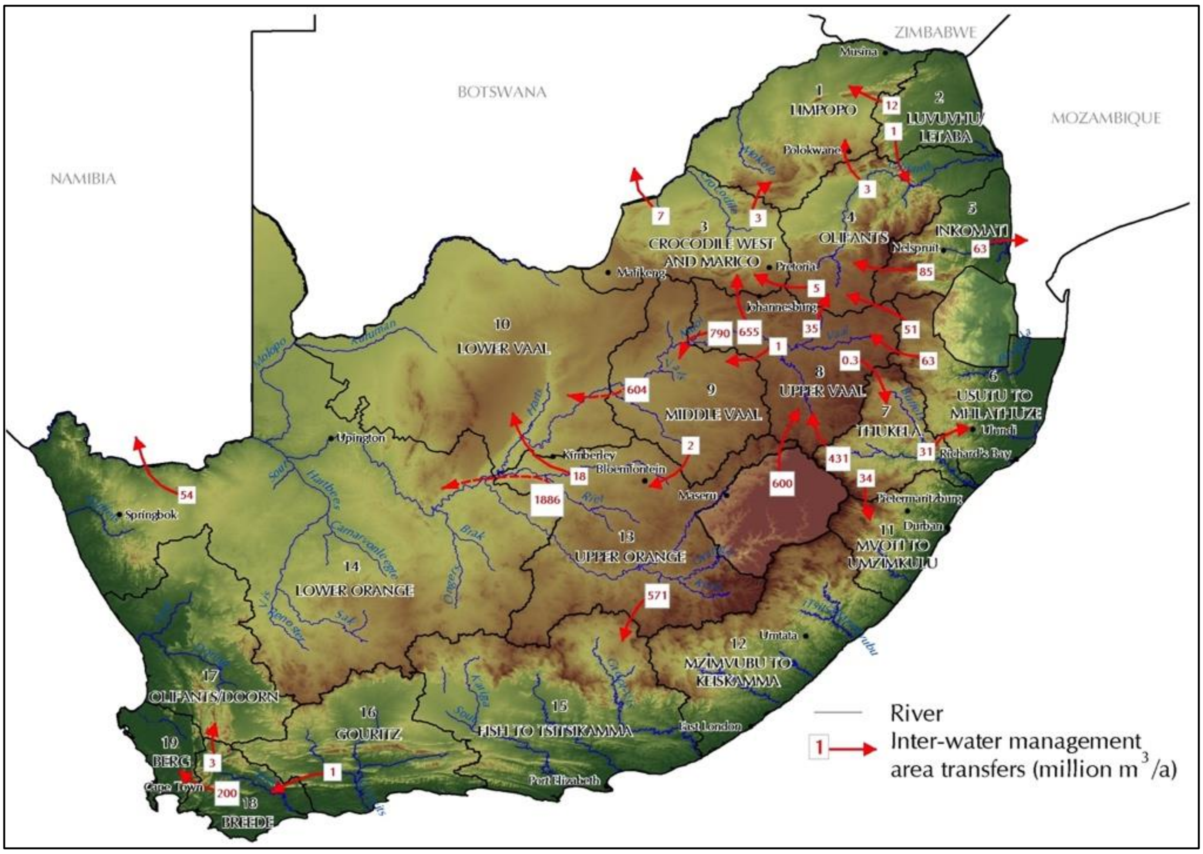


Figure 13: Water management areas in South Africa and inter basin transfers of water (Source: DEA, 2007)

For many years South Africa's urban areas and industries developed with a disconnection from freshwater ecosystems. The influencing factor for cities to develop was not the availability and proximity of large water resources, but rather mineral availability in the area or the political boundaries of the past (DWAF, 2004:15). This form of planning, which did not take into account the ecological reserves and natural processes within a catchment, together with mismanagement, resulted in many cities in South Africa, including Tshwane, not being self-sufficient in terms of their own water supply (SACN, 2011:91). South Africa's cities are progressing towards a socio-ecological challenge which is that by 2025, in more than 50% of South Africa's WMAs, including the Crocodile West and Marico WMA, demand will exceed water availability. This projection is illustrated in Figure 14 and is based on a future scenario taking into account the current transfers of water, population growth and the economic development trends of the year 2000 (DWAF, 2004,:D3.4). Currently, water demand in 18 of the 19 WMAs in South Africa exceeds the naturally available surface water and groundwater capacity, and the WMAs rely on massive water transfers from other catchments (DWAF, 2004:15,17). It is only the Mzimvubu to Keiskamma WMA which does not depend on inter-catchment transfers from other WMAs (DWAF, 2004:15)

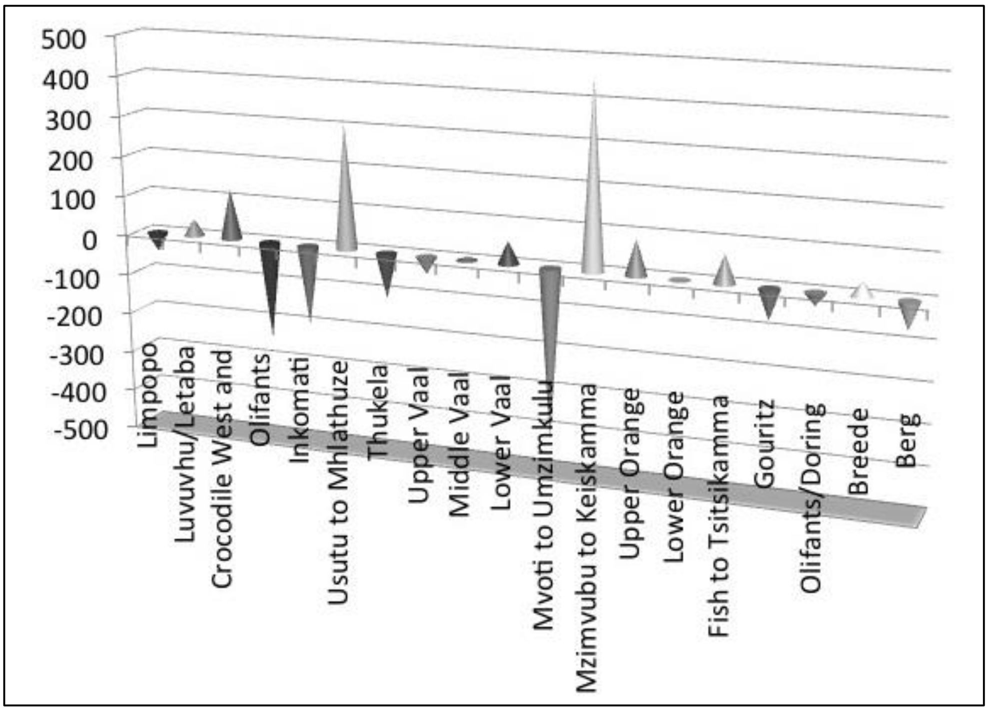


Figure 14: Reconciliation of water requirements and available water for the year 2025 base scenario (million m³/a) of all the water management areas in South Africa (Source: DWAF, 2004:40)

With an increase in urbanisation, the quality of rivers in South Africa will decrease because rivers are over-developed and over-utilised, modified by dams and weirs and incompatible land use affects the flow regime of rivers, in many cases resulting in deterioration of the water quality and aquatic life in rivers (DWAF, 2004:20).

1.2.2 The Apies River as part of the Apies/Pienaars River sub-catchment

The City of Tshwane falls within the Crocodile (West) and Marico WMA, that flows to the Indian Ocean (Stadsraad van Pretoria, 1952:237). The City of Tshwane lies within three sub-catchments, which are: a) The Apies/Pienaars River sub-catchment which drains the central part of Pretoria b) the Moreleta Spruit sub-catchment which drains the east of Pretoria, and c) the Hennops River which drains the Centurion area. The Moreleta Spruit and the Apies River both flow north into the Pienaars River (Dippenaar, 2013:39).

The study area includes the A23E and A23D quaternary WMA areas, and lies within the Apies/Pienaars River sub-catchment, as highlighted in Figure 15.

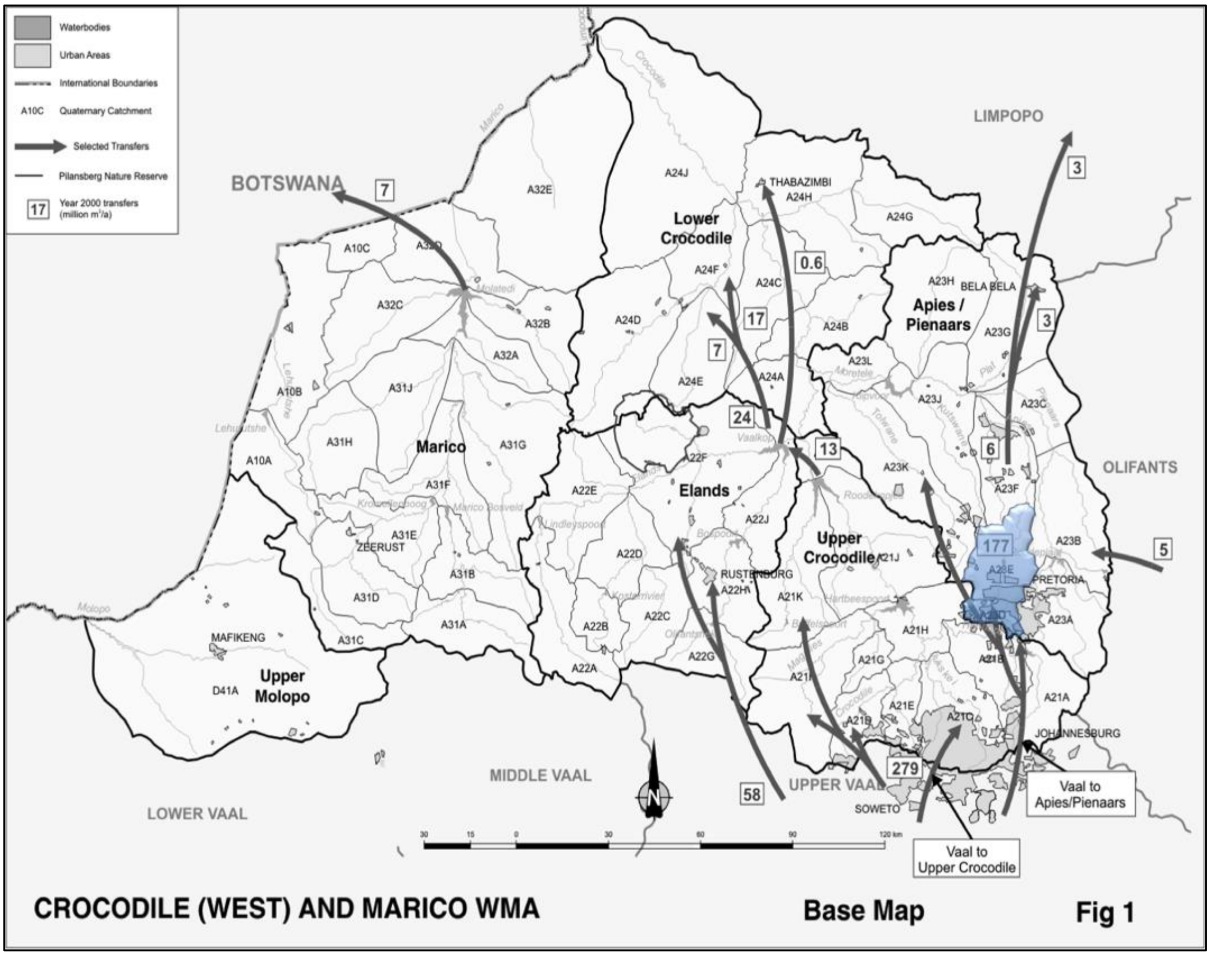
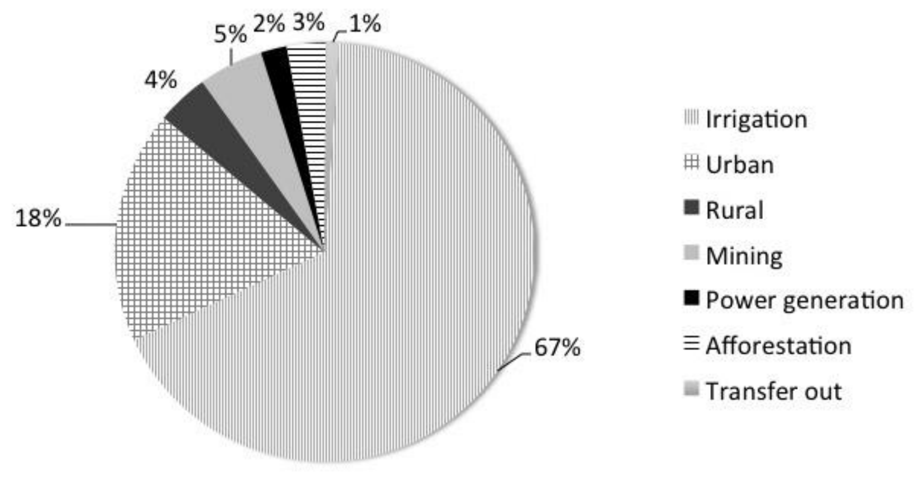


Figure 15: Base map of the Crocodile (West) and Marico WMA (Source: Adapted from DWAF, 2004:D3.1)

Besides the Apies River, the Apies/Pienaars River sub-catchment contains the following rivers: Pienaars, Tshwane, Kutswane, Moretele/Plat and Tooy Spruit (River Health Program, 2005:23).

1.2.3 Consumption of water in the City of Tshwane

In terms of water use in South Africa, statistics indicate that the most water is used for irrigation (67%) while 18% is used for urban requirements and 5% allocated to transfers to neighbouring countries (DWA, 2013:9). The contribution of water needs in South Africa is illustrated in Figure 16.



1) Include the component of the Reserve for basic human needs at 25lt/p/day
2) Mining and bulk industrial that are not part of the urban system
3) Includes water for thermal power generation only

Figure 16: Contribution and current water needs of the major economic sectors in South Africa (Source: Adapted from DWA, 2013:9)

Although irrigation is nationally the dominant water user, in the Apies/Pienaars River WMA the dominant need is water for urban use, which amounts to 211 million m^3 per annum and is five times the amount required for irrigation (DWAF, 2004:D3.3). The water requirements in the Apies/Pienaars River WMA are illustrated in Figure 17.

The bulk of the water consumed in the City of Tshwane is imported. In 2011 the City of Tshwane received 81.3% of its water from Rand and Magalies Water and 18.7% from underground water (springs and boreholes) (City of Tshwane, 2011:2), which means that the WMA within which the City of Tshwane is situated, cannot sustain the city's water requirements. The Water from Rand Water is transferred from the Tugela River in KwaZulu Natal, the Lesotho Highlands Water Project (LHWP) and the Orange River, which transfers water to the Vaal Dam (Rand water, n.d.)

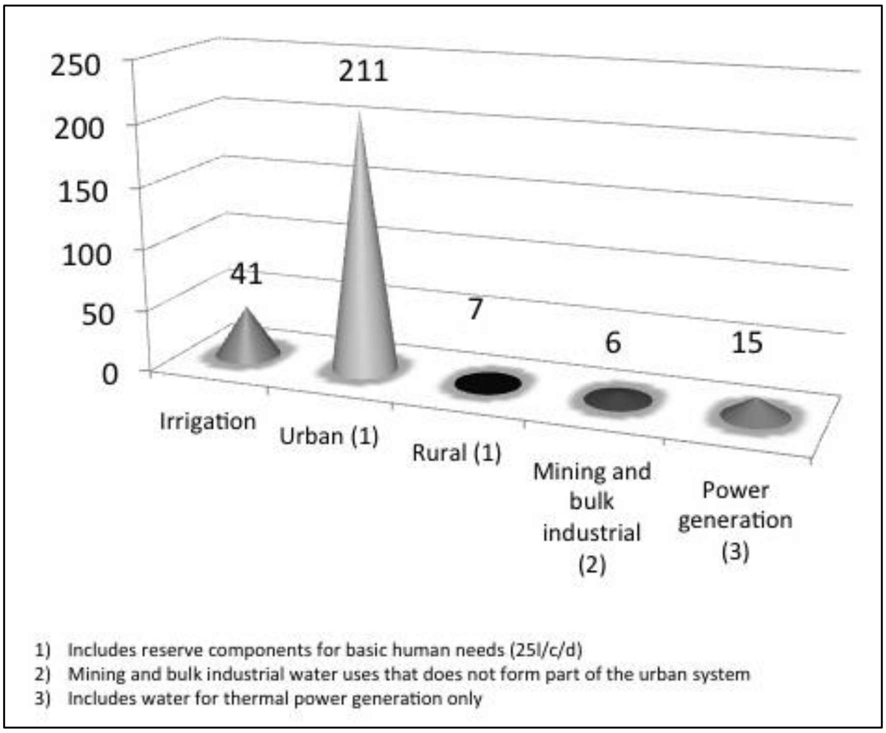


Figure 17: Water requirements year 2000 (million m³/a) for the Apies/Pienaars River WMA (Source: Adapted from DWAF, 2004:D3.3)

It can be concluded that the Apies River is in a WMA where very little natural yield exists but with a large amount of mean annual runoff. Runoff occurs when the water cannot permeate the soil and is the biggest cause of erosion and return flows from land use activities in the area, as indicated in Figure 18. The runoff in this catchment is diverted away into stormwater channels and then into watercourses, prohibiting the water to sustain natural ecological processes. This WMA does not function in a sustainable manner. Mean annual runoff and return flows in this WMA amount to 112 million m^3 per annum which is nearly as much as the amount of water that needs to be imported into the WMA (182 million m^3 per annum) from other water management areas, a costly and ecologically destructive process.

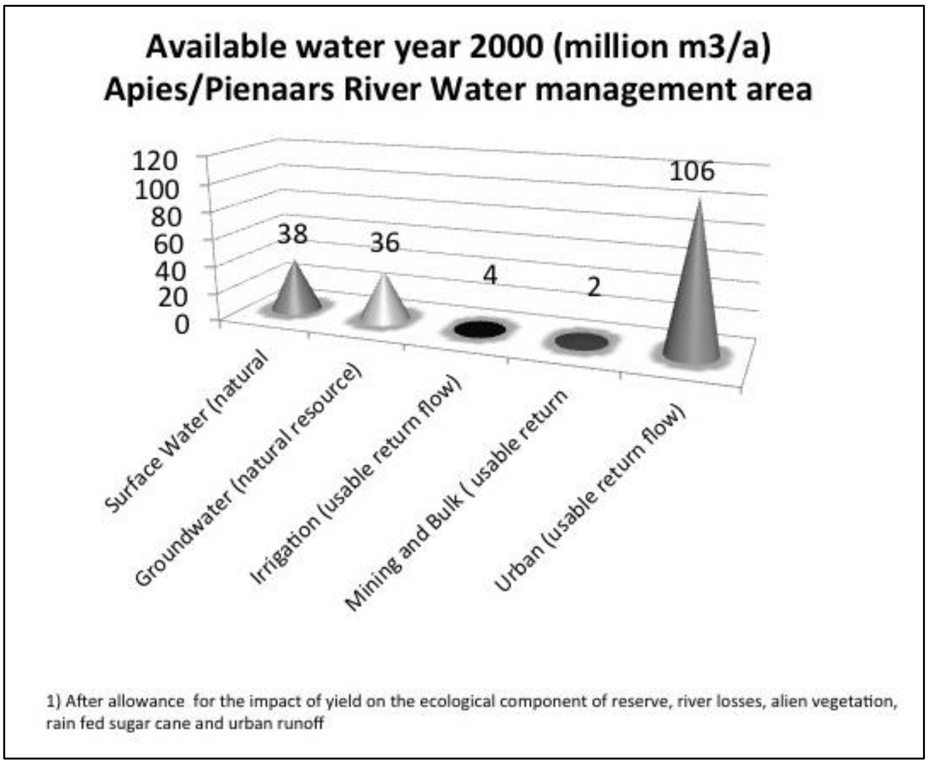


Figure 18: Available water in year 2000 (million m3/a) in the Apies/Pienaars River WMA (Source: Adapted from DWAF, 2004:D3.3)

1.2.4 Tributaries of the Apies River

According to Van Veelen, Le Grange, Grobler, Hein and Baker (2004:2-1), the Apies River originates from tributaries in the eastern, southern and western suburbs of the City of Tshwane. The two fountains in the Fountains Valley in Groenkloof also contribute to the flow of the Apies River. The river runs north through the CBD and is fed along its course by various tributaries until it reaches the Wonderboompoort. Once through the Wonderboompoort, the Apies River is joined by the Wonderboom Spruit coming from the east, and the Boepens Spruit coming from the west before entering the Bon Accord dam, which is 15 km north of Pretoria. From here the Apies River flows further north and joins the Pienaars and the Plat Rivers which become the Moretele River and eventually becomes the Crocodile River.

One of the main tributaries of the Apies River is the Walker Spruit, which originates in New Muckleneuk and joins the Apies River just south of Church Street. It was named after a surveyor, Arthur Hamilton Walker. Another main tributary is the Steenhoven Spruit, which originates on the hillside in Mitchell Street, flows through Pretoria West and Marabastad and joins the Apies River at the Daspoort sewage works. The Steenhoven Spruit got its name from the brickworks that were situated in its vicinity. During heavy or prolonged rains these small streams could transform into swollen rivers in very little time, taking with them anything in their path (Van der Waal & Associates, 2000:25). Figure 19 illustrate the Apies River with some of its tributaries where it flows through the tightly knit urban fabric of the CBD from where it flows in a northerly direction through Daspoort.

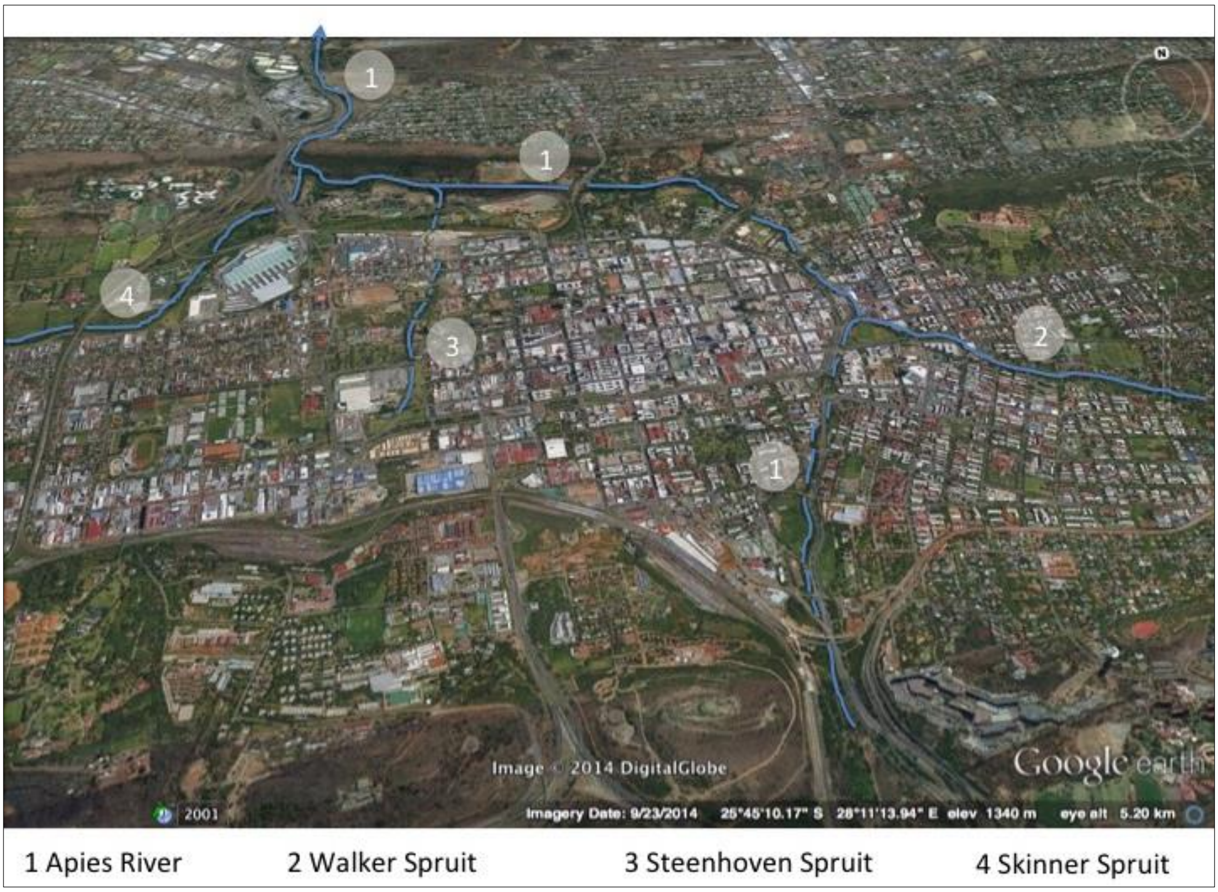


Figure 19: Apies River and its tributaries running through the CBD of Pretoria (Source: Google Earth 7.1.2.2041, 2014a)

1.2.5 Wetlands in the City of Tshwane

Wetlands, together with rivers, lakes, subsurface water and estuaries comprise the components of freshwater ecosystems (Nel *et al*., 2011:1). These components contribute to the biodiversity of the freshwater ecosystem and, according to Venter (2007:2,3), play a very important role in contributing to service delivery in the urban context, providing flood attenuation, recharging of groundwater, habitat for biodiversity, an environment for recreation, resources which can be harvested for livelihoods and purification of surface water contaminated as a result of inadequate sanitation.

The study area, quaternary catchment A23D, which drains 14,484.7 ha to the Apies River south of Daspoort, contains four wetlands which covers 124.9 ha. The wetlands consist of two valley bottom wetlands and two seepage wetlands. The wetlands relating to the Apies River are under constant pressure from the dominant land uses such as roads, residential development, recreational facilities and sewage plants. The pressures on the wetlands of the Skinner Spruit area consist of agricultural activities, golf courses, roads, residential developments, railway and power lines. Pressures on the wetlands along the Walker Spruit are dams, residential development and roads (Grundling & Venter, 2007:69). The Apies River basin, draining the CBD of Pretoria, was identified as the water basin in Tshwane with the highest loads of contaminants and in most need of the rehabilitation of wetlands to reduce bacterial load in the water (Venter, 2007:II, III).

Quaternary catchment A23E, which is north of the CBD, covers 21,926.5 ha. There are 17 wetlands in this area which is mainly drained by the Apies River and consists of the upstream portion of the Bon Accord dam. These wetlands include ten valley bottoms, six seepage wetlands and one pan. The functional wetlands in this catchment contribute to flood control through the drains and canals and the management of the water table in the floodplain wetland, situated upstream from the Bon Accord dam (Grundling & Venter, 2007:76). The status of these wetlands is poor with 23% of these wetlands threatened and 65% identified as having problems. Rehabilitation of these wetlands poses a challenge because of their close proximity to built-up urban areas (Grundling & Venter, 2007:77). The dominant land use and perturbations which impact negatively on the wetlands in this area along the Apies River are recreational facilities, roads and bridges, residential development, agriculture, industries, canals, dams and railways (Grundling & Venter, 2007:76).

It has been noted that the main disturbances to wetlands in the City of Tshwane are land uses such as roads which impact 70% of the wetlands in the area. Wetlands are affected by roads because of increased stormwater causing erosion, which changes the flow pattern of the wetlands and causes the wetlands to dry out (Venter, Prinsloo, Grundling, & Barnard, 2005:99). Zedler and Kercher (2005:50) find that in general, when wetlands are lost or degraded it affects biodiversity, the natural water purification system, flood management and the carbon sink function.

Rehabilitation of wetlands is costly and not a high priority for the City Council of Tshwane. There is a current proposal to rehabilitate 43 wetlands but the proposal exceeds the available funds of the City Council (Venter, 2007:11,12).

1.2.6 The current state and health of the Apies River

> *Not many a South Africa city can boast a river running, right through the heart of it. But do we make the most of what could be a beautiful part of Pretoria, to be enjoyed by all? No. We have allowed it to become a dangerous rubbish dump* (Goodman, 1992).

The Apies River has over time been transformed from the natural flowing river that it was when the first Ndebele settlers came to live on its banks, to being partially converted into a concrete channel where it runs through the central part of the city. The channel continues as far as the Wonderboompoort where the river continues to flow north as a natural river (Van Veelen *et al.,* 2004:2-1).

The ecological status of the Apies River has been altered mainly through anthropogenic activities of urbanisation and the alteration of the flow patterns of the river as a result of canalisation of the riverbed (River Health Program, 2005:24). The impact of urbanisation can be seen in the morphology of the Apies River downstream from development, caused by the canalisation, which increased the peak water flow, forcing the river to search for an equilibrium (Van Veelen *et al.,* 2004:2). In general, urbanisation and modifying rivers into channels causes an overload of water discharged in a short period of time downstream and has the negative impact of flooding downstream. This alteration of making the channel deep and straight triggers the stream to regain its balanced flow and it does so by deepening and widening the stream channel through erosion and by depositing sediment downstream. The deepening of the channel can in cases also cause draining of wetlands in the area (Dunne & Leopold, 1978:404).

Other constraints in the Apies River system are the altering of the energy flow of the river between the Wonderboompoort and the inlet of the Bon Accord dam, which forces the river to disperse its energy between these fixed points. In order to compensate for these constraints energy can only be disposed of by increasing the river's length or changing its slope, which happens through horizontal/lateral movement and the process of erosion deposition (Van Veelen *et al.,* 2004:2).

The water quality of the Apies River has been in a poor condition for many years. This is evident in the State of the Environment Report for the City of Tshwane, 2001–2002, which indicated that as a result of urban development the bacteriological quality deteriorated with an increase in faecal coliform count which is well above the 100 count and a risk for bathing and washing laundry. At Skinner Street the faecal coliform count was 6,000 per ml and at

Onderstepoort 32,141 per ml (City of Tshwane, 2004:100). Recent evidence shows that the situation has not improved when dangerously high counts of *E. coli* were found in the Apies River in July 2015, caused by leaking sewage sludge from the Rooiwal water treatment plant. There is a concern about the effect of this contamination on the drinking water of the Hammanskraal community and the irrigation of vegetables (Frankson, 2015).

In another study conducted between March 2003 and February 2004 in the Apies River between Wonderboom and Hammanskraal, the water was found to be so polluted that it was not suitable for human consumption or for the irrigation of food crops, especially not those consumed raw, according to Tshivhandekano (2006:26,51). Faecal coliform and E.coli contamination exist throughout the year and contamination by the human pathogen viruses, Adeno, Entero and Rota. The Entero virus was found on irrigated food crops along the river causing a risk of food-borne disease if the contaminated fresh produce was consumed. Water-borne disease pathogens can be prevented by sufficient water treatment processes, and water contamination by bacteria, viruses and protozoa parasites can be prevented by avoiding the development of informal settlements along watercourses. Heavy metal and chemical pollution contamination can be prevented by monitoring industrial pollution (Tshivhandekano, 2006:65-67).

This vulnerability to pollution of households which are located at the lower reaches of the Apies River Basin is highlighted in a study by Venter (2007:69) where she finds that the severe pollution pressure which is caused by the high percentage of waste water treatment works along the river, releasing 93% of the effluent from these treatment works directly into the Apies River, are much higher compared to any other pollution source.

There is not only pressure on the quality of this urban water system, but also pressure on the quantity of the water, with an increased demand for water for residential use as well as from water-thirsty invasive plants (City of Tshwane, 2004:100). In order to increase the ecological integrity of the stretch of the Apies River from the Wonderboompoort to the Bon Accord dam, a rehabilitation project was identified by the City of Tshwane in 2004 to combat the effects of pollution, flooding, erosion and sedimentation deposition at the inlet of the Bon Accord dam (Van Veelen *et al.,* 2004:1-3). In 2010 Habitat Landscape Architects was appointed by the Council to develop a Rehabilitation Framework for the Apies River from the Wonderboompoort to the Rosslyn Bridge in order to combine the hydrological model and design with regenerating the ecology of the Apies River.

During 2005, another report, the State-of-Rivers Report, which was compiled by the River Health Program under the auspices of the Department of Environmental Affairs and Tourism, also concluded that the status of the overall ecology of the Apies/Pienaars water management area was poor and that it was caused by pollution from urban stormwater runoff, sewage spills and waste from the urban area (Pretoria Central), settlements (Atteridgeville) and industry (ArcelorMittal). The functional integrity of the river was further compromised by the straightening and canalisation of the river's course where it runs through the urban area, which increased the flow of the water, and resulted in downstream change of the river channel and shape of the river bed (River Health Program, 2005:24).

The 2005 River Health Program, State-of-Rivers Report of the Department of Environmental Affairs and Tourism highlighted that the Apies River has also been affected by the poor integrity of the riparian vegetation and riparian zone which were degraded or destroyed completely when the river was straightened into a channel, prohibiting the river's natural flow and flood patterns. The riparian vegetation has either been degraded by the encouragement of invasive species such as mulberries, jacarandas and Sesbania species or it has been removed and replaced by development (*ibid.*).

The ecological importance and sensitivity of the Apies/Pienaars water management area is marginal to low, which means that there is a low diversity of species and habitat in this management area. However, wetland habitats are present and there are plans to rehabilitate the Apies River near the Bon Accord dam and the Wonderboom Nature Reserve, which contributes to the natural integrity of the Apies/Pienaars water management area (River Health Program, 2005:24)

Management responses have been identified to minimise the impacts of change in the Apies/Pienaars management water area which include to: a) restore the riparian vegetation and natural morphology of the river; b) reduce litter and waste from settlements that pollute the river; and c) manage urban runoff, which degrades the water quality (*ibid.*).

The study explores the history of the Apies River, which was formed through its interaction with the built environment and telling the story of how the current state of the freshwater system came about. The story explores what caused these changes and how the system dealt with the pressures on the system from outside. By getting answers to these questions, it will be easier to understand the resilience and adaptive capacity of the system and the dynamics that might influence the system to change in future.

Table 6 provides a summary of the water quality issues in the Crocodile (West) and Marico water management area.

Table 6: Summary of water quality issues in the Crocodile (West) and Marico WMA

Water quality issue	Driver	Effect
Eutrophication	Wastewater treatment works; intensive agriculture; fertilizer use; dense urban sprawl; un-serviced sewage.	Algal growth; smell; toxic algae; additional cost for water treatment; taste and odour; irrigation clogging; aesthetics and recreational water users.
Microbial contamination	Wastewater treatment works; informal, dense settlements; vandalism of sewerage reticulation system and pumping infrastructure; sewage spills into receiving streams.	Recreational users (human health risk); washing and bathing; poor bacterial water quality; impacts on downstream users; low dissolved oxygen and ecosystem impacts; water-borne diseases.
Salinisation	Mines – operational and non-operational; wastewater treatment works; agricultural runoff	Water treatment costs; soil salinity; irrigation system clogging
Toxicants	Pesticides; industry; DDT for malaria.	Fish killed; human health threat; KNP mammals; bioaccumulation.
Suspended solids (turbidity, sedimentation)	Land degradation and over grazing; soil erosion; mining; informal, dense settlements, subsistence agriculture.	High suspended solids during high flows; silting up of rivers, weirs and dams; loss of habitat; increased water treatment cost; irrigation clogging.

Source: Adapted from DWA, 2013:40

Embracing the concept of resilience when designing cities is useful in allowing for their responsiveness and adaptation to the changing needs of people and ecosystems (Spirn, 2011:20). Designers should "look deeply at the surface of things, and also beyond that surface to the stories landscapes tell, to the forces that shape human lives and communities, the earth, and the universe …" (Spirn, 2008a).

A historical overview of the Apies River follows, depicting the three different eras of the river's existence as part of the Tshwane SES.

1.3 The first era, 1855–1909: The Apies River as a natural system

1.3.1 Introduction

This section will describe the first of the three eras of the Apies River, which covers the period 1855 to 1909, when the river still existed as a natural system connected to the settlement through which it flows. Figure 20 shows the natural state of the Apies River where it flowed through the Fountains Valley with stones in the water and shrubs on its embankment.

There is evidence to indicate that civilisations in the Apies River valley date back as far as the Stone Age (Van der Waal, 1996b:3). Later, in the 1600s, the Bakwena tribe (Western Sothos), ruled the area between the Apies, Crocodile and Pienaars River, which was described as a peaceful area abundant with water and game.

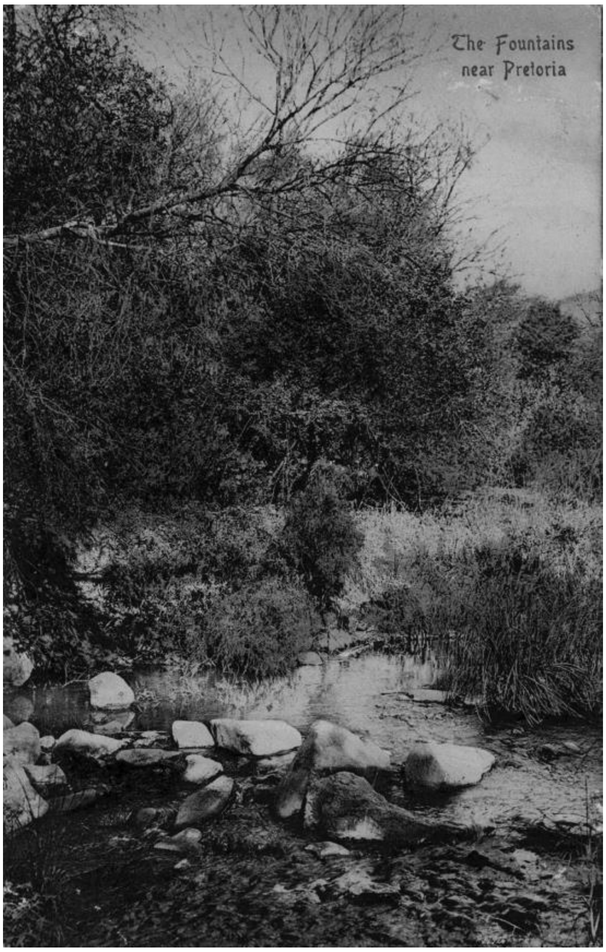


Figure 20: The Apies River in Fountains Valley (n.d.) (Source: Anon, 2013a)

Then, during the 1800s, Mzilikazi, also referred to as Mosilikatse Silkaats, the leader and founder of the Matabele tribe, arrived in 1825 from Zululand and reigned in terror, killing almost the whole Bakwena tribe by 1826. Mzilikazi remained here until he was chased by the Voortrekkers, Potgieter, Maritz and Uys, to the north in 1837. Mzilikazi's capital contained permanent kraals and was situated between the Apies River and the Crocodile River. His fortress, called Kungwini (the place of mist), stood on the banks of the Apies River where Pretoria North is today. During the 1800s there were also many travelling explorers who passed through the area, such as the two Scottish hunters and traders, Robert Schoon and William McLuckie, who arrived from Grahamstown in 1829; Sir Andrew Smith, a military doctor, natural scientist and explorer who came to the Apies River area in 1835; and then also Sir William Cornwallis Harris, a traveller, author and artist, who wrote *The wild sports of southern Africa* about the Cashane mountains (Magaliesberg) and the great Matabele king. It was published in London in 1839 (Andrews & Ploeger, 1989:3).

Pretoria in those days was also part of an important wagon route to Delagoa Bay which crossed the Apies River close to Pretoria, and the abundance of water and grazing provided refreshment for travellers and transport riders (Haarhoff *et al.*, 2012a:18). Even before the establishment of Pretoria, early transport riders and travellers would make use of the water provided by the Apies River and the natural grazing as an overnight stop (Haarhoff, Juuti & Mäki, 2012b:770).

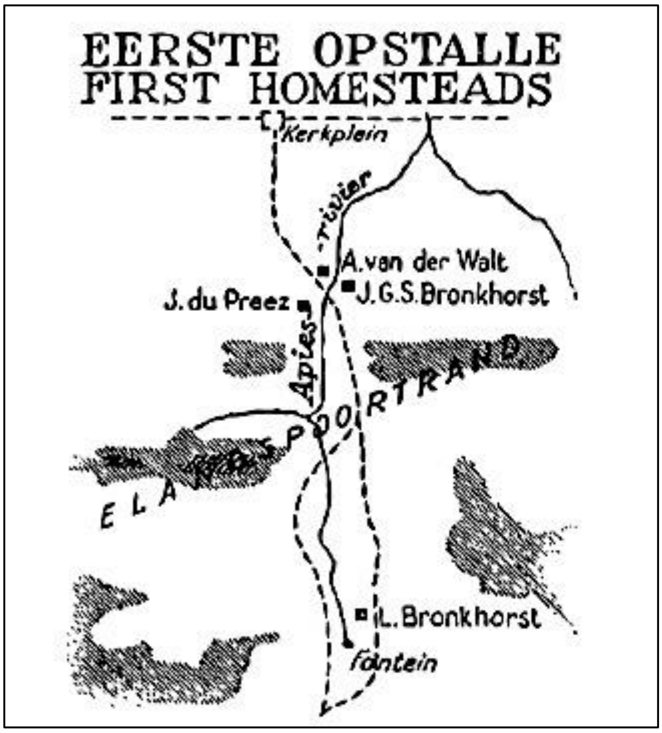


Figure 21: First homesteads in Pretoria along the Apies River in 1855 (Source: Adapted from Punt & Manser (n.d.), Map of Pretoria1855–1955)

According to Coetzee (1992:14), the first Voortrekker settlers arrived in Pretoria between 1838 and 1842, and settled in the Fountains Valley where they erected their tents and houses made from poles next to the clear water of the Apies River. It was during this time, in 1839, that Lucas Bronkhorst built his home next to the Apies River (Van der Waal, 1996b:3). The fountains, according to Bolsmann (2001:9), delivered water at a rate of 25 Ml per day. These two strong fountains, on the farm Groenkloof, originate in the dolomitic strata, which are divided into eastern and western compartments which are 500 m apart, separated by prominent dykes, and are called the upper and lower fountains. The two springs in the Fountains Valley supplied water to Church Square by means of a furrow, which is 4,800m away with a 1% fall, which helped with gravitational flow, and where the first residents settled. To date these two fountains are responsible for the supply of water at 40 Ml per day to the CBD, with no need for purification other than chlorination (Haarhoff *et al.,* 2012a:18-19). Today, the upper and lower fountains supply water to 5,000 people in the inner city of Pretoria (Dippenaar, 2013:56).

Because of the abundance of water, the Apies River became the centre for the establishment of the then City of Pretoria. The Apies River determined the position of the first settlements with the city centre placed in the elbow of the river, this is illustrated in Figure 25. On 16 November 1855, the City of Pretoria was officially proclaimed on the banks of the Apies River (Bolsmann, 2001:9). Marthinus Wessels Pretorius, the son of Commandant-General Andries Pretorius, was the driving force behind the establishment of the new capital of the Zuid-Afrikaansche Republiek in the Apies River valley and motivated it to the *Volksraad* (the national council) stating that it is ideal "… due to its abundant water supply …" (Haarhoff *et al.,* 2012a:18).

1.3.2 The first era: A water catchment area with natural vegetation and rich biodiversity

Descriptions of the character of the landscape during this era provide an indication of the health of the freshwater system in the water catchment. It was described in the 1840s as natural and lush, and the area of Church Street in the centre of Pretoria, where the first houses were built, was covered in *bontveld* [scientific name unknown], which included the sweet-scented *buffelpeer* [scientific name unknown, it is assumed that it was most probably *Dombeya rotundifolia*] with its white flowers. In 1844, the Apies River was described as a river covered with dense and lush vegetation (Visser, 1992:18). There were also deep pools of water in places along the river and the banks downstream were densely grown with, *Combretum erythrophyllum, Senegalia karroo, Ziziphus mucronata,* reeds, sedges and brambles, the latter which was harvested and eaten; in some places the trees were so dense that the canopies blocked out the sky (Coetzee, 1992:14). The banks of the Apies River also became the place where lions were hunted on Saturdays and Wednesdays (Coetzee, 1992:14;16, 18). There were also descriptions of the hills and the valleys as covered in a dense forest of *Acacia* spp*.* trees (Visser, 1992:18).

During these years the valley did not only provide productive food systems and a healthy, natural freshwater system for the inhabitants but it was also a place which provided cultural and spiritual fulfilment to the people in Pretoria. The Wonderboom and the Fountains Valley became popular places to spend leisure time during the late 1800s and early 1900s, with all-day picnics and dancing in the evening (Jeppe, 1906:7). Groenkloof Spruit, in the Fountains Valley was described as a pleasant place, with its abundance of trees, plants and rich biodiversity of wild ducks and water birds and finch nests hanging from the trees (Coetzee, 1992:15). Many picnics were also held during 1877–1880 in the shade of the treed covered banks of the Apies River (Pretoria City Council, 1955:73).

Figure 22: Pretoria 1855 painted by Frans Oerder, Oil on Canvas, 114 x 165 cm, Pretoria Art Museum (n.d.) (Source: Bolsmann, 2001:124)

Figure 22 is a painting by Frans Oerder of what Pretoria must have looked like in 1855, based on the descriptions of the first settlers as they arrived in Elandspoort and the Fountains Valley. It depicts a scene with campfires, ox wagons, a tent, an eland, a kudu and a river (Bolsmann, 2001:123). By 1855, Pretoria had 80 houses and 300 residents (Njeru, 2014).

The Apies River was an inspirational theme for paintings, linocuts and sketches. The painting in Figure 23 shows the river winding through a natural landscape with steep slopes, with Meintjeskop, a hill close to the centre of Pretoria, in the background and thorn and pine trees in the foreground (Bolsmann, 2001:135). According to these paintings, the Apies River in the centre of the city used to flow between steep slopes before it was canalised, this is confirmed by Carruthers (1990:47). Despite the eroded banks, the river was still a clear stream and Carruthers (1990:47), further describes that the river had a brisk and clean flow through the urban area due to the natural fall from the Fountains Valley towards the Wonderboompoort. Jansen van Vuuren (2015) also supports this and states that the erosion of the riverbanks was most probably caused by the fluctuation of the water level and the increase in the velocity of the water after a rainstorm. Therefore under circumstance of normal flow there would not have been erosion and the flow of the river would be clean. Van der Waal (1996b:3) also indicated that the rains in 1909 caused erosion in many of the banks of the river.

Figure 23: The Apies River with Meintjeskop painted by J H Pierneef, Oil on Masonite, 50x65cm, Collection Pretoria Art Museum (Source: Bolsmann, 2001:135)

A 1909 painting, by Hugo Naudé, illustrates what the Apies River looked like at the time. The painting depicts Meintjeskop in the background, shows eroded riverbanks caused by strong floods and depicts exotic *Eucalyptus sp.* on the edge of the river (Bolsmann, 2001:135,136). The introduction of the alien *Eucalyptus* spp*.* trees in the riparian zone of the Apies River by 1909, is an indication of the type of challenge that the freshwater system already had to cope with. According to Chamier *et al.* (2012:345) alien invasive trees in the riparian zone of a river, such as the Eucalyptus spp. in this painting, affect the river system in the following ways: a) they decrease the flow of water as the deep root systems of the exotic species extract water from the underground water supply, decreasing the source of base flow which the river needs to sustain itself in the drier seasons; b) exotic species in the riparian zone contribute to the loss of indigenous riparian vegetation; and c) exotic species increase biomass, increasing the impact of fires and therefore erosion.

Figure 24: Apies River painted by H Naudé, Oil on Canvas, 35x45cm, 1909 (Source: Bolsmann, 2001:135)

1.3.3 The first era: Naming of the Apies River

Throughout the history of the Apies River, various settlements were established on the banks of, or in the vicinity of, the river. These communities gave the river different names. The Nguni-speaking people named the Apies River, Tshwane, which means “little ape”. This was later translated into Afrikaans as *Apies* which is still the name used for the river today (Van Veelen *et al*., 2004:2-1). It is believed that the name Tshwane derived from the blue vervet monkeys which roamed the *Celtis africana* forests adjacent to the river (Andrews & Ploeger, 1989:10; Engelbrecht, Agar-Hamilton, Pelzer, & Behrens, 1955:247). When the Matabele arrived in 1825, the Apies River was called *Enzwabuklunga[u]* (Andrews & Ploeger,1989:19). It was also called *Zubuhlung*u (Van der Waal & Associates, 2000:23) as well as *Entsabotluku* (Raper, n.d.). All of these names translate as “something that hurts” or “something painful”, referring to the sharp dolomitic stones at the two fountains in the Fountains Valley which hurt the feet of the water bearers (Van der Waal & Associates, 2000:23; Raper, n.d.) or simply hurt your feet when crossing the river (Andrews, 1985a:19). It is also believed that in Sesotho the Apies River was called *Enswabasloto*, which also has a resemblance to the meaning “water and pain”, referring to the pain experienced crossing the river or to the pain experienced after circumcision (Garner, 1996:3).

The Apies River annotation first appeared on a map in 1857 and was recorded as the AapRiver (Engelbrecht *et al.,* 1955:247) and later the name was spelled Aapies Rivier. The Apies River was mapped again 23 years later, and appeared on an 1880 Compass Sketch Plan of Pretoria, shown in Figure 25, which was drawn up during the British occupation, compiled by Great Britain’s Army Royal Engineers. This map referred to the Apies River as the “Anapjis River’’ (Great Britain, Army Royal Engineers, 2009). The word “Anapji’’ refers to “Goose and Duck Lake” which is connected to an ancient garden constructed in 674 in South Korea, which is now a world heritage site. The Anapji gardens were constructed during the rule of Munmu, the 30th king of Silla, and consist of a pond and rare plants and animals which creates a garden with a pleasant atmosphere and tranquillity where people come and relax (Korean Office of Cultural Properties, 2014). Could it be that this map draws the connection between the lush and beautiful Apies River and this ancient garden of tranquillity?

In 1899, Winston Churchill called the Apies River the “Mighty Apies’’ referring to the strong flow of the river when he swam across the river on 12 December 1899, in his escape from the Boer military offices where he was kept a war captive (Pienaar, 2010:15).

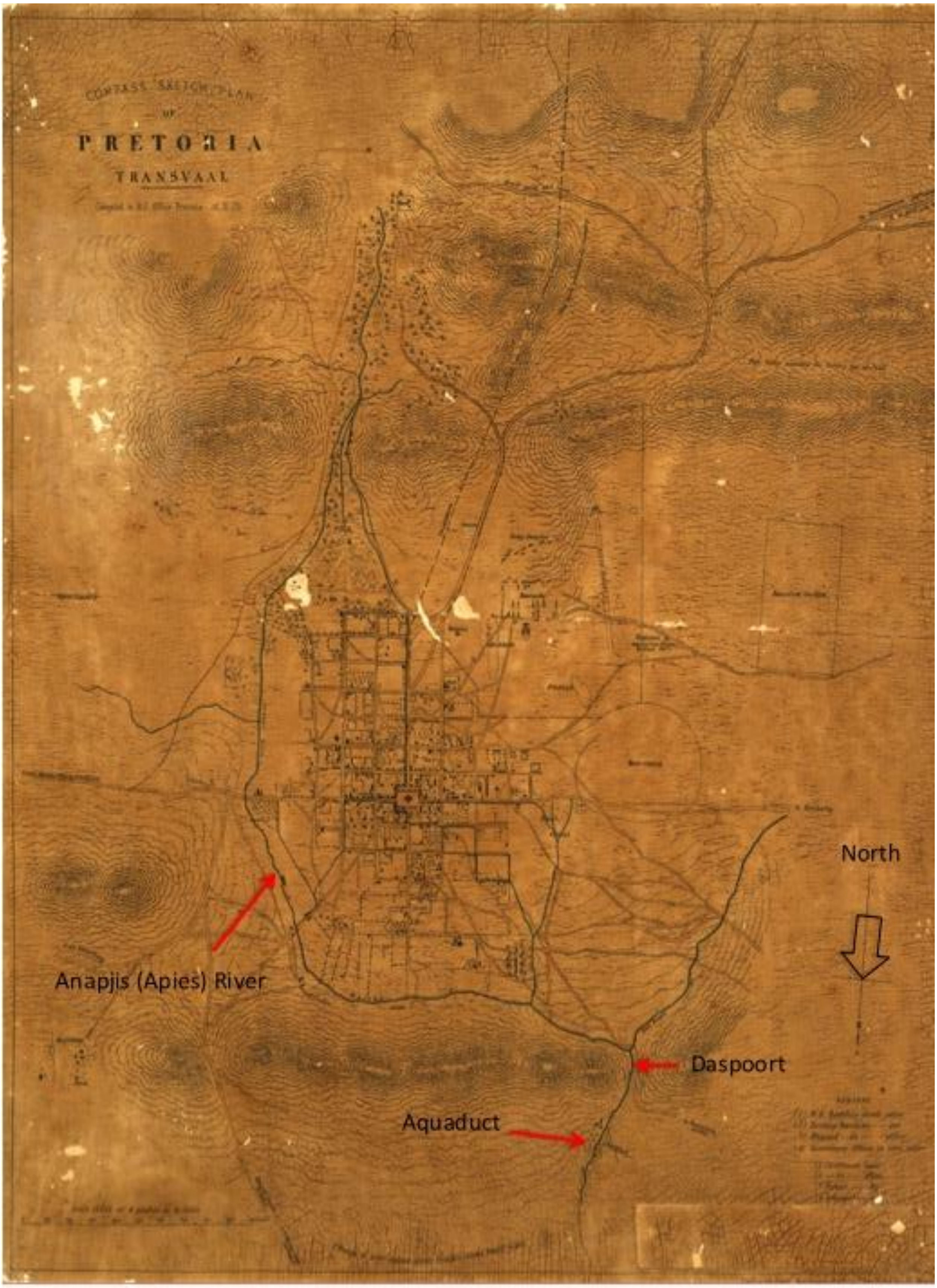


Figure 25: 1880 Compass Sketch Plan Pretoria Transvaal, compiled in 1879 by the Great Britain Army Royal Engineers (Source: UCT Libraries Digital Collection, n.d.)

1.3.4 The first era: Pretoria, a scenic town

In 1903, during the natural era of the Apies River, Haarhoff *et al.* (2012a:22) find that Pretoria was regarded as one of the most scenic towns in the country and one of the most abundant in the world in terms of water supply according to a brochure published at the time. During the 1860s and 1870s, Pretoria was well known for its abundance of fragrant rose hedges, creepers on walls and verandas, grassed streets with a narrow gravel path in the middle, and its abundant water supply in the furrows feeding every house, as depicted in Carl Jeppe's book, *The Kaleidoscopic Transvaal*. There were between 200 and 300 houses in Pretoria in the 1860s, each with their own self-sufficient vegetable gardens and fruit trees (Jeppe,1906:13). The diary of Dr Wangemann, dated 25 April 1867, tells about Pretoria's sandy roads and roses (Bolsmann, 2001:16) and Carl Jeppe describes some of the streets, some as wide as 23.4 meters with narrow roadways in the middle (Jeppe,1906:6).

Ten years after his first visit to Pretoria in 1877 Haggard (1887:249) published his book *Jess* in which he describes Pretoria as one of the prettiest towns in South Africa, set in a landscape with green veldt complemented by the beautiful afternoon light, tall clumps of trees in the town and pink rose hedges.

1.3.5 The first era: Altering the vegetation cover of the water catchment area

The natural vegetation in the Apies/Pienaars River water sub-catchment is classified as Western Bankenveld, Bushveld basin and Eastern Bakenveld eco regions (River Health Program 2005:23).

Tree planting in Pretoria was mostly an ad hoc activity of individuals and, although there was a request by Reverend James Grey for the formalisation of an annual arbour day in August, nothing was realised. The first jacaranda trees were imported from Brazil and arrived in the Cape in 1830. Jacarandas are the symbol of the City of Tshwane, which is often called the Jacaranda city. It was only in 1888 that a travelling nurseryman named Tempelman supplied two jacaranda trees for the new private garden of Mr Jacob Daniel Cilliers in Sunnyside. The trees were brought from Cape Town to Pretoria and thought to be expensive at £10 each while only 30 cm tall, but the flowers were thought to be so remarkable that they soon justified the price. In 1898 Cilliers secured a concession from President Paul Kruger for planting trees in Groenkloof. Seeds were ordered through James Clark, the first commercial nurseryman, seed merchant and florist in South Africa, and among the blue gum seeds which were ordered from Australia, some jacaranda seeds also arrived. James Clark had his shop in Church Street and his nursery was established in a reclaimed wetland area, which later became the suburb of Riviera. Clark, nicknamed Jacaranda Jim, donated 200 jacaranda trees during the 51st anniversary of Pretoria in 1906. The trees were planted in Koch Street (Bosman Street today) and in Arcadia Park. After Clark died, the planting of jacarandas was driven by Frank James Clark, a former town engineer, and by 1939 there were 17,000 trees planted by Council (Bolsmann, 2001:183-186). Today there are 50,000 exotic jacarandas trees growing in Pretoria in the Apies River catchment area (Njeru, 2014:1).

1.3.6 The first era: Land use change from permeable to non-permeable surfaces

The first plots of land in Pretoria were set out in the vicinity of Church Square, which is indicated in Figure 26, a map of Pretoria drawn in 1859. The map also shows the close proximity of the sites to the Apies River.

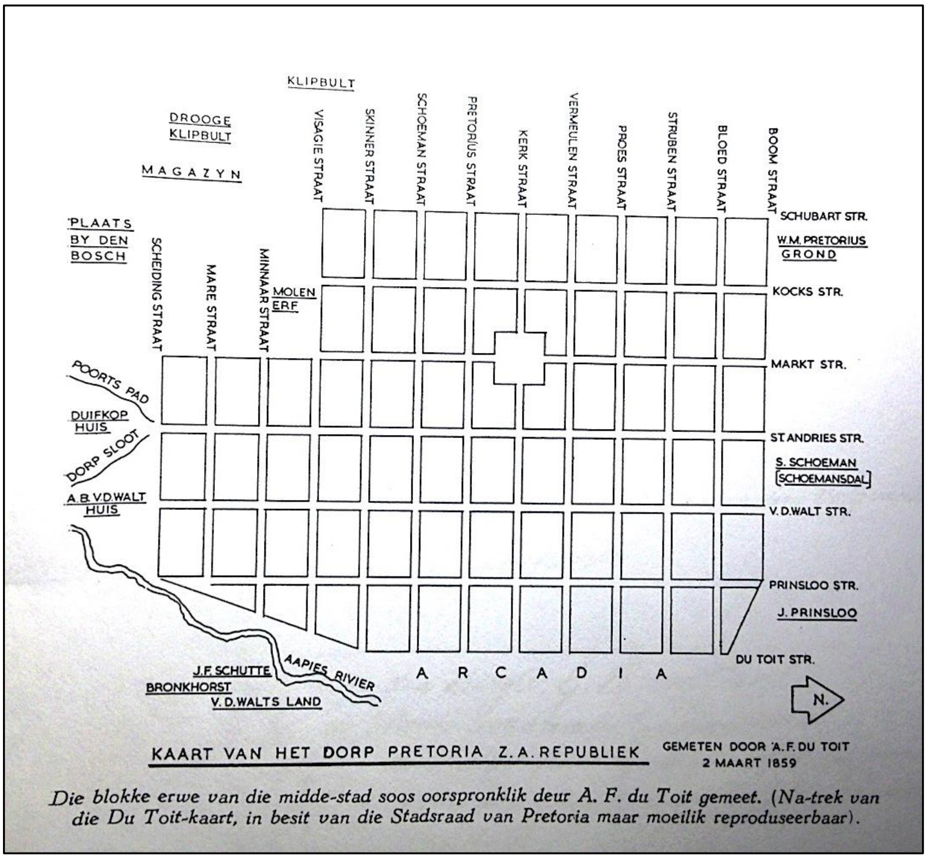


Figure 26: Map of Pretoria dated 2 March 1859 originally measured and drawn by A F du Toit (Source: Engelbrecht et al. 1955:150)

Ox wagons and tents gave way to farm houses, and by the 1860s, according to Bolsmann (2001:14), there were 70 buildings around Church Square with its thatched roof church as the focal point. The pencil sketch in Figure 27 depicts Church Square in 1867, with the thatched roof church in the foreground and the Daspoort and the Magaliesberg range in the background. The other buildings are shops and the Vicarage of Begemann on the northern end of the square, where the current Palace of Justice is today (*ibid*. 17).

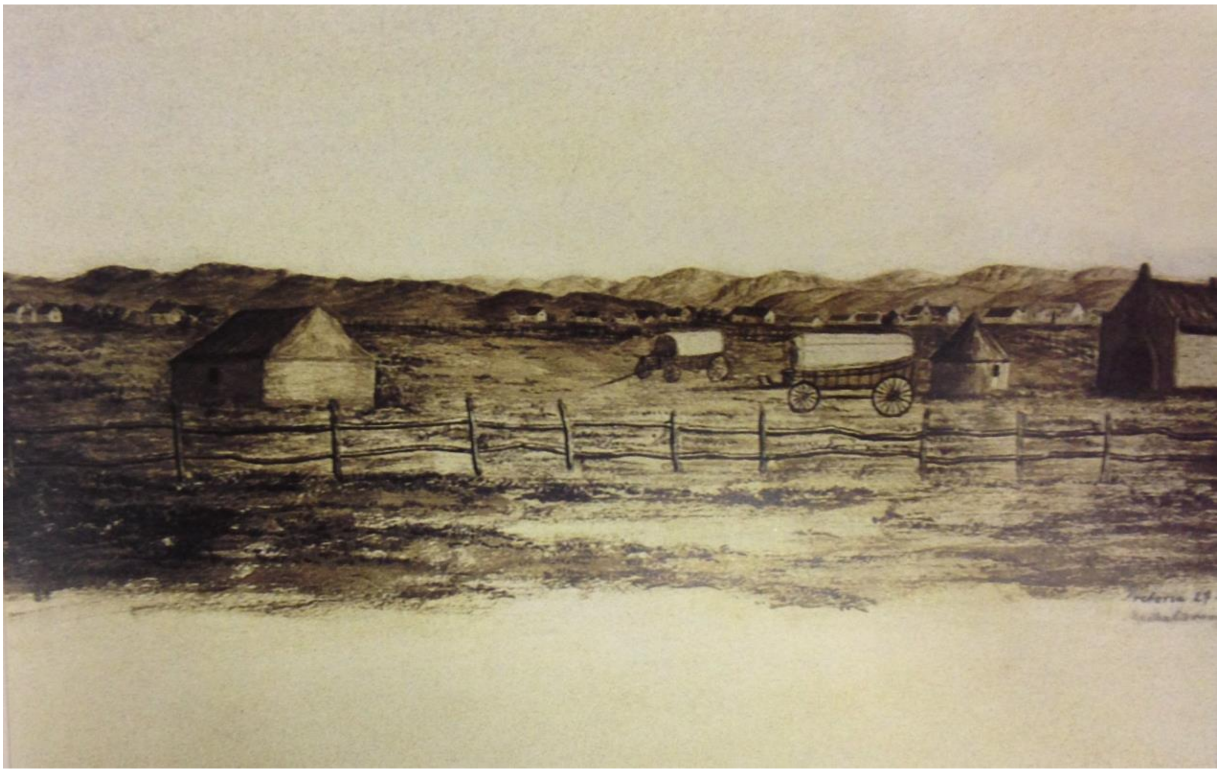


Figure 27: Pretoria 27 April 1867, sketched by Dr T H Wangemann, Pencil sketch, 33x50cm, National Cultural History Museum, Pretoria (Source: Bolsmann, 2001:17)

During the First Anglo Boer War (1877–1879) when the British occupied Pretoria, the water catchment area was largely undeveloped and undisturbed and it could be assumed that the natural freshwater processes were still supported by rainwater seepage into the ground supplying a steady flow of water to the riverbed. Figure 28 shows a view from the Daspoort hills looking over Pretoria during the British siege of Pretoria from 16 December 1880 to 23 March 1881 (Bolsmann, 2001:32), during the first Boer war or also called the Transvaal war.

This picture would soon change with the influx of people and development to Pretoria with the discovery of gold in the Witwatersrand in 1886. The Witwatersrand Gold Rush changed the rural town with its wide streets and single-storey houses into a city (Clark & Corten, 2011). In the 1880s Pretoria expanded well beyond its central grid with its north-eastern and southern boundaries. A new orthogonal grid expanded residential development to the south-east of the city into an area called Sunnyside, followed by Arcadia (*ibid.*). The orthogonal grid indicates that the town expanded towards the Apies River.

Figure 28: View of Pretoria during 1880–1881 showing the tents of the military camp, by Earl Robert, Lithograph, Collection of the National Cultural History Museum, Pretoria (Source: Bolsmann, 2001:32)

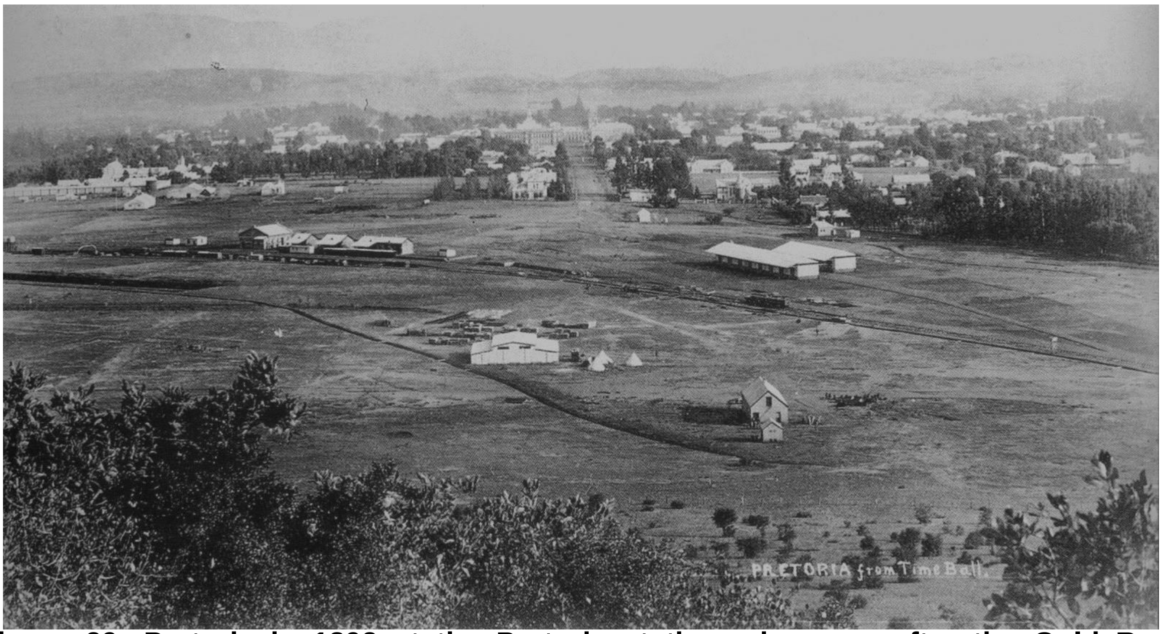


Figure 29: Pretoria in 1892 at the Pretoria station, six years after the Gold Rush (Source: Van Biljon, 2015)

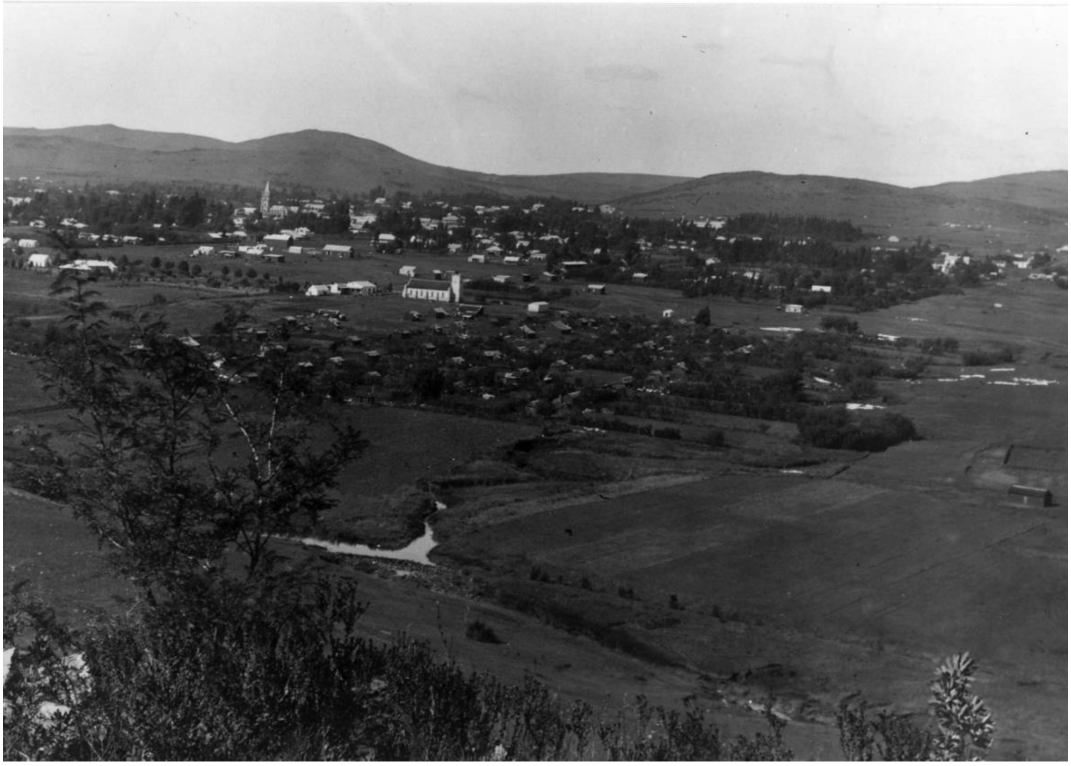


Figure 30: Pretoria in 1886 as seen from the Daspoort hills, with the confluence of the Apies River and the Steenhoven Spruit in the foreground (Source: Anon, 2013b)

Figure 31: Apiesriver, 1897, by F D Oerder, Oil on Canvas, Collection of the NCH Museum (Source: Bolsmann, 2001:121)

During the 1890s, a few years after the Gold Rush of 1886, industrial buildings started to form part of the landscape. Figure 31 depicts the Kirkness brickfield industrial building with its chimney, in Groenkloof in 1897, with Salvokop in the background.

Towards the end of the natural era of the Apies River, 1855–1909, changes in land use started to alter the surfaces of the watershed from permeable to non-permeable. In 1900 Boom Street and Bloed Street were already tarred, while the other roads were still uneven ways constructed with hand labour (SAHO, n.d.). A further increase in non-permeable surfaces occurred with the appointment of the third engineer of Pretoria in 1902, Mr Badcock, who, in an attempt to manage the stormwater runoff problems in the city, and the water and sewerage reticulation issues, initiated and guided the installation of several infrastructure projects, which included paved footpaths along the major roads, granite road kerbs and concrete gutters to divert stormwater. Construction of subsurface stormwater drains started in June 1906. The stormwater drainage system, which was completed in 1911, was constructed from brick and installed in the city centre to redirect the surface flow into the closest watercourse (Haarhoff *et al.,* 2012b:780).

During 1900–1910 rapid development took place in Pretoria, which radiated outwards from the central area. There was no public transport or cars in the town at this time (Engelbrecht *et al.,* 1955:153). This era of rapid and intense development was followed by an era of very little development between 1910 and 1920, particularly during the First World War, from 1914 until 1918.

1.3.7 The first era: Bridges across the Apies River and mills on the banks

Until the end of the 1880s there were no significant bridges across the Apies, which made crossing of the river difficult during the rainy season when the river was frequently in flood, and the only means was though the use of drifts (Vorster, 1994:30). Ox wagons were able to cross the river in three places: Leeudrif, Hove's drift and Daspoortdrif. Each of these drifts had water mills for milling flour (Van der Waal, 1996b:3). Figure 32 is an illustration of the mill in 1887 that Johannes Meintjes built on the banks of the Apies River (west of Lion Bridge as we know it today), with his house on the opposite side of the mill (Bolsmann, 2001:40). The picture also portrays water-loving exotic *Eucalyptus sp.* and *Salix babylonica* trees.

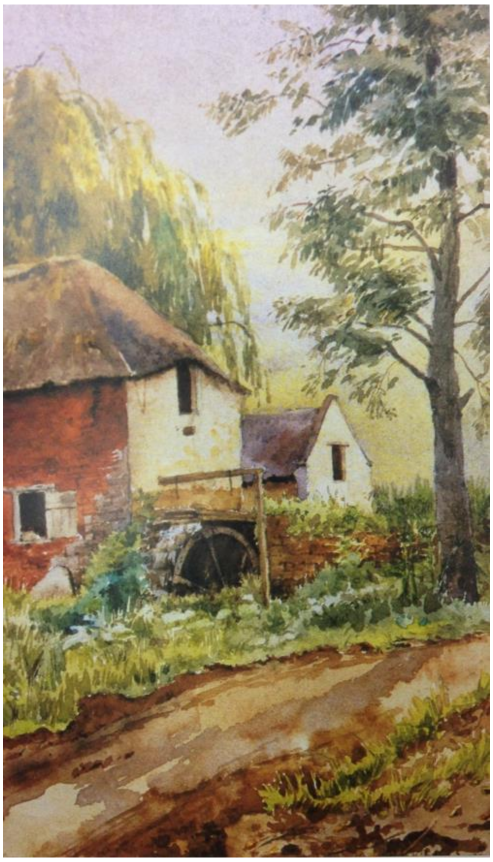


Figure 32: Mill at Meintjes Drift, by Henry Croxall Whitehead, Water Colour 18x10.5cm, Collection Pretoria Art Museum, 1887 (Source: Bolsmann, 2001:41)

Victoria Bridge was the first bridge constructed in Pretoria and north of the Vaal River. The bridge was initially a wooden structure built over the Apies River by Phillip Minnaar in 1848 where Marè and Rissik Streets meet. Victoria Bridge made crossing the Apies River possible when the drifts became impassable during floods and was an important link in the expansion of Pretoria to the east as it carried tram tracks to the area (ABLEWiki, 2012). Between 1878 and 1888 the wooden structure was replaced by a wrought iron bridge designed by Sytze Wierda, architect and engineer of the Transvaal government, and constructed by JJ Kirkness (*ibid.*). Figure 33 and Figure 34 illustrate what the bridge looked like then. Later in 1911-1912, the bridge was rebuilt with a concrete arch, as depicted in Figure 35, by Ingram & Co, this was done at the same time as the concrete river channel between Victoria Bridge and Esselen Street was constructed (Van der Waal & Associates, 2000:25). According to Bolsmann (2001:232) the bridge was named the Queen Victoria Bridge by the British military government, after Queen Victoria of Britain.

Figure 33: Victoria Bridge as seen from the riverbed in the 1900s (Source: Anon 2013e)

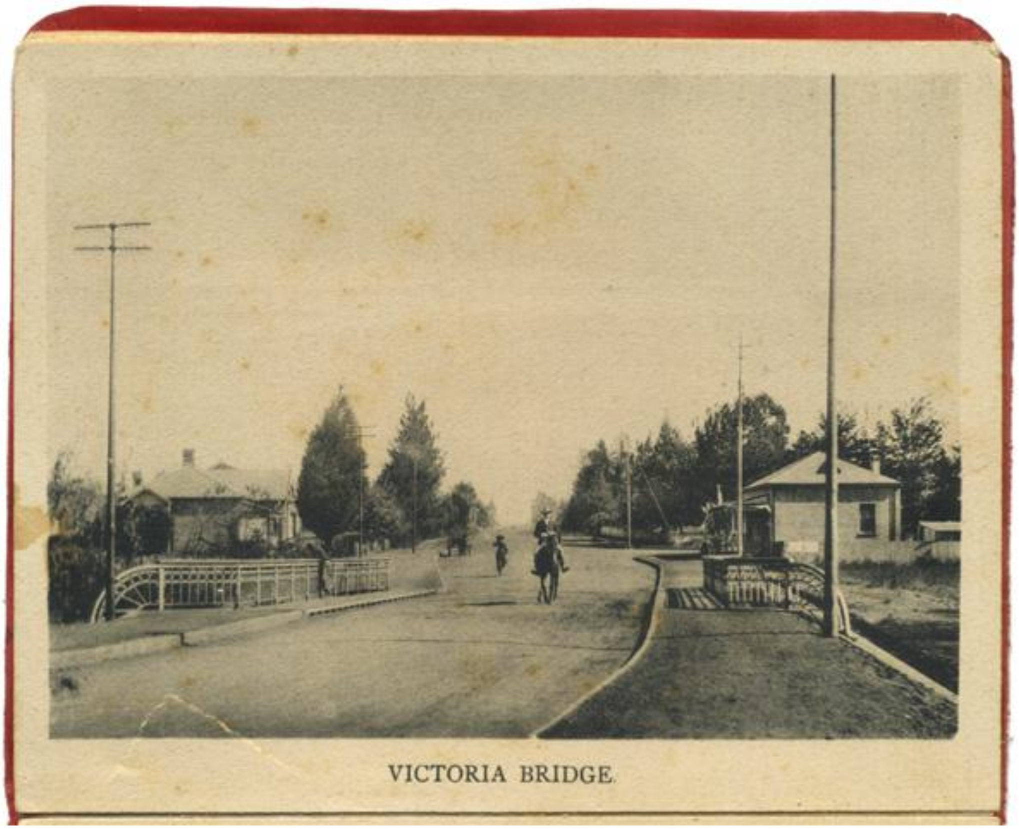


Figure 34: Victoria Bridge on a postcard c 1903 (Source: Anon, 2015)

Figure 35: Victoria Bridge built in concrete as it is today (Source: ABLEWiki, 2009)

In 1887 there was a plea from 135 residents for the construction of bridges to make crossing of the river easier. During the 1880s and the 1890s several bridges were constructed across the Apies River. One of these bridges is Lion Bridge, which was originally called Leeudrif (Lion Ford), named after the roaming lions that often attacked grazing cattle in the surrounding marsh areas (Andrews, 1985a:18). Initially a small iron bridge then called Arcadia Bridge, was constructed at Leeudrif in 1888, which was regularly damaged by stormwater and after severe floods in 1890 was rebuilt in 1893 and named Lion Bridge (Anon, 2015b). The bridge, which today is known as Lion Bridge, was officially opened on 11 June 1894 (Vorster, 1994:30). Figure 36 shows the Leeudrift area in the 1860s before the bridge was constructed. Figure 37 illustrate what the Arcadia Bridge looked like before it was rebuilt with sandstone supports and mounted cast iron reclining lions as depicted in Figure 38 and 39.

By 1889 there were two bridges in Pretoria over the Apies River, one in Church Street (today named Stanza Bopape Street) and the other one, Queen Victoria Bridge, where Marè and Rissik Streets meet. Ten years later, in 1899, three bridges capable of taking vehicles, were recorded on an 1899 map by Donaldson and Hills—Arcadia Bridge in Church Street (today known as Lion Bridge), Tram Bridge in Esselen Street (today named Robert Sobukwe Street) and Victoria Bridge where Marè and Rissik Street meet. All the other streets had pedestrian bridges only (Swanepoel, 2012).

Figure 36: Apies River drift below Lion Bridge (1860s) (Source: Anon, 2013 –1960c)

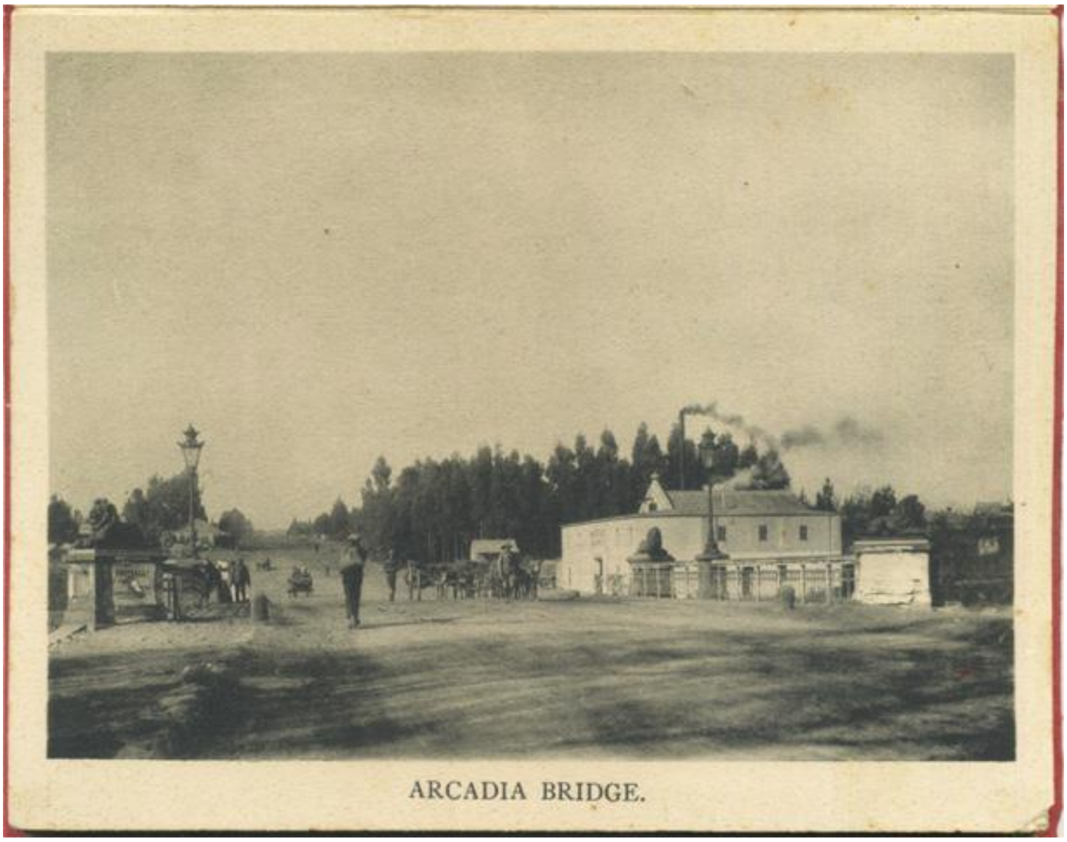


Figure 37: Arcadia Bridge on a postcard c 1903 (Source: Anon, 2015b)

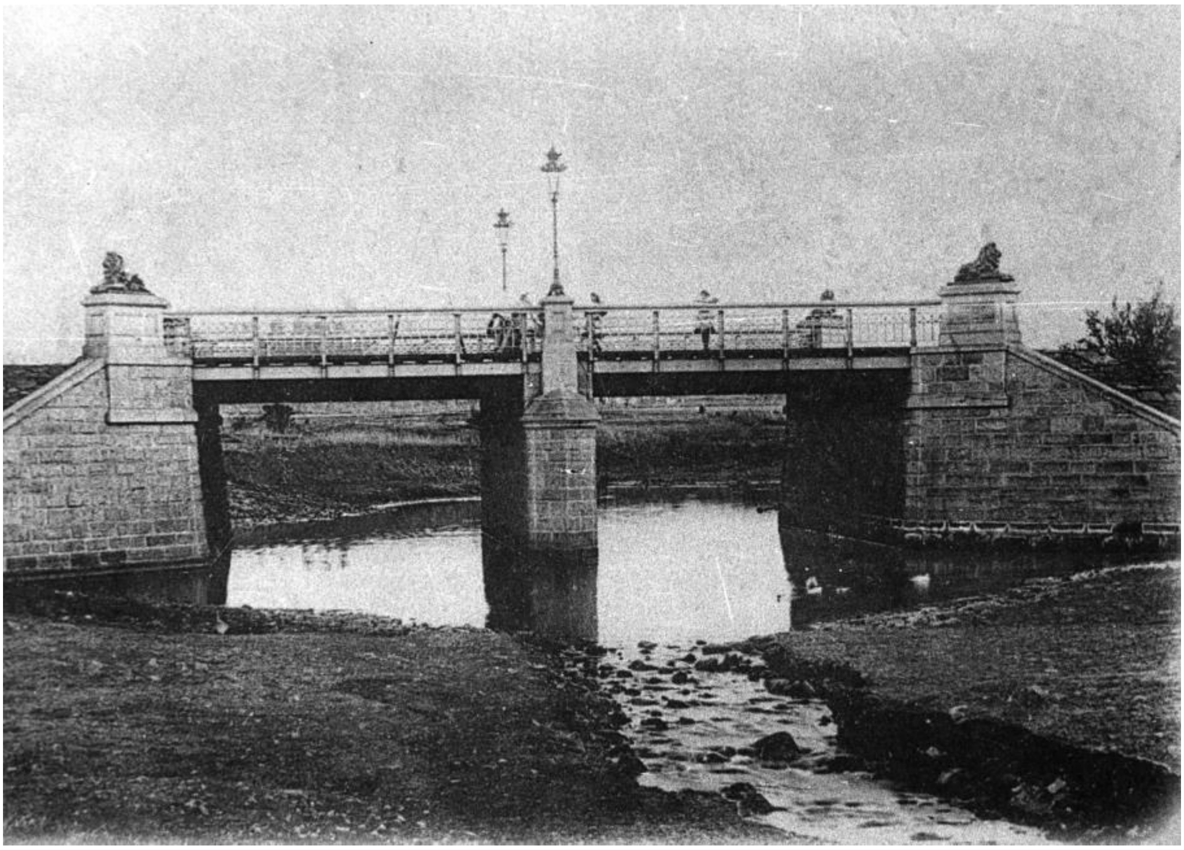


Figure 38: Lion Bridge before the canalisation, as seen from the riverbed (1890s) (Source: Anon, 2013d)

Figure 39: Lion Bridge today (Source: E Otto, 2014)

In 1897, the Tram Bridge was built over the Apies River in Esselen Street (today known as Robert Sobukwe Street). According to Andrews (1985b:24) it was a narrow iron construction just wide enough to accommodate a one-horse tram to Sunnyside. The iron bridge was enlarged in 1909–1910 by Tilburg and Engel (Van der Waal & Associates, 2000:24), and was modified again in 1939 to accommodate an electric tram and motorised transport (Andrews,1985b:24). A photograph of the bridge after it was modified in 1910 is depicted in Figure 40.

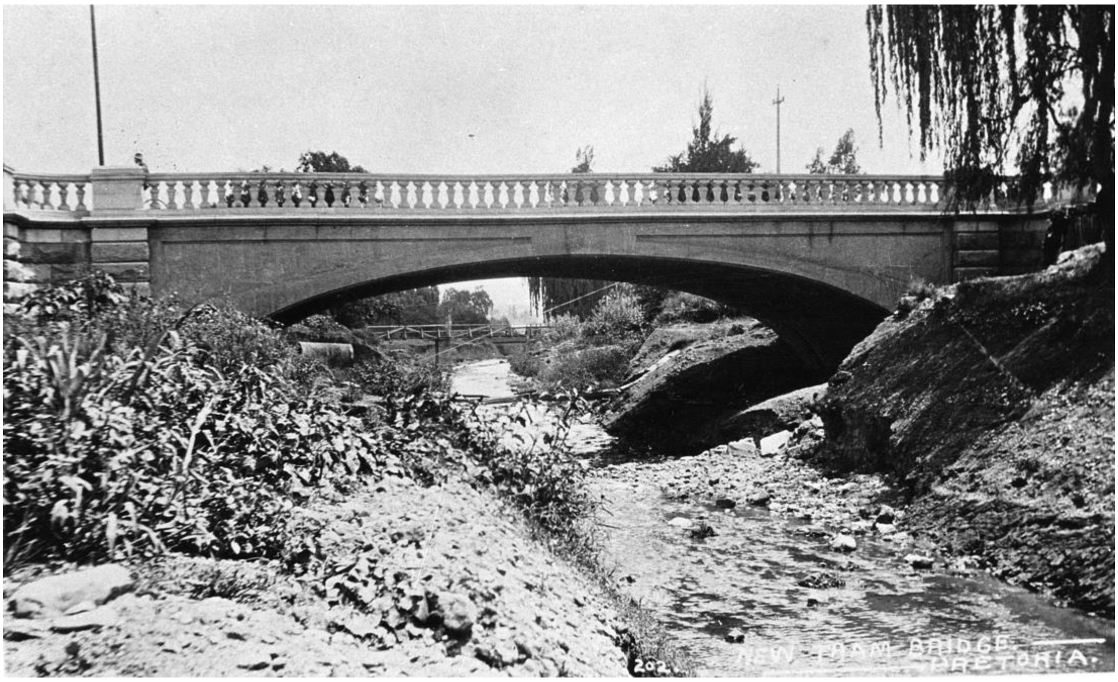


Figure 40: Tram Bridge in Esselen Street across the Apies River after it was rebuilt in 1910 (Source: Anon, 2013f)

There were various drifts, which were used for access through the Apies River in the 1800s, which eventually became heavy traffic bearing bridges. Following is a description of some of these bridges, the Wonderboompoort Bridge, the Daspoort Bridge and Hove's Bridge.

The Wonderboompoort Drift cuts through the Magaliesburg mountains and was the main access in the 1880s to and from Pretoria to the north. Figures 42, 43 and 44 depicts the natural state of the river as it flowed through the mountains in the 1880s. Lady Florence Dixie describes in her book *the Land and the Misfortune* in 1882, the magical qualities of the Wonderboompoort with its striking narrow gorges, rich plant life of ferns and trees and the pleasant sound of the water moving over the rocks. The poort with its shallow stream and rocky riverbed was originally a pass through for wagons to or from the north (Bolsmann E., 2001:179-180). Figure 45 shows the road modification of the drift at Wonderboom as it looks like today where the river meanders underneath and on the side of Paul Kruger Street

(R101) where it cuts through the Wonderboompoort.

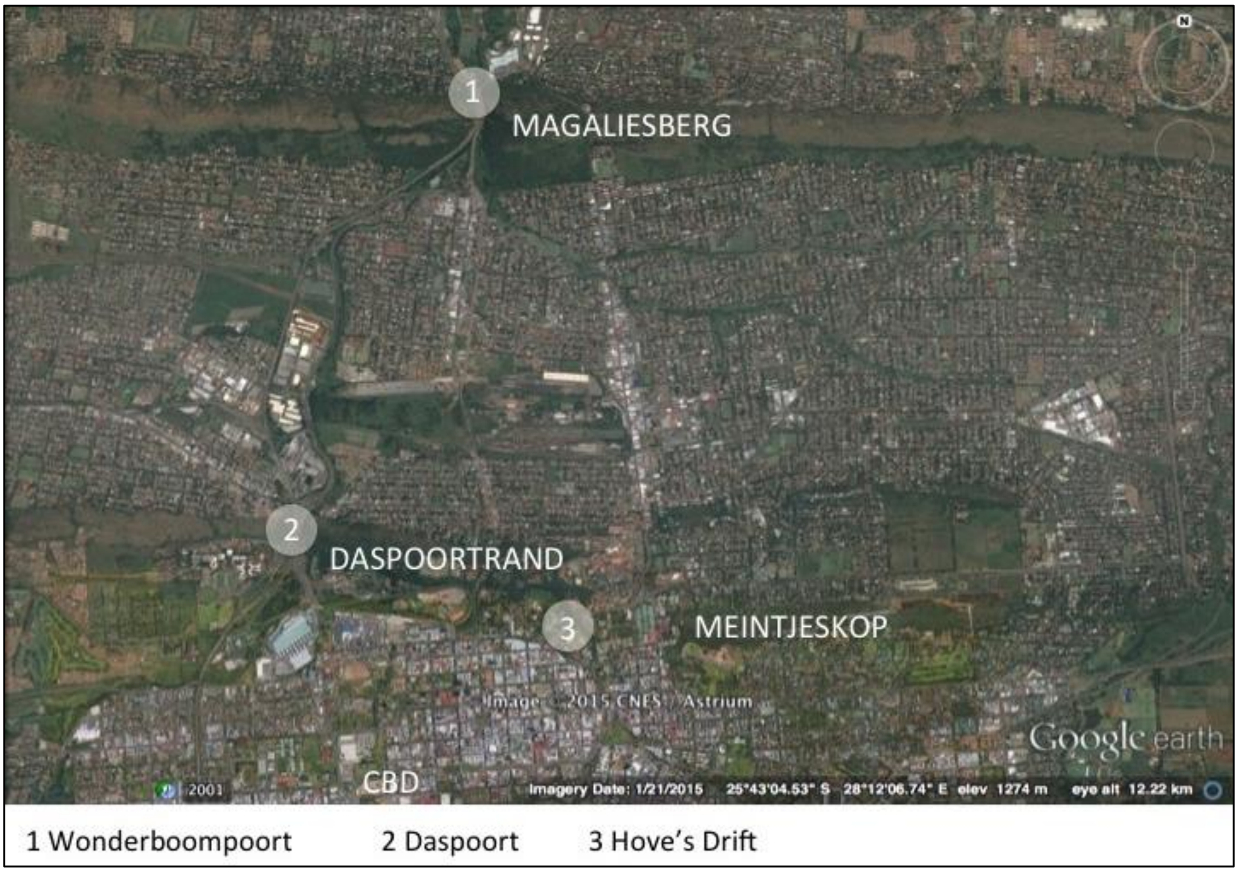


Figure 41: Position of drifts in the Apies River (Source: Google Earth 7.1.2.2041, 2015c)

Figure 42: Wonderboompoort 1800s (Source: Anon, 2013g)

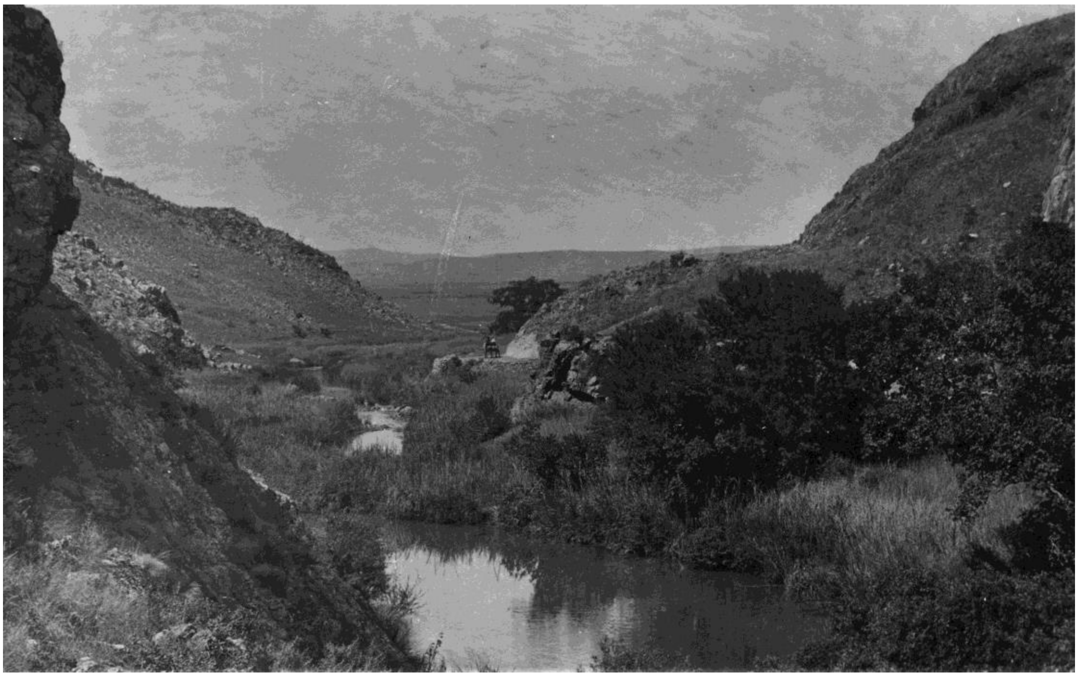


Figure 43: Wonderboompoort 1880s (Source: Anon, 2013h)

Figure 44: Wonderboompoort 1883 (Source: Anon, 2013i)

Figure 45: Wonderboompoort 2001 (Source: Google Earth 7.1.2.2041, 2015a)

Daspoort cuts through the Daspoortrand hills which are south of the Magaliesberg stretching from Silverton, across Meintjeskop westwards to Hartbeespoortdam. In 1841 these hills were still called the Witwatersberge; today they are called Daspoortrand (Engelbrecht et al., 1955:248). Figures 46 and 47 shows what the Apies River looked like before 1900 and before the floodplain was modified by road construction. Figure 48 shows what the road looked like in 1950 through the Daspoort. Figure 49 shows what the Daspoort looks like today.

Figure 46: Daspoort in 1888 before the bridge was built (Source: Anon, 2013j)

Figure 47: Daspoort before 1900 (Source: Anon, 2013k)

Figure 48: Daspoort 1950 before the building of the double road (Source: Anon, 2013l)

Figure 49: Daspoort today (Source: Google Earth 7.1.2.2041, 2015d)

Hove's drift is depicted in Figure 50 in the year 1890 where ox wagons passed though the Apies River with Meintjeskop in the background, then still undeveloped. The position of the drift was where Sisulu Street (previously Prinsloo Street) and Bloed Street are today at their junction with Dr. Savage Road. Hove's Drift was named after T.H. von dem Hove, the owner of the mill at the drift. During the South African war, a British camp was also built at the drift (Swanepoel, 2013). Many years later, between 1931 and 1932, the Hove's Drift Bridge was built by Proudfoot and Bain in Dr Savage Road transforming the drift into a road for vehicles, as shown in Figure 50 and 51.

Figure 50: Hove's Drift 1890 with ox wagon crossing and Meintjeskop in the background (Source: Anon, 2013m)

Figure 51: Hove's Drift today with Meintjeskop in the background (Source: Google Earth 7.1.2.2041, 2015b)

Figure 52: Hove's Drift today with the Hove's Bridge crossing the Apies River's concrete channel (Source: Google Earth 7.1.2.2041, 2009a)

1.3.8 The first era: Inefficient local governance and its effect on the quality and quantity of water

For 48 years, between 1855 and 1903, Pretoria was without a democratically elected local government close to the issues of its residents and with the authority to collect taxes. This lack of a local Council affected:

a) development of sewerage and wastewater reticulation, stormwater management and piped water, which over time affected the quality of Pretoria's freshwater system; and
b) management of the use of water, impacting on the quantity of water in Pretoria.

According to Haarhoff *et al*. (2012b:772) proper infrastructure and services to communities can only be provided by a well-managed local government system with the authority to collect taxes from residents and provide necessary infrastructure to communities.

When Pretoria was established as a town in 1855, the town was managed by a magistrate who was appointed by, and reported to the central government of the independent Republic of the Transvaal, situated in Pretoria. Service delivery happened at the discretion of the central government with a lack of decision-making close enough to the people that were paying property taxes, to provide sufficient services and infrastructure to the new town. In order to meet their infrastructure needs, the citizens requested the establishment of a local Council. The request was granted on 2 May 1864, nine years after Pretoria was founded. However, in September 1864, nine months after it was established, the Council was disbanded, as it could not function due to a lack of funds as a result of the inflexibility of the central government and its unwillingness to supply the Council with the necessary revenue, even though it had collected revenue from the local taxpayers. Residents continued to request the establishment of a local Council, but to no avail (*ibid*.).

Pretoria continued to grow but still lacked a local Council and proper management of stormwater, water supply and sewerage reticulation (Haarhoff *et al*., 2012b:772). By 1870 the absence of a local Council and the lack of proper services caused contamination of drinking water in the furrows and the outbreak of disease, which negatively affected the reputation of Pretoria as a beautiful town. The situation of poor health as a result of the polluted water was captured in a medical history publication called *South Africa: Its Medical History, 1652–1898* which described the bad state of the watercourses, the lack of stormwater drainage and poor management (*ibid.* 771). However, even the pressure placed from the inhabitants as a result of their deteriorating health linked to the lack of proper sewerage reticulation in Pretoria, their continued requests for a local council to be established to improve the infrastructure in the town to address the water contamination, were still not reason enough for the central government to establish a local council (*ibid*. 772). Seven years later, in August 1877, concerns were still being raised in *De Volkstem* about the unhealthy disease-ridden state of the furrows and the foul smell of sewage (*ibid.* 773). Pretoria continued to expand under a central government up to 1877-1879 when the first British occupation of the Transvaal took place The British Military then governed Pretoria during the First Anglo Boer War. At the time of the Anglo Boer War the already poor sanitation and stormwater situation was put under even more pressure with the increase in population from the influx of troops and businesses into Pretoria (*ibid*.). According to Haarhoff *et al*. (2012a:19) the population increased from 1,500 to 2,000 between 1877 and 1878. The need for a Council to address the pollution in the water furrows, the lack of sanitation and stormwater management was now even more urgent.

The British Government established a local Council in 1877; however, this failed for the second time, because the Council was established under British rule, an authority which was disliked by the citizens of Pretoria. During this first British occupation of Pretoria, the military government made sure that the furrows were cleaned and an attempt was made to line the furrows with brick, but this had to be abandoned due to a lack of funds. No real improvements were made during the time of British rule (Haarhoff *et al*., 2012b:772).

Stormwater management remained a problem, making roads unusable during rainy seasons, and causing pollution of the drinking water as the stormwater overflowed into the furrows. There was also the dumping of wastewater and sewage into the furrows which forced private owners to revert to water wells on their own properties as an alternative water supply (Haarhoff *et al*., 2012a:19). However, using wells carried risks from contaminated groundwater. By 1888 when the granting of the concession for night soil removal came into effect, the use of cesspools for sewage disposal was banned in an attempt to combat pollution of the water system. However, because the situation did not improve much, prohibition of the use of cesspools was repeated again with a similar regulation in 1894 requesting the cesspools to be filled up and covered and pollution of the Apies River upstream from the town was made illegal (Haarhoff *et al*., 2012b:775, 780).

After the first British occupation ended in 1879, Pretoria was again governed by a magistrate of the central government of the Transvaal Republic for the period between 1880 and 1899. During this time issues around water and health worsened with renewed pressure from population growth, this time due to the Gold Rush of the Witwatersrand in Johannesburg in 1886, which caused a rapid increase in population from 2,000 people in 1878 to 7,000 in 1888. Attempts at a solution, such as supplying a cart and oxen to clean the furrows, were made, but there were no plans for the building of a water and sewerage reticulation system. By 1887 the water pollution was so bad that the central government took the step of granting concession rights to improve the water supply and waste and sewage removal (*ibid*. 773, 774). The link between the poor water and poor health was set out in research of Drs Stroud and Impey, which was used at a public meeting in 1888 to motivate for a local Council to improve infrastructure and management to change the situation. Then in 1889, Pretoria suffered a major outbreak of enteric fever caused by contamination in the wells and the furrows (*ibid*.776, 777).

The work of the concessions came into effect through a central government concession policy with the first concession contracts awarded in 1887. These concessions were not allocated with the necessary transparency and the process of parliamentary approval was bypassed by government officials, which caused some polemic (*ibid*.773, 774). Pretoria Water Works Company Limited was tasked to supply piped water to Pretoria in 1889, as a ceded responsibility of an existing water concession. This was also the same time as the outbreak of enteric fever in Pretoria. The company built a combined water collection chamber for the two fountains in the Groenkloof valley and installed steel pipes to direct the water to the town, and with a network reticulation of cast iron pipes (*ibid*. 774).

By 1889 contamination of water had worsened except for the collection of night soil to manage sewage discharge, and by 1893 erven and furrows were polluted with the dumping of night soil and wastewater. In 1897 the Public Works Department and a commission of enquiry reported that the pollution was very bad. The commission reported that dead animals were to be found in the streets, waste water was emptied in the streets and into the furrows, there was a high incidence of disease, people were dying at a higher rate than before, and the water used for domestic drinking water was contaminated by human and animal faeces (*ibid*. 775). The need to install a proper wastewater and sewerage system required the appointment of a town engineer, who was then appointed in 1896 by the magistrate. A full time water-bailiff was also appointed in 1889 and a works inspector in 1887 (*ibid*. 776).

In 1898 in an attempt to manage the quantity of water used, the Pretoria Water Works Company Limited wanted to introduce water meters for individual users and proposed an increase in the price of water. However, this was met unfavourably with a petition by 1,060 residents, which resulted in the recommendation that the concession of the Pretoria Water Works Company Limited be cancelled. If it was not for the war, which was declared on 11 October 1899, the transfer to an alternative water provider would have come into effect. However, before this could be executed, a second British occupation followed from 11 October 1899 to the middle of 1902 (*ibid*. 774).

The central government finally bowed to pressure and a temporary Local Council was put in place by 1897. This temporary Council functioned for a year and was followed by another temporary Council in 1899 that took full control of water management in the city (*ibid*. 777).

It was during this second British occupation by a military government that the first real Local Council was established in Pretoria by means of governor nominations in 1902. A year later, in 1903, 48 years after Pretoria was established, the first democratically elected Local Council came into being. However, the Local Council was under British rule and a decision was made that during the military occupation minimal work would be executed and for that reason a sewerage system was once again not built. The population kept on growing and pressure on the availability of water increased. One improvement did take place which was the installation of pumps and the building of larger collection chambers at the Fountains. In 1890 more water pipes were installed to expand the network (*ibid*. 777,778).

The newly elected Council, which had the power to collect taxes, started a process of development and improvement in Pretoria and to catch up on the backlog of services inherited from the previous government (*ibid*. 778)

After the war, in 1902, there was a big shortage of water provisioning in Pretoria as a result of an inadequate bulk water conveyance system linked to the water source, a lack of storage of water in the system to ensure a constant supply of water and an insufficient water reticulation system to individual consumers. In order to improve the situation the management of water was transferred from the Water Works Company in May 1903 and placed under the direct control of the new City Council (*ibid*. 778-779).

Another issue affecting the quantity of water in Pretoria other than an inadequate reticulation system, was the wasteful consumption of water. The water from the fountains in the Fountains Valley was regarded as a very strong yield that was able to provide approximately 100,000 people with water, and this abundance of water was fully exploited by the people of Pretoria. In 1903 Pretoria was described in a brochure as one of the prettiest towns in South Africa and one of the most water abundant towns in the world (Haarhoff *et al*., 2012b:782). When water use in Pretoria was measured by Augustus Karlson, the manager of the Pretoria Water Works Company, in 1901, it was 358 litres per capita per day, supplied by furrows and a limited piped reticulation system. This was regarded as a very high per capita water use. Karlson proposed that consumption could be reduced by 30% if the water supplied by the furrows was piped, and by another 50% through the introduction of water meters and regulating domestic water misuse (*ibid.* 783).

By 1904 the lack of sanitation and drainage in Pretoria had become unbearable (Haarhoff *et al*. 2012b:781) with a population of now already 36,700 but still no sewerage reticulation infrastructure. In 1907 it was found that none of the 75 water wells in use in Pretoria were suitable for potable water (*ibid.* 775, 780). According to Kreamer and Usher (2010:261) on-site sanitation has the potential to contaminate groundwater, thus the contamination in the wells could have been as a result of the use of cesspools, which were still in use despite their earlier banning. It was in 1904 that the first plans for a water-borne sewerage reticulation system, which discharges to purification works, were submitted. Four water purification works were constructed between 1913 and 1920 (WAMTechnology CC, n.d. 2). The drainage and sewerage systems were designed to operate separately (Haarhoff *et al*., 2012b:781).

Although there was enough water provided by the springs in the Fountains Valley, it was not effectively reticulated for use. Due to the water shortage, resulting too few reservoirs, three additional reservoirs were built in 1907 and more water mains to feed the system. In 1916 the Finely reservoir was built. The reticulated water system improved the quality of the drinking water significantly (*ibid.*780).

The first water meter system, introduced in 1898 by the Pretoria Water Works Limited, was opposed by the public and by 1922 the government had not placed any restriction on the domestic use of water in Pretoria; meters were only installed at businesses and government institutions. This scenario did not provide any incentives for the public to save water. By 1923 the water provided by the springs in the Fountains Valley could not sustain the demand any longer (Haarhoff *et al*. 2012b:783).

In 1910 the new government under the Union of South Africa was not as much concerned with water and sanitation improvement as with water as a source of irrigation for agriculture and through the Department of Irrigation dams were built and irrigation schemes were developed (*ibid*. 782).

The struggle to manage water usage intensified in the second historical era, between 1910 and 1970. Water contamination was less of an issue as it was resolved with expansion of the piped water system and the installation of a sewage system. Water contamination did increase again in the third era of 1971–2014 as a result of the mismanagement of the sewerage systems built on the edge of the river.

1.3.9 The first era: Flooding

Heavy rains in Pretoria on Saturday 6 March 1886 were reported in the newspaper *De Potchefstroomer* dated 9 March 1886. According to the newspaper, the heavy rains caused the river to come down with an intensity worse than ever experienced in the previous 12 to 14 years (Swanepoel, 2012).

After the establishment of a permanent local council nominated in 1902 and under the supervision of the newly appointed town engineer of Pretoria, Mr Badcock, who was appointed in 1902, projects were initiated to upgrade stormwater drainage of the roads, construct paved walkways, canalise streams to avoid flooding, and construct bridges to make the town more accessible during wet seasons (Mäki & Haarhoff, 2009:243). In 1903, seventeen years after the previous recorded heavy floods, Pretoria experienced floods again. The impact of these floods was not as destructive in Pretoria itself as the flooding occurred further outside the town (Municipality of Pretoria, 1909:20-21). The canalisation of the river started in 1905, and the subsurface stormwater drainage system was begun in 1906 (Mäki & Haarhoff, 2009:243).

Six years after the floods of 1903, Pretoria was again subjected to heavy rains and flooding on 9 January 1909. The rains were not as heavy as in 1903, but the flooding was much worse, impacting on the livelihoods of the people in Pretoria, and resulting in the death of a Mrs Mallandain and her two children (Municipality of Pretoria, 1909:20). The floods of 1909 followed four years after the commencement of construction of the canalisation of the river in 1905, and took place three years after the installation of the drainage system began in 1906 (Mäki & Haarhoff, 2009:243).

Minutes from the Mayor’s office in the Mayoral year ending 27 October 1909 claimed that the impact of the floods in January 1909 would have been much worse if it was not for the canalisation of the river, which had already been completed in places, and for the existing drainage system which was installed, although it was inadequate and not yet fully implemented. It was also believed that the deepening and widening of the river directed away more water than would have occurred had the river been still in its natural state, and the unobstructed concrete channel was thought to have reduced the impact of the floods. It was also recorded in the Pretoria Chronicle on Monday 11 January 1909 that the return on the investment in the stormwater infrastructure was huge as the system alleviated the impact of the floods on the lower parts of the town and improved stormwater management in the streets (Municipality of Pretoria, 1909:20-21).

Figure 53: Apies River during the flood of 1909 (Source: Anon, 2013n)

The Pretoria Chronicle on Monday 11 January 1909 reported that the Mayor opened a flood relief fund of £225.60, for temporary relief and incidental expenses of serious loss due to the floods. It was reported that £179.10 of these funds were allocated to a total of 30 people from the public who suffered as a result of the floods (Municipality of Pretoria, 1909:27,28). The Chronicle further depicted the damage of the floods as not such a big disaster but merely flooding of houses and overturning of fences and light constructions (Municipality of Pretoria, 1909:26). Other media sensationalised the event into a disaster and coloured it with much drama. It was reported that the streets were turned into rivers and Church Square into a lake, with the drainage systems overloaded and water erupting through the manholes and flooding places close to the river where the pressure was higher. The impact of the floods was felt mostly at and close to the river. Some of the first effects of the flooding were in the streets around Victoria Bridge (Rissik and President Street, which run parallel to the spruit), which were covered in 600 mm deep water coming down with a high velocity. The spruit, which was 3.6 m wide, changed within two minutes to 137 m wide (*ibid*. 20, 21, 22).

As the water level decreased, the damage from the force of the water became visible. For example, the foundations of Victoria Bridge were exposed after the soil around the foundations was washed away, the pathways on the opposite road were also destroyed leaving the subsurface stormwater pipes exposed. The Tram Bridge, where Esselen Street (today known as Robert Sobukwe Street) meets Du Toit Street, was completely covered in water during the floods and was thought to have been washed away; however, only the rails on the south side of the bridge were damaged. There were also uprooted telephone poles, iron stone foundation of portions of the roads which was exposed, houses which had remains of mud and slush and gardens which were destroyed. The floodwater left a debris of bicycles and furniture in some places up to 6 m up the trees along the banks of the Apies River. Houses adjacent to the river were the hardest hit and caused small structures to be overturned and flattened (*ibid*. 23).

The flooding in 1909 was so severe that it turned places like Du Toit Street into a river flooding its banks 91.4 m on both sides. This is the natural flood attenuation area where the river used to store its water. Figure 54 shows how much the town encroached onto the floodplain, with the development of Du Toit Street, which was already built then. Damage was also visible in places like Schoeman Street (today known as Francis Baard Street), except for a mealie patch which remained intact as the water diverted along the road back to the river.

Figure 54: Simulation of area of flooding of the Apies River in 1909 around Du Toit Street (Source: Google Earth V 7.1.2.2041, 2009b)

1.4 The second era, 1910–1970: The Apies River disconnected from the urban system

The second era of the Apies River covers 60 years, years which were mainly dedicated to the modification of the Apies River in response to the challenges of flooding which came about as a result of the changes in the hydrological cycle of the urbanised watershed. The responses of the city to the flooding challenges altered the integrity of the freshwater system and changed the quality of the connection between the urban structures and the Apies River.

It took the Apies River SES 55 years (1855–1910) to develop to a point where the freshwater system had to be contained in a stormwater channel. This step was a response to the river's attempt to reassert its natural processes which were slowly being encroached upon and altered through a new urban hydrological system, natural processes which were now no longer accommodated spatially by the urban infrastructure of the fast growing city of Pretoria. Although stream modification and canalisation had already started in 1905, the canalisation of the Apies River and its man tributaries in the inner city was intensified in 1910 as a matter of national priority, a process of stream modification which lasted for decades. The part of the

Apies River flowing through the CBD was contained in a large concrete channel, detached from its ecological processes and natural beauty, and in places even hidden. The river became a channel to direct floodwaters away from the built-up area in a short period of time, to keep residents "safe" from flooding. The river was successfully changed into a stormwater channel. However, the overall functional integrity and the health of the river were compromised. This changed the city's relationship with the freshwater system, once its central lifeblood and the energy that provided health and well-being to the SES. The river became a dangerous and foul smelling channel where children were prohibited to play, especially after it had rained.

The original reason for the establishment of Pretoria on the banks of the natural flowing Apies River, a river with an abundance of water, a place of tranquillity and natural diversity, which was an inspiration for artists and writers, was now forgotten and the river became a disturbance to the society it served. The Apies River, which had functioned as part of an SES for more than five decades, entered a new functional era from 1910–1970 where the structure of the river had been modified and the river was hardly recognisable when compared with the natural state in which it once existed.

The challenges during the second historical era of the Apies River (1910–1970), and their causes, are: The canalisation of the Apies River; pollution of the Apies River; water supply issues; more flooding; realisation of the lost ecological value of the river. These will be discussed in the following sections.

1.4.1 The second era: Canalisation of the Apies River

> *… so changed does it [the Apies River] appear in its concrete walled and bedded course* (Municipality of Pretoria, 1911:43).

Just after the "disastrous" flooding in January 1909, and in an attempt to avoid such a disaster from happening again and to make the river safer for the people of Pretoria, the Transvaal Colonial Government provided an amount of £50,000 on 24 June 1909, for the intensification of the canalisation of the Apies River. This enabled excavations to proceed for a new and much wider river channel (Van der Waal & Associates, 2000:23). According to Haarhoff *et al*. (2012b:781) the town engineer of Pretoria during that time, Hugh Badcock, had already initiated the canalisation of the three rivers flowing through the CBD in 1905. The canalisation of the Apies River (spelled Aapies River in those days) and its main tributaries was described as a project ''taking in hand by Government, as a National work'' (Municipality of Pretoria, 1909:20). The expansion of the canalisation of the river began in Proes Street (today known as Johannes Ramokhoase Street) progressing to the south and, according to Bolsmann (2001:170), was completed in the late 1930s.

The Irrigation Department of the Council drew up design proposals for the concrete channel, which were submitted to the Council in February 1910. It was intended to have a channel with a side slope of 45%, which is wide enough and deep enough to accommodate 25 mm per hour rainwater runoff from each km^2 of the water catchment area. To accommodate all the water the riverbed would have to be straightened and made wider, and additional land acquired adjacent to the channel. Based on the designs submitted to the Council, the Council decided to construct a concrete channel with a vertical retaining wall at the top, a V-shaped trough at the base of the canal and sloped at an angle of 1.5:1. It was proposed that the walls be constructed from concrete, the slope from a concrete slab and the base of the canal from granite. In April 1910 the construction of the channel began between Vermeulen Street (today known as Madiba Street) and the Lion Bridge. This was the beginning of an intensive 30-year canalisation project, a process determined by the availability of funding, available labour and when land became available to make space to realign and straighten the channel. The thinking around the canalisation of the river was to address the lowest, most likely area for flooding first, which was Proes Street (today known as Johannes Ramokhoase Street), and then work upwards towards Victoria Bridge. Downstream from Proes Street, the river had to be widened and deepened past the bend at Hove’s Drift, whereafter the water would then be dispersed in the wider and deeper natural river bed south of Daspoortrand between Hove’s Drift and Daspoort (Van der Waal & Associates, 2000:23-24).

The Council reported that accessing the necessary land from landowners adjacent to the stream was effortless, except for the Caledonian society which had special requirements to be met. These requirements included payment, construction of a footbridge and continued ownership of the water rights. However, the Council declined this and proceeded with a compulsory purchase (Municipality of Pretoria, 1911:43). Figure 55 shows a section of the channelled river system cutting through the CBD.

By 1928 the Walker Spruit was canalised between the Apies River and Pretorius Street and the remainder of the Walker Spruit between Pretorius and Jorrison was completed between 1934 and 1935 (Van der Waal & Associates, 2000:24).

Figure 55: Canalisation of Apies River with bridge (1951) (Source: Anon, 2013o)

1.4.2 The second era: Pollution in the Apies

During 1911, according to the minutes of the Mayor of the Municipality of Pretoria, while the Apies River was being transformed from a natural river into a concrete channel, residents of the city expressed a need for a body of water with aesthetic value for recreational purposes. A proposal was put forward for the construction of an artificial lake at the Zoological Gardens, forming a dam in the Apies River, in the area between Market Street and Hove's Drift (Municipality of Pretoria, 1911:95-96). However, in October 1911, a report was presented to Council which concluded that the lake would not be viable due to health concerns, and pollutants which enter the river through the subsurface stormwater drainage system. This stormwater drain system was also used at that time to transport wastewater from the CBD, Arcadia and Sunnyside into the river during non-rainy seasons. It was argued that damming the river, which contained pollutants in the dry season, could be dangerous for activities such as swimming and boating. The pollution was described as being so bad that it could be smelled and created a concern to improve the state of the river. In 1911, a sewer system was also being constructed to divert the sewage, which flowed through the stormwater drains, and to link it to the main outfall sewer of Pretoria proper (*ibid*. 95-97).

In an attempt to reduce the pollution of drinking water, the Daspoort Wastewater Treatment Works, with its bio-filtration system, was constructed in Pretoria in 1913. It is still operational today and is one of four wastewater treatment works situated along the Apies River (City of Tshwane, 2011:2). By 1922 the new sewerage reticulation system, commenced in 1913, was still in process of construction in certain remote parts of the city, these areas were also difficult to service in terms of waste water treatment (Haarhoff *et al.*, 2012b:782).

1.4.3 The second era: Water supply issues

Pretoria existed for 62 years (1855–1917) with abundant water supply and often wasteful water usage practices. The trajectory of this scenario changed in 1917 when, for the first time in Pretoria's history, there was a warning sign that there were indeed limits to the town's freshwater resource, which had been used so freely until then. The springs in the Fountains Valley experienced a yield problem, which caused fluctuation in the delivery rate. This matter was discussed at a meeting on 9 March 1917, as reported in the Minutes of the Mayor of Pretoria for the four Mayoral years dated 31 October 1919. According to the Municipality of Pretoria (1919:24), the cause, as concluded by the Town Engineer, the Rand Water Board and the Director for Irrigation, was most probably the extraction of underground water by the mining groups operating on the East Rand. There was great concern as the delivery rate of the springs had decreased over the 14 years preceding 1917, from 36 million litres per day to 18 million litres per day, with an even greater decline since March 1917. This triggered the need to investigate other sources of water and to deal with wasteful water consumption. However, there was no water metering system in place, which made controlling the distribution and consumption of water very difficult. On 9 March 1917 the issue of the water supply for Pretoria was elevated to top priority for the Town Engineer who had to delegate all his other technical duties so that he could focus solely on the issue of water supply (*ibid*. 24).

By February 1918 there were also changes in the land cover of the WMA with a forestation project where various species of *Eucalyptus* (*E. paniculata, E. rostrata, E. xyrodresthrum*) were planted in a golf course. The golf course was situated close to town (*ibid*. 23), [the author assumes that the golf course referred to is the Pretoria Golf Club (also known as the Pretoria West Golf Club), established in 1894] and situated close to the town and in the vicinity of Skinner Spruit in Pretoria West. The main motivation for the forestation project was to create relief work in close proximity for unemployed white people who previously had been employed by the City Council (Municipality of Pretoria, 1919:23).

Alien invasive trees such as *Eucalyptus* spp. are known for their high water consumption when compared to native plants, due to their large scale biomass and root systems and longevity, causing a high rate of evapotranspiration and water use which reduce surface water runoff and groundwater recharge. The reduction of groundwater reduces the base flow feeding rivers and streams. It is estimated that if invasive species in South Africa should grow and cover the area to the full extent of their range it would reduce the amount of groundwater by eight times more than current. In order to avoid this, the Working for Water Program was established in 1995 with an annual budget of R 500 million to control alien invasive species such as the *Eucalyptus* spp*.* so as to decrease water reduction in freshwater systems (Chamier *et al.,* 2012:345).

The underground water supplied by the fountains was the main source of water for Pretoria for 75 years. By the 1920s the water from the fountains was no longer deemed sufficient to meet the demand (Dippenaar, 2013:30). In order to address this problem a comprehensive metering system was proposed in 1923, which was completed in July 1928 (Haarhoff *et al*., 2012b:784). The metering system was not well received despite a general awareness of the declining water resource and high consumption. At the annual meeting of the "Africa District" of the Institution of Municipal and County Engineers in 1923, it was argued that a Council's role is to provide water and not a metering system. At the same meeting a concern was also raised about the extensive watering of gardens, which comprised 50% of the total water usage in Pretoria (*ibid*.). When the metering system was installed, the water saving was 15%. This was not enough to solve the water problem and additional water for Pretoria was needed. The decision was taken to build the Rietvlei water scheme which was completed in 1934 (Haarhoff *et al*., 2012a:23). Most of the Rietvlei dam was constructed by hand with the help of ox wagons and donkey carts (WAMTechnology CC, n.d.7). It was estimated in 1927 that the Rietvlei water supply scheme would double the supply of water (Haarhoff *et al*., 2012b:784).

Downstream, north of Pretoria, the Bon Accord dam was completed in 1923 as part of the Apies River system. It served mainly as a supply for irrigation purposes. From an ecological health perspective, studies in 1975 by Pitchford and Visser indicated that large dams have a negative effect on downstream ecology as they increase water temperature, which can intensify the risk of bilharzia (cited in Ashton, Roux, Breen, Day, Mitchell, Seaman & Silberbauer, 2012:26). This link between ecological and human health was also later confirmed in a report entitled *Atlas of bilharzia in South Africa*, which was published in 1982 by the South African Institute for Medical Research, the South African Medical Research Council and the Johannesburg Department of Health (*ibid.* 36).

By 1943 after several years of negotiations between the City Council and Rand Water, a water pipeline was installed from Germiston to Pretoria. This was operational by 1947, and by 1952 Pretoria consumed 77 million litres of water per day (Stadsraad van Pretoria, 1952:237).

By 1955, the bulk of the water from the Fountains Valley had been taken away in pipes as the water supply to the city, which depleted the supply to the Apies River which was no longer a strong, thriving river (Engelbrecht *et al.,* 1955:152).

1.4.4 The second era: Flooding

Flooding continued to occur in Pretoria and was recorded in 1914, February 1915, 1927, January 1928, January 1931, November 1939, 1940 and 1955 (City of Tshwane, 2006:1; Van Veelen *et al*., 2004:4-18). Figure 56 shows the flow of water in the Apies River during a flood in the 1930s.

During 1923 and 1949 rains were recorded that were accompanied by hail and as a result of the damage and the loss of roofs from the hail, increased the use of concrete for building and houses. The 1923 floods were described as being as severe as the floods of 1909 (Van der Waal, 1996a:3,6).

Figure 56: Flooding of the Apies River in the 1930s (Source: Anon, 2013p)

1.4.5 The second era: Realising the ecological value of freshwater systems

Between 1946 and 1979 the concept of ecosystem services became established in the freshwater landscape in South Africa, both in the institutional as well as the research field (Ashton *et.al.,* 2012). Institutionally, this change in thinking was reflected in 1952 when the Department of Inland Fisheries was changed to the Department of Nature Conservation (*ibid*. 32). In 1953 the first textbook on ecology, *Fundamentals of Ecology* by Eugene P. Odum, was published, explaining trophic dynamics and ecosystems (*ibid*. 17).

The earlier focus on water supply for irrigation changed in 1956 in South Africa with the promulgation of South Africa's first Water Act, Act No. 54 (RSA, 1956). The Department of Irrigation changed its name to the Department of Water Affairs to reflect wider concerns with the problematic state and deteriorating quality of water and the increased demand. The Water Act also introduced standards for treating wastewater effluent before it is discharged back into the natural stream where the natural system completes the purification process (*ibid*. 17). Before this Water Act, South Africa's water policies focussed more on the supply of water for agriculture, mining, industries and urban areas (*ibid*. 32).

Internationally, a seminal work, *Silent Spring,* written by Rachel Carson, was published in 1962, and which gave impetus to the rise of the environmental movement (*Ibid*. 18). This book influenced the change in thinking about how humans, through the use of chemical pesticides, were altering the natural world, causing damage to ecosystems and affecting human health. This book was published 17 years after World War II when there was a great dependence on chemicals in the agricultural production process (Lear, 1998).

1.5 The third era, 1971–2014: Failed attempts to regenerate the Apies River

1.5.1 The third era: Realising the disconnect between the city and the river

This third era in the history of the Apies River, from 1971 to 2014, coincided with a change in international and national thinking about the ecological value of freshwater systems. However, the Apies River flowing through the heart of Pretoria, remained an isolated stormwater channel deprived of ecological functions. This era saw attempts to save and regenerate the derelict and degraded Apies River, but to no avail. Only in 1973, more than 60 years after the Apies River was concreted into a channel, were flood lines determined for the rivers and streams in Pretoria and bylaws promulgated, prohibiting development in the 1:50 flood line. This promulgation was motivated not necessarily in the interest of ecology but more to save buildings and people from floods, and only later, in 2005, did frameworks emerge to protected floodplains because of their ecological significance, as set out in the Tshwane Open Space Framework adopted by the City of Tshwane in 2005. The ecological health of the Apies River deteriorated with many incidents of pollution triggered by adjacent land use, which resulted in serious health issues in the river and the surrounding communities. Despite knowledge of how the ecology of inland freshwater systems function, this era experienced an increase in flooding incidents, which resulted in intensified canalisation of the Apies River in the 1980s. This era also saw conflict between the Local Council and the public about the state of the Apies River and the slow response by Council to improve the pollution situation (Goodman, 1992; Fourie, 1993; Pretoria City Council, 1992:2). There was also unhappiness in the community about the inflexibility and apathy of the Council to regenerating the Apies River where it flows through the CBD. The river was now seen as a danger when floodwaters come down, and an unsightly concrete channel. There was clearly a need to connect with the river again, making it part of the urban fabric, to make it safe, to fight pollution and to create a place where people want to be.

1.5.2 The third era: Realising the ecological significance of freshwater systems

During the 1980s and 1990s in South Africa, the importance of the ecological functions of water slowly started to be understood in the water management arena, for example with the first textbook on wetland ecology in South Africa being published by Mitsch and Gosselink in 1986; also in 1986, following a workshop arranged by Tony Ferrar, an approach was developed to define the ecological flow requirements of rivers and the functioning rules for water storage reservoirs; and in 1990 the text book on *Inland Waters of Southern Africa: An Ecological Perspective* was published by Allanson, Hart, O'Keeffe and Robarts. Environmental considerations emerged about the consequences of inter-basin transfers and the irreversible effects of taking water from where it naturally occurs and transporting it far away to serve urban centres, agriculture and industry, degrading the natural system. The necessity of carrying out in-depth environmental impact assessments (EIAs) was recognised. As a requirement for this, the *Red Book* on the management of water resources in South Africa was published by the former Department of Water Affairs in 1986, and recognised the importance of valuing ecosystems in water resource management and ecosystems as water users (Ashton *et al*., 2012:37). A set of river health indicators was also developed during the 1980s and 1990s, a system for the classification of rivers was defined, and detailed ecological studies of rivers were carried out, including the Vaal and the Crocodile (East) rivers. In 1998, South Africa's Inland Water Ecosystems Program (IWEP) was evaluated and it was found that despite the state of the country's scarce water resources, limnology research in South Africa was under-funded and not supported even though it is one of the most needed research fields in South Africa. Secondly, the evaluation found that the programme did not adequately address environmental concerns and threats to water (Ashton *et al.,* 2012:36-41,49,50,67).

During the early 1980s, awareness of how much water is required to fulfil ecosystem services emerged in South Africa and by the end of the 1980s ecosystems became a recognised water user in terms of water management in South Africa. In the early 1990s this realisation motivated the development of the River Health Program and guidelines for water quality in order to sustain aquatic ecosystems. Globally the twentieth century was the era of dam building and in South Africa, 100 new dams were built every decade for the last part of the century (Ashton *et al.* 2012:57). From an ecological perspective, it was evident already in the 1970s that dams are responsible for costly river degradation, and internationally information started to emerge about the link between water flow and ecological processes in rivers. However, due to the political sanctions against South Africa during that time, the new scientific thinking was not mainstreamed in South Africa (*ibid*.57, 58, 60).

It is ironic that with this background of new ecological thinking in the 1980s, the canalisation of the Apies River was intensified and expanded in 1981 in response to severe flooding in 1978. Canals were built in Sunnyside, the CBD and other parts of the city in order to control the path of flow and to minimise flooding. During the floods in 1978, the Joos Becker Caravan Park was flooded and had to be moved as it was situated in the 1:10 flood line. One solution put forward to tame the Apies River was a 4 m-high retaining wall, but this was considered by the Council to be too expensive (Hefers, 1981).

1.5.3 The third era: Pollution in the Apies River

During late September and October 1981 an outbreak of cholera was reported, which was caused by raw sewage contamination of the river due to an ineffective sewerage pump at the Hammanskraal Sewage Works. More than 10 different newspaper articles were written about this in October 1981. The reports included the following information: cholera broke out on 26 September 1981 in Temba in the former Bophuthatswana, situated 45 km north of Pretoria, where 4 people died and up to 30 patients were admitted to hospital per day. Clean water had to be brought in by the army to relieve the communities (Strydom, 1981). The cholera contaminated the stretch of the Apies River between the Bon Accord dam and the former Bophuthatswana with most of the contamination occurring in Hammanskraal where communities drank untreated water. On 6 October 1981, 116 cases of cholera were reported

(Stoltz, 1981). By 13 October 1981 it was reported that 150 people had been treated for cholera and 4 had died (Loubser, 1981). The majority of the people that were admitted to hospital lived on the banks of the Apies River (Anon., 1981).

The river was also used by some for illegal dumping and in 1984 one of these cases ended up in the Pretoria Supreme Court. A Mr Botha, who lived next to the Apies River, went to court to try to stop illegal dumping of building rubble, which caused damming of the river and resulted in silting and flooding when the river came down. The silting blocked a water pump which meant that heritage plants on Mr Botha's property could not be watered, and the stagnant water created a breeding place for mosquitoes and an unpleasant smell (Anon., 1984).

The poor and unhealthy state of the Apies River continued and, in 1988, the Bon Accord dam was infested by hyacinth washing in from the Apies River. The hyacinth covered 80% of the surface of the dam, a maintenance problem for Mr Degenaar, who leased the dam during that time and who had the responsibility to keep the dam clean. It would have costed Mr Degenaar between R50,000 and R100,000 if he would have had to clean the dam on his own. An increase in flood severity, caused by the increase in tarred roads, concrete and buildings in the Pretoria CBD, damaged and eroded the 17.5 m-high, earth wall of the Bon Accord dam, and the wall had the potential to be eroded to such an extent that it could collapse during heavy rains. The Department of Water Affairs refused to provide support to clean up the dam as it did not belong to them; however the Council did indicate that they were prepared to consider providing support through negotiations with the Bon Accord Irrigation Board (Blackie, 1988). It is not clear whether the Council provided the support in the end or not.

On 11 March 1992, 10,000 litres of transformer oil were spilled into the Apies River, spreading 11 km along the river. All the pollution was cleared except for the shallower ponds in Flower Street. Fast cleaning up stopped the oil reaching the Bon Accord irrigation dam and it was reported that there were no fish or bird deaths (Anon., 1992a). It is believed that the oil was spilled from a storage tank in the Pretoria West area and oil-absorbing barriers were erected in the river to prevent the spillage spreading. This oil spill followed six months after an accident caused half a million litres of aviation fuel from the Waterkloof Air Force base to be spilled into the Apies River close to the Fountains Valley, causing numerous bird deaths (Snyman, 1992).

In 1996 rainwater and stormwater infiltrated the sewerage and grey water system in Pretoria, either due to illegal connections between the two systems, or as a result of rain overloading a system already filled to capacity and causing the system to overflow, spilling sewage-contaminated water through lower lying manholes, and polluting surface water. Such a situation could not be managed until such time as the surface water flows had normalised (Muniforum, 1996:4).

During 2000, and as a result of high levels of eutrophication in the Apies River, fish died due to low oxygen levels upstream and downstream from the Bon Accord dam, combined with a high concentration of Atrazine, a herbicide, and Endosulphan, an organochlorine insecticide, which is very toxic to fish (Hohls & Van Niekerk, 2000:9). It was reported in November 2006 in the publication *Atlas of Freshwater Ecosystem Priority Areas in South Africa* that the biological control agent*, A. katangae,* which uses neustonic organisms which are the microscopic organisms floating on top of the water, disappeared from the river system as a result of pollution, abstraction of water and the use of pesticides (Smith-Adao, Nel, Roux, Shonegevel, Hardwick, Maree, Hill, Roux, Kleynhans, Moolman, Thirion & Todd, 2006:31). The ecological integrity of the river was also under threat because of the destruction of habitat.

In 2002, reports again emerged of pollution and erosion in the Apies River, especially during rainy seasons, causing siltation just before the Bon Accord dam. The pollution was so severe that the contaminated mud left behind on the floodplain resulted in the death of livestock. Farmers and residents complained as they had to carry the cost of the effects of this pollution (Sieberhagen, 2002).

In 2010, the Apies River was again plagued by pollution, this time caused by raw sewage, which leaked from the Rooiwal Sewage Works, due to an inadequate pumping system. Concerned farmers claimed that the pollution caused loss of livestock and affected the irrigation of more than 500 ha of vegetables. Fish in the dams on the farms also died and irrigation pumps feeding water from the river clogged up as a result of the raw sewage (Claassen, 2010a). It was later reported that the pollution was in fact not only caused by the inadequate capacity of the pump which caused sewage to leak into the water after the last sewage treatment stage, but also general lack of management capacity and maintenance at the works. Water tests that were conducted on 2 November 2010 at the sewage plant indicated that the water which was released was unsuitable for irrigation of vegetable crops that will be consumed raw, for drinking water or for recreational activities such as playing and swimming in the water. The poor quality of the water was caused by contamination from *E.*

coli with a count of 22,000 and a faecal coliform count of 59,000. Both of these counts were far beyond acceptable limits. There should be no *E. coli* in drinking water and *E. coli* should not exceed 1,000 units per ml in rivers (Claassen, 2010b). The faecal coliform count should be between 0 and 100 units per 100 ml, otherwise there could be serious health consequences. It was alarming that children were exposed to the polluted water in the Hammanskraal area where they played along the river (*ibid*.). AgriForum was tasked by the commercial farmers in the Hammanskraal area to lead an investigation and discussions with the City Council on this matter. They requested the Council to declare the area a disaster area (Metro Reporter, 2011). In 2011 this area was in fact declared a disaster area by the Department of Water Affairs and Forestry and R11 million was allocated by the Council for the upgrade and maintenance of the Rooiwal Sewage Works (Anon., 2011a). Although the Council had tenders in place in October 2011 to appoint contractors, a management plan and funds of R303 million to increase the capacity of the sewage plant, there was still no relief for the farmers. For the farmers the sewage spillages posed a serious health threat and a challenge to economic well-being as they compromised their source of irrigation and water for household use. The impact of the Rooiwal Sewage Plant on the quality of the water had been a concern since 2009 when the farmers first complained, but no concrete action was taken by the Council other than to say that the water is suitable for irrigation should precautions be taken (Anon., 2011b). The contaminated water also filtered into the groundwater supply, which serves as a water source for household use (Batt, 2012).

A year later, on 18 July 2012, it was reported that much improvement has been done at the Rooiwal Sewage Plant and more improvements are planned with tenders, for the extension of the plant, already awarded (Batt, 2012).

1.5.4 The third era: Attempts to upgrade the Apies River

The Apies River, tightly contained in a concrete channel, between buildings on both sides with their backs turned to the river, was a concern for residents who wanted to see the quality and aesthetics of the river improved. Proposals to upgrade and revive the Apies River in the centre of Pretoria were presented in the 1970s.

In 1974, a group of University of Pretoria architectural students described the Apies River as "… a litter-strewn drain slicing through the heart of Pretoria." They developed a proposal to upgrade the Apies River which entailed constructing a river on top of the existing channel to serve as a water feature with a constant water level, allowing for greenery and recreation and allowing the Apies to flow underneath in a closed stormwater drain (Anon., 1974a). Two months later another group of third year architecture students proposed an upgrade of the Apies River channel and the areas around it to include bicycle and pedestrian lanes from one end of the city to the other and a big lake at the Kirkness Brickfield excavations (Anon., 1974b).

Later, during the mid to late eighties, community organisations and forums were established to try and improve the state of the Apies River. There was the *Burgerlike Trust* (Civic Trust) which started with action to upgrade the area around Lion Bridge in 1985, in the hope that the Council would extend the beautification of the river from the Fountains Valley to the Zoo. The upgrade included paving, cleaning the cast iron lions on the bridge and students painting colourful decorations on some of the walls of the river channel. The Trust also put forward some ideas relating to elevating the water level of the Apies River using weirs to regulate the river's water level (Anon., 1985).

Hillview High School in Roseville rehabilitated sections of the river in 1987 by cleaning up the river, removing exotic plants and rehabilitating the river's edge with vegetation that would have been indigenous to the area 200 years ago, restoring the area to its original ecological state. They used cranes to remove large chunks of concrete from the river which had been dumped there after the construction of the Apies River Road (Anon., 1987b; Millard, 1990).

In 1991 the City Council upgraded the Apies River channel in the Moot, in the area from the Portland Cement factory to Es'kia Mphahlele Road (previously DF Malan Road) in order to combat erosion, siltation and rubble. The upgrade included the widening of the river channel, planting grass and trees on the edges and cleaning away sedimentation (Anon., 1991).

During 1992 a public debate started between the Council and citizens with news headlines about the desperate state of the Apies River. This debate was triggered by the fact that the Council wanted to approve the development of a lake in Sunnyside, prior to addressing the state of the Apies River. This triggered various responses by the citizens in Pretoria. One of these responses was by Mr Herman Strydom, the spokesperson for Earthlife Africa, who wrote a letter to the Pretoria News dated 26 August 1992, expressing his concern about the neglect of the Apies River as a natural asset for the city, when compared with the beauty of the other natural assets such as the surrounding hills. Herman Strydom further reflected that the concrete channel of the Apies River was a high-speed water channel which caused loss of life for both humans and animals. He recommended that in order to improve this, the river should be made more accessible and human friendly by making the channel smaller therefore decreasing the depth of the channel and creating variation in water levels in order to reduce the velocity of the water. He also recommended planting grass and trees and building pedestrian walkways along the edges, making Pretoria a people-friendly city for its citizens (Strydom, 1992).

The neglect of the Apies River and failure to upgrade it led to a protest by Earthlife Africa on Saturday 29 August 1992, which requested privatisation of the properties along the river in an attempt to create ownership to manage pollution. The cleaning up of the neglected Apies was supported by the organisation *Hou Pretoria Skoon* (Keep Pretoria clean) (Anon., 1992b). The protest took place on the Lion Bridge in Church Street (today known as Stanza Bopape Street) and protestors demanded that pollution in the river be eliminated and that the Apies River become a green open space, safe for animals and residents (Helfrich, 1992). On 4 September 1992, another organisation, The Pretoria Civic Trust, also lobbied that the Apies River should be upgraded before the commencement of the Sunnyside lake project. They argued that upgrading the Apies River from Fountains Valley to the Zoo and even up to Wonderboompoort would increase the value of properties along its banks and that the area around Steenhoven Spruit would be better suited for the development of a lake (Anon., 1992c).

There was increased debate about the Apies River after the Earthlife Africa protests and more newspaper coverage. Another letter appeared in the Pretoria News on 1 September 1992 written by a Mr Goodman with the headline "Save the Apies River before it is well and truly past saving". The letter supported Earthlife Africa's approach of privatisation of land next to the Apies River, suggesting also the planting of trees and grass on the edges of the river and the cleaning up of rubble to create spaces along the river for activities that would encourage people to use the area, making it safer. Mr Goodman stated in his letter about the Apies River "We have allowed it to become an ugly and dangerous rubbish dump" (Goodman, 1992).

On 5 October 1992, this debate continued with another newspaper article, with the headline "Call on Council to clean up Apies", which reported on a second protest which was held on Saturday 3 October 1992 at Lion Bridge by Earthlife Africa who were still waiting for a reply from the Council on what would be done about the litter, the proposal for a walking trail and the mobilisation of the residents to own the area next to the river. As the Council did not respond, it was compared to the three monkeys who see no evil, hear no evil, and do no evil in an article in the Pretoria News in October 1992 (Anon., 1992d).

Eventually, in response to the protests, newspaper articles and letters, the Council responded in the Council's Muniforum publication of October/November 1992 and addressed the main issues which were raised by the public which were: a) the pollution of the Apies River; b) the dangerous steep slopes of the concrete channel which pose a hazard for children; c) the removal of the concrete channel to make the river more natural; and d) upgrading of the river through developing hiking trails and establishing trees and grass along the river. The Council responded to these concerns as follows: a) The pollution cannot be solely the responsibility of the Council as it has a limited cleaning team who has to manage all the litter accumulating from the streams feeding into the Apies. b) The dangerous angle of the concrete slope cannot be changed to step down gradually, because it is impractical and would interfere with the flow space of the water and the management of the current 1:50 year flood line which the channel accommodates. This solution would require the rebuilding of the channel and the loss of mature trees along its edges and it would be too costly for the Council. c) The option to return the river to its natural state was also not supported by the Council. It was felt that it would interfere with the discharge capacity of the river and could cause flooding to nearby properties. The width of the river in 1909 was much broader and still resulted in flooding and death, which according to the Council triggered the process to canalise the river in 1910. d) Upgrading of the areas surrounding the channel would be discussed with the potential developers of the Sunnyside Lake project. The paving of a walkway along Walker Spruit leading to Sterland was nearly completed. The Council reiterated that they would try to improve rivers and streams and keep them in their natural state as far as possible. The Council also mentioned that this had already been done in Parktown estate and Mayville where grass and 200 trees were planted in an attempt to naturalise the edge of the river. The Council also mentioned the partnership with the Hillview High School that became guardians of their river frontage which they cleaned and beautified (Pretoria City Council, 1992:2).

A few months later there was more criticism relating to the Apies River. On 25 January 1993 it was stated in the Beeld newspaper that the Apies River, once the reason for the establishment of the city, was now a forgotten landmark (Fourie, 1993).

Earthlife Africa gained some support from organisations such as the heritage organisation, Stigting Simon van der Stel, which also demanded an upgrade to the river in the inner city to make it more human friendly, and demanded privatisation of the properties next to the Apies River in order to create custodians of the river that could be responsible for keeping their section of the Apies clean. The city engineers responded that removal of the concrete channel would be too expensive and that it would require the design to accommodate the 1:50 year flood line (*ibid*.).

In January 1993, the Council confirmed a R7 million upgrade and widening of the river canal in the Parktown Estate and Mayville North area in order to accommodate houses which had been built within the 1:50 year flood line (*ibid*.).

Despite the protests in 1992 about the neglected state of the Apies River, the Council pursued the proposed controversial city lake project while the river was still in a state of dereliction, and in July 1995 the outcry to save the Apies was in the media headlines again. Mr Mike Meyer, a Pretoria attorney, objected to the rezoning application for the city lake, which he argued was against the Council's city planning priorities of renewing the river for recreation and business activities before a new lake development could proceed. The Council then conducted an ecological and urban design analysis of the Apies River in order to establish principles to guide development adjacent to the river. It was reported that the Council regarded the Apies River purely from a practical point of view, i.e. the river should fulfil the function of a stormwater drain, and the Council took the attitude that it was not financially feasible to remove the concrete and re-naturalise the river (Fourie, 1995a).

In an attempt to improve the Apies River, and in response to the city lake project, third year landscape architecture students at the University of Pretoria again developed proposals in November 1995 for the redesign of the canalised Apies River. Some proposals included keeping one side of the river natural in an attempt to change the historical disconnection between the river and adjacent developments which had turned their backs on the unsightly channel (Uys, 1995). Some of the proposals suggested that the Apies River be rehabilitated back to a winding natural river and making it more accessible to humans (Fourie, 1995b).

During 1995 the Action Apies River Forum was established to revive the Apies River and its surrounding area as an asset and to enhance the tourism potential of the city. In order to achieve this, the forum suggested upgrading historical bridges such as the NZASM Bridge built in 1889 near UNISA and the Lion Bridge built in 1895 (Hlahla, 1996).

In 1998 work began on the cleaning of the Apies River in the city centre and Sunnyside included the fixing and strengthening of the concrete channel and the removal of the indigenous trees, *Vachellia karroo* (previously *Acacia karroo),* on the edge of the river, which residents were not very pleased about, as a preventative measure for when the river comes down in flood (Strydom, 1998).

Another cleaning-up initiative was launched in 2003 as part of a public private partnership led by the Hercules branch of the PPC cement factory and the owner of the DF Malan Street (today known as Es'kia Mphahlele Drive) filling station. They initiated the clearing of pollution and alien vegetation from a section of the Apies River which flows through the west of Pretoria (Lourens, 2003). There was also upgrading of the Apies River in the area of the low water bridge in Capital Park, with desludging and the construction of a river edge protection where the edge was eroded and planting of trees and grass (Bruwer, 2003).

According to Van Veelen *et al.* (2004:1) the flow of the river has been altered by erosion in the floodplain, caused by land use changes upstream. The erosion has caused siltation which congests the inlet of the Bon Accord dam. In order to address this problem the Council had to develop a restoration management plan for the area of the Apies River from north of Wonderboompoort to the Bon Accord dam. The City of Tshwane appointed the consultants BKS (Pty) Ltd in association with PD Naidoo and Associates (Pty) Ltd, who compiled a restoration management plan by August 2004, for the specific section of the Apies River.

Action needed to be taken with regard to existing structures and services that were located in the floodplain of the Apies River area from north of Wonderboompoort to the Bon Accord dam. There were two options: a) relocate the structures or b) let the structures remain, and reduce the floodplain by building berms to contain flooding. A river course summary was compiled with the assistance of historical aerial photographs from the years 1937, 1948, 1958, 1964, 1968, 1991, 1994, 2001 and 2003 to determine the extent of the movement of the river in this floodplain. The recommendation of the management plan was to reduce the floodplain, which was called "improvement of the flood lines", and protect buildings from flooding by constructing a berm on both sides of the river to contain the flow of the river (*ibid*. 6, 4-18). The river course summary of one of the sections of the study area where the river flows underneath the N4 Bakwena highway and enters the inlet of the Bon Accord dam is illustrated in Figure 57. It contains flood movements extracted from historical aerial photographs which show how the bridge, which was built over the original delta, obstructed and diverted the flow of the river, forcing the river perpendicular to the road. This man-made stream diversion could be a contributing factor to the erosion in the delta during high floods, affecting the conditions at the inlet of the Bon Accord dam and changing the reservoir sediment deposition pattern (*ibid*. 4-23, 4-24, 4-26).

Additional to the clean-up campaigns in the early 2000s, a campaign to manage the area next to the channel in Sunnyside, which had become a hiding place for vagrants and a store for stolen goods, was initiated on 14 August 2008. The waste management section of the Council and the metro police launched a joint campaign to make the river safer and to clean the edges of the river along Sunnyside. Trees were also planted in Sunnyside at the Apies River as part of the *Bontle ke Botho* initiative (beauty is humanity) (Poo, 2008).

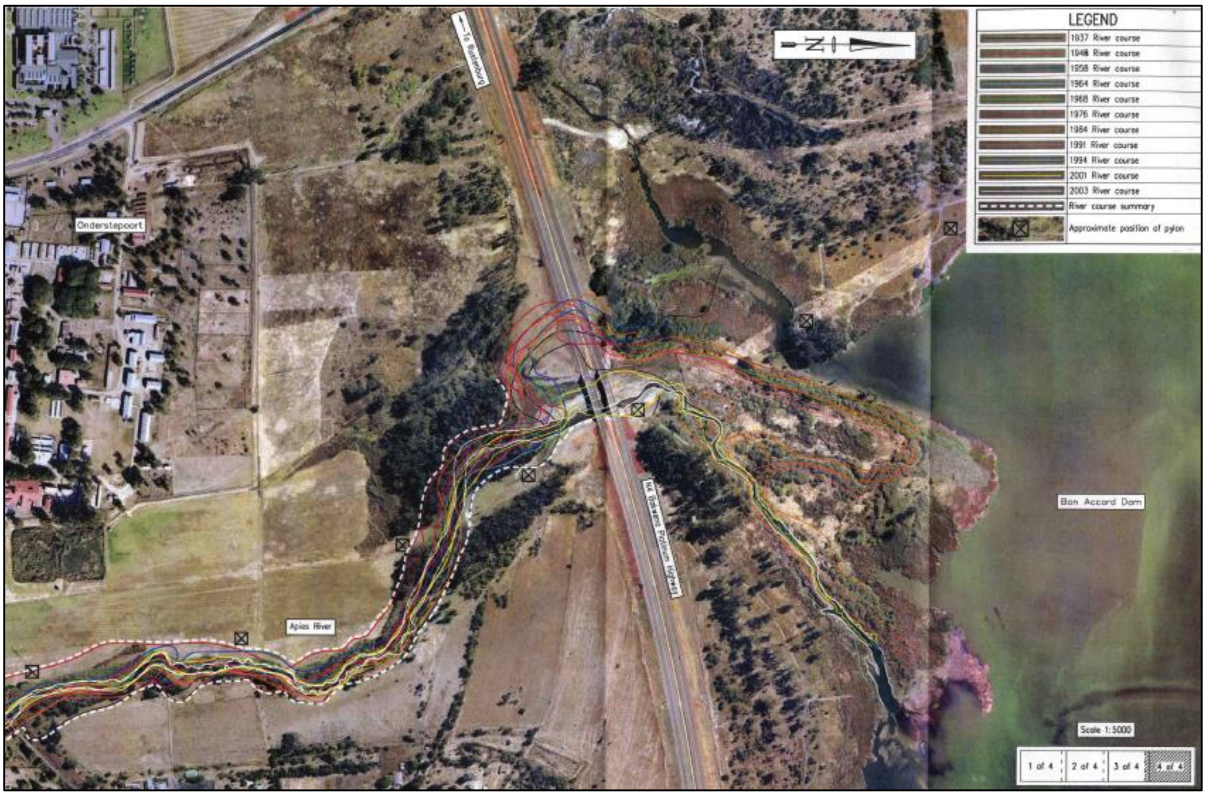


Figure 57: Apies River Rehabilitation: Course summary (1937–2003) (Source: Van Veelen et al., 2004: Appendix B, Figure B.1 (4 of 4))

1.5.5 The third era: Flooding

During the third era of the Apies River (1970–2014) flooding incidents intensified as follows:

January 1978

Although this flood had the same magnitude as the flooding of 1909, the impact of the flooding was much worse due to increased development close to the Apies River (Van Veelen *et al.,* 2004:4-18).

1 December 1987

Rains of 15.2 mm per hour caused severe flooding (Anon., 1987a). In response to these floods, the Council, in 1981, converted almost the entire length of the river flowing through Pretoria into concrete channels in an attempt to reduce future flooding (Hefers, 1981).

22 December 1992

Intensive rain over a short period of time with reports of three bodies seen in the Apies River (Anon., 1992e).

12 February 1994

Severe flooding occurred when 62.3 mm of rain fell over approximately 24 hours. Most of the flooding occurred in developments closest to the river such as the Wonderwaters caravan park in Wonderboom. The streets in Sunnyside, the basement of the Sunnyside shopping centre and Fountains Valley were flooded (Gouws, 1994). Fallen trees were reported, and the Watloo business park was 1 m under water. The Joost Becker caravan park in Mayville was flooded for the second time in a year when it was hit by a backlash wave in the horse shoe bend of the river where the caravan park is situated (Botha, 1994). Houses were damaged by the floods in Laudium, Menlo Park, Faerie Glen, Brooklyn, Mamelodi, Saulsville (where squatters suffered the most), Atteridgeville and Hatfield (Rodney, 1994).

By 1995 most of the Apies River had been canalised, making it very dangerous for people to go close to the river. On 11 March 1995 news headlines warned about the danger of the Apies River for children. The channel is particularly dangerous after a heavy rainstorm when a sudden flush of water, conducted into the channel by the stormwater pipes, can move rapidly. This flash flood can last for at least fifteen minutes and is a danger for children playing in the river when caught unexpectedly. An added danger is that the water can contain pieces of rubble, broken glass, sharp stones and tree trunks (Neethling, 1995).

January and February 1996

Again, although the floods in January 1996 had the same magnitude as the 1909 floods, the impact was much worse due to increased development close to the river (Van Veelen *et al.,* 2004:4-18). Heavy rains of 266 mm fell over 3 days from 12-14 February 1996 (measured at the Pretoria Zoological Gardens), which caused severe flash floods (De Coning, Forbes & Poolman, 1998: 25,26).

2004

Several articles in the public media reported loss of life in the Apies River, due to floodwaters. The headlines of these articles included: "Police search for child in raging Apies River'' (Zeilhofer, 2004a); "Body is found in the Apies" (Hills, 2004; Zeilhofer, 2004b), "When in flood the 'mighty' Apies is a killer" (Zeilhofer, 2004c). The water was described as too turbulent for rescue workers and the emergency personal of Pretoria pleaded for people to stay away from the river.

January and February 2006

Pretoria received 258 mm of rain in January 2006, as opposed to the average of 136 mm, and 159 mm in February, as opposed to the average of 75 mm (City of Tshwane, 2006:4). The severe rain caused flooding of the Lower Apies River basin and resulted in 1) blocked stormwater catchment pits; 2) selective flooding of houses due to a stormwater system which was either blocked or inadequate; 3) potholes in the roads; 4) flooding along water courses where a 1:50 year flood was not accommodated by a number of bridges, such as the bridge in Flower Street in Capital Park, bridges in Sunnyside which were flooded by the Walker Spruit, and bridges which were overtopped by the Moot Spruit. Lastly, erosion and sinkholes formed in the Groenkloof Nature Reserve, as a result of intensive stormwater coming from the Waterkloof air force base (*ibid.* 7). It was estimated that the funds needed to address the problems related to this flooding amounted to R16.7 million in the Lower Apies River Basin and R113.5 million in the Upper Apies River Basin (*ibid*.29).

The floods of 2006 were worse in the areas north of Pretoria where there were no proper stormwater drainage systems. Pretoria and Centurion experienced less flooding as they had sufficient stormwater drainage systems (*ibid*. 1). In an interview conducted with Mr Jansen van Vuuren, Chief Engineer: Integrated Stormwater Planning from the City of Tshwane's Transport and Infrastructure Planning Division, on 21 June 2013, it was highlighed that another factor which played a part in the flooding in 2006 was that water could not seep into the soil due to the impenetrable granite layer underneath the granite sand layer. It was therefore not the rivers overflowing that caused these floods, but the standing water, which was unable to penetrate into the subsurface layers of the soil.

On average five people reportedly fall into the Apies River every year (Zeilhofer, 2004c). Particularly vulnerable to the floods are the homeless people who use the river on a daily basis. It is dangerous because the sides are steep and slippery, particularly at Lion Bridge, Johannes Ramokhoase Street (previoulsy Proes Street), Struben Street, Burgers Park and the low level bridge in Capital Park (*ibid.*).

1.5.6 The third era: Water shortage

In 2004 it was projected that the Crocodile West and Marico WMA, within which the Apies River flows, would require large additional water transfers by 2025 from the Upper Vaal WMA to meet the increase in demand for water. The transfers would increase the amount of return flows downstream and so would require management to balance the re-use of return flows and the transfer of water (DWAF, 2004:41).

1.5.7 The third era: Recognising the importance of flood lines in land use

As described earlier in this chapter, Pretoria was governed for 48 years without a Local Council to guide local development and address residents' needs. In addition to this, for the first 120 years of Pretoria's existence (1855–1975), there were no laws to protect freshwater ecological assets or integrate them into urban land use or requiring their consideration as part of development proposals. Laws, bylaws and Council decisions guiding developments in relation to the Apies River and its flood line were only enacted between 1973 and 1975.

In 1973 the Pretoria City Council started to determine flood lines along the rivers and streams. Then in 1975 the Council passed a bylaw prohibiting any building to be built within the 1:50 year flood line (Redelinghuijs, 1996:3).

In 1998 the National Water Act (Act No. 36), (RSA, 1998), required that the 1:100 flood line must be indicated and noted on all development plans. However this section (144) of the Act does not prohibit developments within the 1:100 flood line.

Further national regulations include Section 10 of the National Building Regulations and Building Standards Amendment Act (Act No. 49) (RSA, 1995), which prohibits building on sites which are subject to flooding.

In 2005 the Tshwane Open Space Framework was approved by Council, which stipulates that no developments are allowed within the 1:50 year flood line, and that this flood line area, or the area which extends 32 m on either side of the centre line of a watercourse, whichever is the greatest, should be reserved as public open space and Council land. It also stipulated that stream modification in the form of canalisation or installing artificial linings should not be allowed. It would also not be allowed to amend the 1:50 year flood line by means of infilling (City of Tshwane, 2005:123).

1.6 Conclusion

It can be concluded that the Apies River functioned as a natural freshwater system during the historical era between 1855 and 1910, a total of 55 years. During this era, several disturbances challenged the state of the river and eventually weakened the resilience of the natural freshwater system to such an extent that the river changed from a natural system to a man-made concrete stormwater channel. Over this period, the Apies River experienced both press and pulse disturbances. One of the main press (slow) disturbances which acted continually on the Apies River system was the absence of a Local Council to manage service delivery and which caused pulse disturbances of pollution of the drinking water, which in turn, caused pulse disturbances of disease. Another slow pressure on the Apies River system, which spanned the first and second era, was the absence of a regulatory framework for development in relation to floodplains. This resulted in a press disturbance of development in the Apies River floodplain, which slowly degraded the freshwater ecosystem and reduced the freshwater ecosystem services that the natural flowing river used to provide. Years of urban land use change, which slowly pressed against the functioning of the freshwater system, caused an increase in the pulse events of flooding. The lack of regulation of development within the floodplain can be ascribed to a lack of understanding of the dynamics of the natural freshwater system and a disregard for the freshwater system's value as a provider of services for human well-being. There was also a psychological disconnection – a perception that nature is separate from cities and that nature cannot exist in urban areas. This first era ends with the first democratically elected Local Council in Pretoria in 1903.

The Apies River freshwater system entered a second historical era which lasted for 60 years (1910–1970), during which the connection between the urban fabric and the river underwent visible changes. There was the change in the quality of the connection between the city and the river with the construction of the concrete channel to contain the Apies River in an attempt to prevent flooding and to divert stormwater from the city centre. The channelling of the river changed the physical and physiological connection between the river and urban dwellers — the river became a place to fear, an object to hide and to push away into a confined space where its function as a stormwater channel could be controlled. This trajectory of change turned the Apies River from a natural system with ecological functions and services to a sterile concrete channel conveying stormwater and floodwater away as quickly as possible, with a reduction in ecosystem services. This era was typified by a lack of appreciation for freshwater as a limited resource of which the allocation and consumption needed to be managed. There was also a lack of understanding of what natural freshwater systems can provide to the city and that freshwater systems need to be preserved as part of a water catchment area and their functions acknowledged as an integral part of the urban fabric. After the first democratically elected Local Council in Pretoria was established in 1903 the first sewerage reticulation system was installed in Pretoria in 1913. A response to the desperate need for an improved sewerage system had taken 36 years (1877–1913).

In the third era of the Apies River, (1971–2014) there were many failed attempts at regeneration of the river. Regulations were finally introduced to manage development in flood lines 72 years after the establishment of Pretoria as a town. Incidents of flooding increased compared to the previous eras, which were directly related to the greater percentage of impermeable urban surfaces and the extensive channelling of the Apies River and its tributaries. The quality of the water in the Apies declined, something which can be linked to urban development and land use activities associated with the river such as industries, informal settlements, agriculture and sewage treatment works. The perturbations of land use change, increased sealed surfaces and pollution return flows culminated and worsened in this era. There was also a stronger awareness of the degenerated state of the river and the associated negative impact thereof.

It can be concluded that every historical era of the Apies River SES was characterised by a set of pulse and press disturbances affecting the adaptive capacity and the resilience of the river. The changes in the Apies River system as part of the SES will be analysed further in the next chapter. The analysis will identify how the different press and pulse disturbances affected the adaptive capacity of the Apies River in the context of the SES. The analysis will also identify the principles of resilience that were present or lacking in the system.

CHAPTER 5 - DISCUSSION

1.7 Introduction

> *Since the great flood [9 January 1909] the Aapies River and the Walker's Spruit have been punished for their misbehaviour by being canalised. For the crime of drowning children and peaceful inhabitants, they have been sentenced to imprisonment for life, between walls of reinforced cement. Once upon a time they meandered, unchecked and fancy free, through the suburbs and the town, turning and twisting as their moods prompted. When the storms came, they rushed to Wonderboom, through Daspoort and across the Moat Valley. Then, as they swept past, they tore all their banks and cut fresh races for themselves wither they listed. Such disorder could not be permitted for long. It was all very well while Pretoria was a dorp [town] and land not too valuable. We liked the odd vagaries of the little river and its faithful tributaries; but as time went on this playfulness became a nuisance* (Macmillan, 1936:329-330).

By understanding the history of a system, its various disturbances and its responses to the disturbances, it is possible to understand the resilience of the system (Walker & Salt, 2006: 118, 123). In order to gain a better understanding of the resilience of the Apies River, the following three layers of analysis were applied to the history of the Apies River:

a) Identifying historical disturbances: Based on the description by Lake (2000:574), one layer of the analysis considers the historical disturbances and what the potentially damaging forces in the environment of the freshwater ecosystem were. Disturbances can be pulse (quick) disturbances such as floods, or press disturbances (slow), which are maintained over a long period of time, such as land use change.
b) Identifying characteristics of resilience in the system: A second layer of analysis identifies characteristics of resilience that were present or lacking in the system that can provide an indication of the adaptive capacity of the system. The characteristics of resilience, which are referred to as part of the analysis, are limited to: tightness of feedback, diversity, flexibility, ecological variability, the integration of ecology into urban planning and the acknowledgement of slow variables.
c) Identifying aspects of adaptive capacity: The third layer of the analysis considers the aspects that strengthen the capacity of the system to adapt to disturbance and change. These are: 1) the ability to learn how to live with transformation and unpredictability; 2) the ability to learn how to support diversity in order to allow the system to restructure and regenerate; 3) the ability to combine different types of knowledge and learning; and 4) the ability to create opportunity for self-organising and regeneration (Berkes *et al*., 2002:345, 355).

1.8 Press and pulse disturbances in the Apies River SES

The Apies River experienced several press and pulse disturbances throughout its 159-year history as part of the city, which affected the system's capacity to adapt to change. The press disturbances in particular made the system more vulnerable and reduced the resilience of the Apies River SES.

Press disturbances are slow and constant pressures on a system, which eventually cause a system to deteriorate. According to Walker and Salt (2006:10, 59) slow changes are more difficult to detect and therefore more difficult to act upon, whereas quick changes like floods are very noticeable and easier to respond to. When systems cross thresholds, it is mostly due to the pressures of slow changes. Thresholds are described by Walker and Salt (2006:60) as ''… levels in controlling slow variables after which feedbacks to the rest of the system change crossing points that have the potential to alter the future of many of the systems upon which we depend.'' Biggs *et.al* (2012:429) further describes the relationship between slow and fast pressures in a system, ''Slow variables determine the underlying structure of SES, whereas the dynamics of the system typically arise from the interactions and feedbacks between fast variables that respond to the conditions created by the slow variables.''

The press and pulse disturbances that occurred in the Apies River over 159 years are highlighted in Figure 58, Figure 59 and Figure 60 and are set out according to the three historical eras of the Apies River, based on the detailed timeline given in Appendix 1.

1.8.1 Apies River first era: Natural era (54 years): 1855–1909

Based on the study of the history of the Apies River (focal system), various press and pulse disturbances have been identified during the natural era of the Apies River and are described in Figure 58.

The press disturbances which occurred during the natural era (first era) include:

a) Governance: The absence of a local government, and inconsistent, temporary and inflexible government institutions meant that the management of water resources and infrastructure needs (stormwater, sewerage and water reticulation) were not addressed.
b) Stream modification: The first bridge was built in 1848. Bridges can affect the ecology of freshwater systems if they alter the natural flow of a river or cause the removal of riparian

vegetation and vegetation in the water, which also affects the habitats of fauna and flora and reduces the hydraulic capacity of the stream (GBMCA, 2015). In 1905 the first canalisation of the watercourses in the city began followed by the installation of subsurface stormwater drains and paved walkways in 1906, increasing the disturbance on the natural water system which included the increase in the amount of and speed of water in the water courses in Pretoria.

c) Land use change: Urban land use encroached onto the floodplain with no regard for the freshwater ecosystem's diverse and dynamic patterns. Urbanisation affected the permeability and overall diversity of the vegetation, and the diversity of the freshwater system. Land use close to the river's edge has a bigger impact on the functioning of the freshwater system than activities further away. No legislation or guidelines existed with regard to land use adjacent to a river.

d) Overuse of water: There was very little appreciation for the protection of the abundance of the water resource or attempts to protect the quality of water.

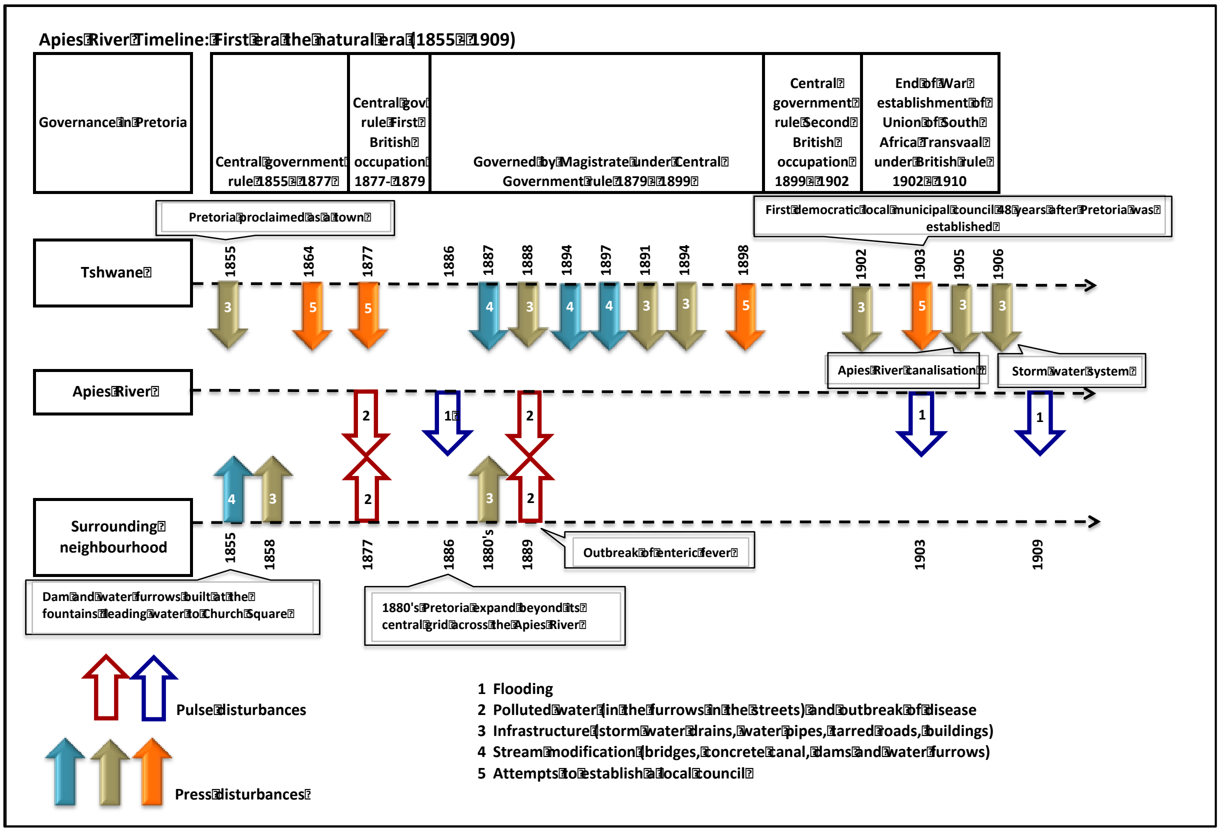


Figure 58: Press and pulse disturbances Apies River: First era, the Apies River as a natural era (1855–1909)

The following pulse disturbances have been identified. These include:

a) Severe flooding: Flooding was recorded in 1886, 1903 and 1909.

b) Pollution of the water: The water in the furrows and the wells was severely polluted causing outbreaks of disease.

1.8.2 Apies River second era: Era of disconnection between the Apies River and the built infrastructure through which it flows (60 years): 1910–1970

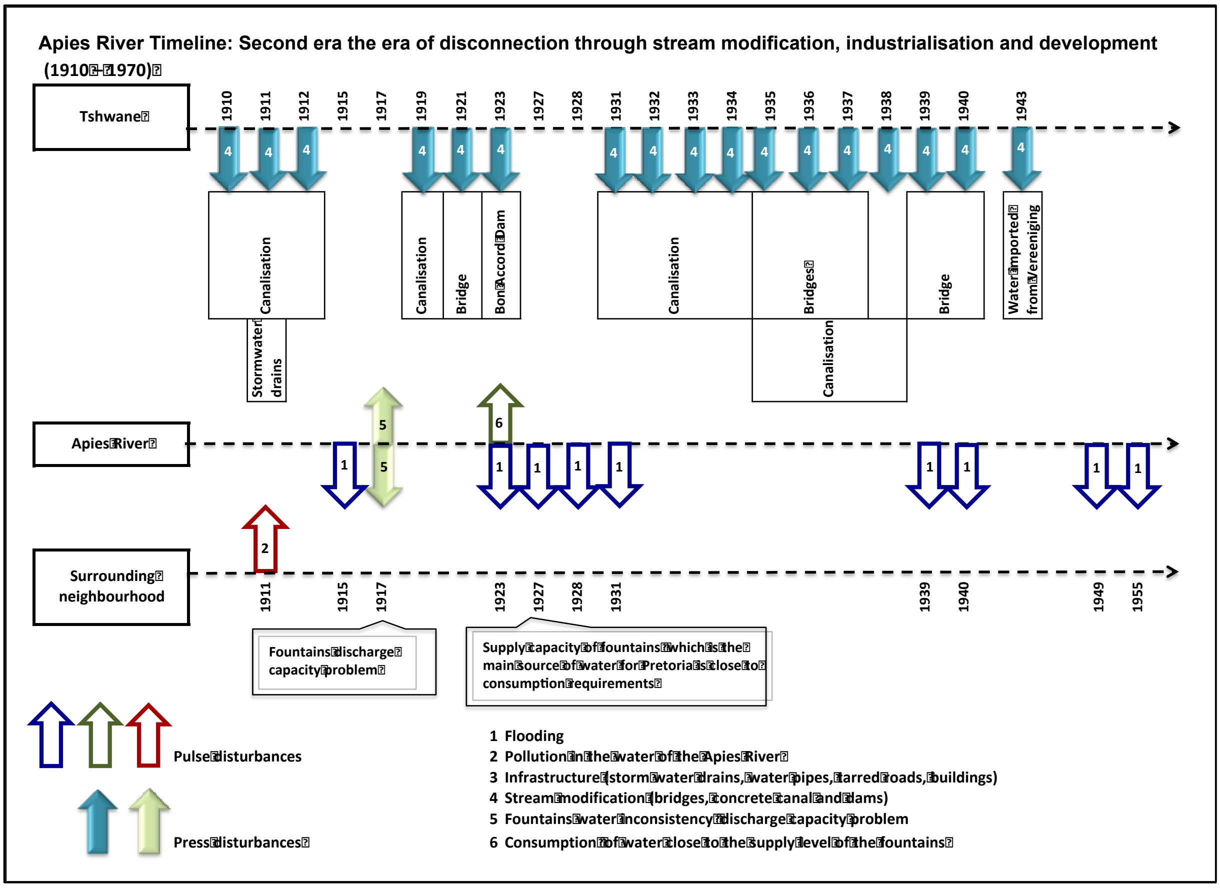


Figure 59: Press and pulse disturbances Apies River: Second era, era of disconnection from the urban fabric (1910–1970)

During the second era of the Apies River, the era of stream modification and disconnection from the urban fabric, more press and pulse disturbances were identified as part of the historical study and are illustrated in Figure 59.

The press disturbances which manifested during the second era include:

a) Stream modification: Following from the stream modification that occurred in the previous era, this era experienced: the building of the Bon Accord dam downstream from the CBD; more construction of bridges; and the intensification of the canalisation of the Apies River and its tributaries that flow through the city centre of Pretoria (a process already started in 1905), as a result of the floods in 1909.

b) Lack of management of water usage: This is another disturbance which manifested during the first era and extended into the second era where water was provided for free from 1855 to 1927 (72 years), used wastefully, and not accounted for or properly managed, resulting in insufficient water in Pretoria by 1923. Eventually leading to the installation of water meters and supplementation of the water supply from an added source.

c) Urbanisation: This perturbation also continues from the previous era with the constant increase in non-permeable surfaces such as buildings and roads, which were being tarred. There were also no restrictions on development encroachment in the floodplains, which continued to intensify as the city expanded.
d) Insufficient water: By 1917 a decline was recorded in the yield of the fountains and in 1923 the water demand in Pretoria exceeded the available water in the fountains which called for urgent action to introduce a system to manage and control water usage and to get alternative sources of water for the city.

The following pulse disturbances of the Apies River, during the era of stream modification and disconnection from the urban fabric, have been identified:

a) Pollution: In 1911, chemical pollution entered the river through the stormwater channel and contaminated the water.
b) Flooding: There was an increase in flooding in the city with severe flooding recorded in 1915, 1923, 1927, 1928, 1931, 1939, 1940, 1949 and 1955.

1.8.3 Apies River third era: Era in which attempts were made to reverse the disconnection between the Apies River and the city's built infrastructure (43 years): 1971–2014

From the historical narrative the following press and pulse disturbances have been identified during the era in which attempts were made to reverse the disconnection between the Apies River and the city's built infrastructure. These press and pulse disturbances are illustrated in Figure 60.

The press disturbances that manifested over time and placed pressure on the freshwater system and eventually causing the system to deteriorate during the second era, include:

a) Stream modification: This included continued canalisation of the Apies River, a press disturbance that continued from the previous two eras.
b) Ineffective governance: The local government failed to prohibit and address pollution timeously.

c) Land use change: This is a disturbance which continued from the previous two eras and especially affected the floodplain area with the increase in non-permeable surfaces, replacing the previously vegetated and permeable surfaces of the water catchment.

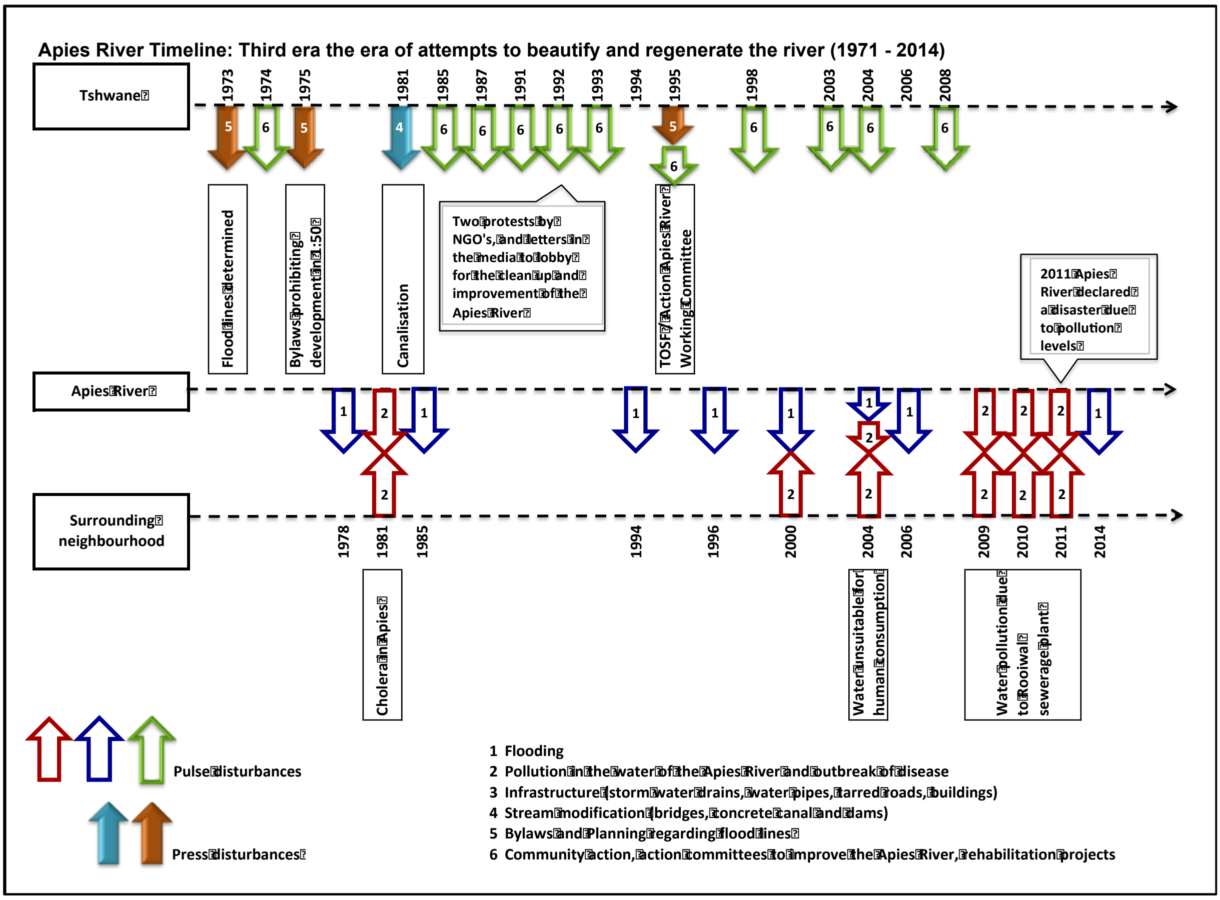


Figure 60: Press and pulse disturbances Apies River: Third era, the era in which attempts were made to reverse the disconnection between the Apies River and the city's built infrastructure

The following pulse disturbances, have been identified during the era in which attempts were made to reverse the disconnection between the Apies River and the city's built infrastructure:

q) Pollution: Incidences of water pollution were reported in 1981, 2000, 2004 and 2009-2011.

r) Attempts to improve the quality of the river: Community organisations, individuals and NGO's pleaded for the improvement of the river. During this time, rehabilitation and clean-up initiatives began.

s) Flooding: The incidences of flooding during this era increased and so also did the intensity of the floods as a result of increased development close to the river and greater surface water and storm water runoff. Flooding and severe flooding was recorded in 1978, 1985, 1994, 1996, 2000, 2004, 2006 and 2014. The floods of 1978 and 1996 had the same magnitude as the floods in 1909 according to Van Veelen *et al.* (2004:4-18). However, their impact was more severe due to the increased development and intensification of non-permeable surfaces close to the river.

In order to understand what the impacts were of the press and pulse disturbances on the resilience and the capacity of the Apies River to adapt to change, some of these disturbances will be discussed next.

1.9 How the resilience and adaptive capacity of the Apies River were affected by various press and pulse disturbances

The changes in the Apies River SES have been driven by various slow pressures in the system. Interventions in the early years could have altered the trajectory of the changes which the Apies River SES has undergone over the 159 years of its history as an urban river.

Appropriate actions and interventions by management in either the transitional period of a system after a threshold has been crossed (but before the system has regrouped itself into a new state) or before the threshold has been crossed during the time that the system moves towards a threshold, can influence the trajectory of a system. Management can mitigate the issues in the system driving the changes that are pushing the system towards a threshold. Success in influencing the system's trajectory of change depends on the amount and sources of natural and social capital that are available in the system and if the system's condition has already been degraded or strengthened before this juncture. After a system has crossed a threshold it might be difficult or impossible to return the system to the state it was before the threshold was crossed (Resilience Alliance, 2010:27).

Based on the Resilience Alliance approach (2010:18) there is a general relationship between spatial and temporal scales where larger systems (in the case of this study, the City of Tshwane and its values and belief systems) change slower and less frequently than smaller systems (in the case of this study, the neighbourhood level in terms of land use and development) relative to the larger whole of the system (in the case of this study, the SES). In general, although not always, it is good practice to first look at the larger scale dynamics when trying to identify the slowly changing variables that help stabilise a system within a particular regime.

It is usually the drivers related to slow variables in the system that cause the system to cross a threshold. In order to strengthen the adaptive capacity of a system it is beneficial to identify the slow changing variables that appear to be system drivers (*ibid*. 28).

The two main slow drivers of change in the Apies River as part of the Tshwane SES which are to be found in the larger scale dynamics of the Apies River SES are: a) the lack of flexible and transparent local governance; and b) ecological ignorance which is the lack of understanding of how freshwater systems function.

The various press and pulse disturbances that resulted because of these two main drivers of change will be discussed next.

1.9.1 Press disturbance: lack of flexible and transparent local governance

Because of the press disturbance on the larger scale of the absence of a local council, a contaminated and unregulated water system resulted which was greatly affected by the lack of a reticulated sewerage system. The governance system, when Pretoria was ruled by the central government of the Republic of the Transvaal, and in the period of British military rule, was not responsive enough to local issues. In resilience terms, the SES lacked tightness of feedback, something that is necessary to build the adaptive capacity of a system. The lack of tightness of feedback was visible as there were numerous press disturbances to the system (such as water pollution and disease), which were opportunities for interventions and change to deeper underlying systems, but the governments of the day mostly ignored these. The repeated requests from the residents to establish a local council to facilitate much needed infrastructure development were disregarded by the central government(s) for 48 years (1855–1903).

During the first era of governance in Pretoria when a democratically elected local council was in place in 1903, a qualified town engineer was appointed and work began to address the huge backlog in infrastructure provision. In 1913, ten years after the first Local Council was established, Pretoria had a reticulated sewerage system in place. This means that there was a combined response time of 36 years since the first pulse pressures on the system of disease and pollution in 1877.

The second era of governance in Pretoria can be described as the era from 1903 to 2014 when local governance was in place and response times to perturbations were improved to some degree. However, in the context of resilience, there were still some lack of innovation and learning in the system to respond to disturbances, which affected the adaptive capacity of the Apies River as part of the Tshwane SES.

According to Haarhoff *et al.* (2012b) history has proven that a democratically elected, sufficiently funded and an administratively and technically competent Local Council is necessary to ensure proper and effective service delivery at local level. Section 4.3.8 described the governance arrangements in Pretoria from when it was established in 1855, and how it did not have a democratically elected local Council until 1903. The absence of a Local Council for 48 years severely affected infrastructure development and service delivery and affected the quality of freshwater resources in Pretoria. The absence of a locally elected Council (1855–1903) acted as a press (slow) driver of change in the Apies River as part of the Tshwane SES.

The effect of the larger scale press disturbance of poor local governance created opportunities for the pulse disturbance of pollution and water scarcity, which is discussed next.

a) Pulse disturbance: water pollution:

As a result of the quality of the drinking water in 1877 there was an outbreak of typhoid and in 1889 enteric fever. These diseases were caused directly by poor sanitation, poor stormwater drainage and the lack of a reticulated piped water system. It was only in 1913 that the first sewage plant was completed in Daspoort in the floodplain of the Apies River and a sewerage reticulation system was put in place.

From a resilience perspective this showed a lack of flexibility in the governance structures with a very low degree of response diversity to obtain appropriate and innovative solutions. The central governance structure at the time (over a period of 48 years) did not allow for tight feedback. Many attempts were made to obtain a Council that could address the local need to avoid pollution and degradation of the water in the city, but the inflexible and inconsistent governments that managed Pretoria during the first half century of its existence prevented this. It therefore took a 48-year response time for a Council to be democratically elected (1855–1903) and a 36-year response time (1877–1913) for the installation of sewerage infrastructure services, from the time it was first requested in order to resolve the contamination of the drinking water.

After 1913, Pretoria developed with a City Council in place which made better service delivery possible. However, the infrastructure that was developed did not take into account the functioning of the underlying natural systems. The Council concentrated on creating efficiency, which according to Walker and Salt (2006:120), is a short-term opportunity gain at the cost of resilience, with a focus on meeting immediate needs but compromising the natural systems in the long term.

The emphasis on efficiency rather than acknowledging the natural systems while planning of services, is visible and since 1913 three more sewerage works have been built along the Apies River encroaching on its floodplains and wetland systems. This would create several pulse disturbances of pollution in later years as a result of problems with the functioning and management of the sewage works. In 1981 the Apies River was contaminated by cholera caused by the lack of proper management and maintenance at the Hammanskraal sewage works. During 2004 and between 2009 and 2012, the Apies River was again plagued by pulse disturbances of pollution affecting recreation activities, drinking water and food crops. It was only after the Apies River was declared a disaster area in 2011 that a response was formulated by the Council, three years after the problem of pollution was brought to its attention. The Council took action and allocated funds for upgrading and maintenance and in July 2012, a year after it was declared a disaster area, it was reported, according to Batt (2012) that much improvement has been done at the Rooiwal Sewage Plant.

Pollution undermines the resilience of a river system and diminishes the system's biodiversity and health that affects its functional integrity. It can be concluded that the quality of the water of the Apies River has been affected by a lack of tight feedback in the system. The response time to attend to pollution issues before a Council was established was 36 years. In 2009, with a Council in place, there was still a long response time of three years. The SES also ignored both ecological variability and the value of ecosystem services when sewage plants were constructed and operated in such a way that they negatively affected the natural process of the freshwater system.

b) Press disturbance: reduced water quantity:

From 1855 to 1927 (72 years) water was used wastefully, provided for free and not accounted for or properly metered and managed. Constraints on the supply of the water in the late 1902s eventually let to the installation of water meters and the supplementation of the water supply from an added water source.

1.9.2 Press disturbance: lack of understanding of how freshwater systems function

> *Thus a fundamental challenge is to change perceptions and mind-sets, among actors and across all sectors of society, from the over-riding goal of increasing productive capacity to one of increasing adaptive capacity, from the view of humanity as independent of nature to one of humanity and nature as coevolving in a dynamic fashion within the biosphere* (Folke *et al*., 2002a:12).

The City of Tshwane, like many other cities in the world, has developed with a certain degree of disconnection from its freshwater systems. This decoupled approach has caused a reduced adaptive capacity in cities and a negative state of resilience. As Folke *et al.* (2002:438) state: "The outdated perception of humanity as decoupled from, and in control of nature, is an underlying cause of society's vulnerability." This has been attributed to a psychological disconnect between the city and freshwater systems, a lack of understanding of how ecosystems function and a disbelief that freshwater systems could function in their natural state as part of the urban infrastructure. Folke *et al.* (*ibid.)* state that: "This ecological ignorance of some contemporary societies undermines resilience." Caused by a lack of understanding of how natural freshwater systems function, these natural systems are degraded, according to Folke *et al*. (2002b:437), affecting the health and resilience of freshwater ecosystems which affects the resilience of the SES. The health of the Apies River was not preserved and enhanced, but degraded, and it can therefore be concluded that as a result of this it could not fully contribute to the resilience of the Tshwane SES, making the social system more vulnerable to disturbances.

According to Folke (2003:2028) freshwater should be seen as more than just a resource; It provides a diversity of functions within the context of a larger system, the catchment, and therefore plays an important role in SES resilience. Freshwater systems should therefore be preserved for their multiple functions in the context of a dynamic landscape and their role as the bloodstream of the biosphere (*ibid*.2027).

Failure to take this holistic approach resulted in various pulse and press disturbances in the Apies River, which affected the resilience of the Tshwane SES, these are set out below:

a) Press disturbance: land use change: altering the vegetation cover in the WMA:

During the natural era of the Apies River SES (1855–1909), the vegetation cover in the water catchment area was slowly altered as development in Pretoria expanded. Vegetation plays a very important role in the hydrology of a catchment as it assists with the interception of the precipitation that falls in that catchment. Vegetation slows down the overland flow of water from the catchment to the river channel. The process of clearing the natural biodiverse vegetation started with land use change to make way for houses in the CBD, where the first plots were demarcated in the vicinity of a natural spring. Alien and invasive tree species were introduced such as willows, eucalyptus and pine trees, and along the river poplars were planted. In 1888 the first jacaranda trees were planted. In SA invasive alien vegetation affects freshwater systems and currently consumes 7% of annual rainwater runoff, according to Nel *et al.* (2011:6).

The loss of vegetation also affected the diversity of the riparian vegetation, which plays a role in maintaining the health of the river. Riparian vegetation protects the edge of the river against erosion and assists with the purification of the water. From 1910 onwards, the vegetation of the riparian zone has been disturbed and in places completely destroyed, for example in the section where the Apies River runs through the CBD. From paintings it can be seen that exotic eucalyptus trees were planted along the streams, negatively affecting the riparian zone even before the river was canalised.

From a resilience perspective, the diversity of a system strengthens its ability to deal with change, and from an ecological resilience perspective diversity is an indicator of a healthy system and therefore the resilience of the system. By changing the natural diversity in a catchment, the resilience of the freshwater system is also changed.

b) Press disturbance: stream modification:

Another press disturbance is stream modification and the canalisation of the Apies River and its tributaries where it flows through the inner city. Canalisation began in 1905 and continued for decades following the flooding of the Apies River in January 1909. From a resilience perspective and a hydrological perspective, the process of canalising the river had already started four years prior to the 1909 floods, and so could have been one of the causes which increased the impact of the floods. And the fact that the canalisation was intensified as a response to the flooding of properties next to the river in 1909, showed that there was a lack of understanding of how natural systems function and how to construct development in such a way that it enhances the functioning of natural systems and where development incorporates the natural freshwater system as part of the service infrastructure of the city.

From a resilience perspective, the Pretoria City Council was inflexible and lacked innovation in its response to flooding and did not allow for the freshwater system to function naturally by amending and compromising and adapting development rather, in order to achieve this.

Instead the solution put forward by the Council was to canalise the Apies River and its tributaries and change the natural flowing river into an effective stormwater canal, now functioning as a specific resilient system by compromising the general resilience of the Apies River and the SES that it flows through.

According to Dunne and Leopold (1978: 411), there are alternatives to structural solutions, such as dams, channels and floodwalls, to avoid flooding. Developments in flood-prone areas that would interfere with the natural flood storage capacity of an area should be avoided and more flood-compatible uses such as woods, recreational spaces and croplands should be allowed. The solution adopted in Pretoria did not protect the ecological variability of the freshwater system but degraded the resilience of the system. Of the total length of the Apies River, 14.57% of the river and 23% of its tributaries have been canalised (University of Pretoria, 2014).

Many decades later, the canalisation of the Apies River has been criticised from an aesthetic and ecological point of view. It is perceived as having created a stark and impersonal concrete channel running through the city where developments turn their backs on the small trickling stream which lies deep down at the bottom of the concrete channel (Garner, 1996:2). Jaksa Barbier, former chief urban designer at the Pretoria City Council, stated that the canalisation created a city centre with a neglected river (cited in *ibid*. 3). This is evident where in some places the river system has been covered completely, as shown in Figure 61 and 62 where the Steenhoven Spruit and the Walker Spruit tributaries of the Apies River are channelled underground.

According to Garner (1996:2) the canalisation of the river greatly compromised the ecological integrity of the river. Van der Riet (cited in *ibid.*), suggested that instead of canalising the river and transporting the floodwater away from the city, the Council could have stored the floodwater for human consumption and allowed the natural flow of the river to continue. However, if it was done the other way around such that the normal flow of the river was stored and flood surplus transported away.

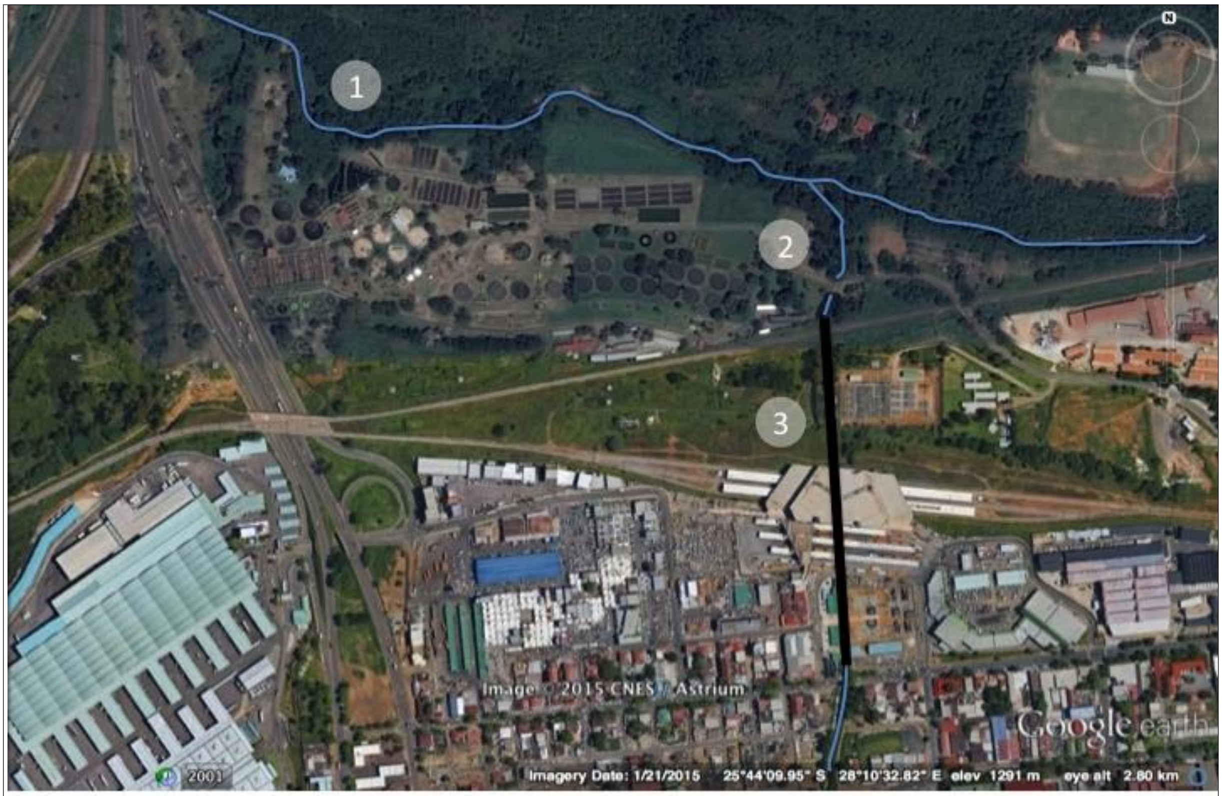


Figure 61: Steenhoven Spruit exposed and concealed (Source: Google Earth 7.1.2.2041, 2015b)

The impact of the canalisation of the Apies River resulted in the overall ecology of the river and instream habitat being given a poor status in a 2005 report of the River Health Program, compiled by the then Department of Environmental Affairs and Tourism (DEAT). The speed of the water increased when the riverbed was straightened into a concrete channel changing the riverbed's natural strata into a channel with less resistance. This changed the velocity and flow of the water downstream affecting the shape of the river channel and the riverbed (River Health Program, 2005:24).

The canalisation also altered the habitat integrity of the riparian zone, which is described as poor, because the channel prohibited the river's natural flood patterns which are used to maintain the riparian vegetation and the floodplains. The riparian zone has also been degraded by the invasion of alien species or the riparian vegetation has been removed completely to make way for development. In addition, the water quality of the Apies River is poor because of the polluted runoff and return flows from the Pretoria city centre, from settlements with poor sanitation and from industries such as ArcelorMittal (previously Iscor) (*ibid.*).

1 Walker Spruit 2 Walker Spruit canalised underground

Figure 62: Walker Spruit exposed and concealed (Source: Google Earth 7.1.2.2041, 2014b)

From a resilience perspective the canalisation of the Apies River in quaternary catchment A23D greatly destroyed the diversity within the Apies River system. This can be seen as the functional response diversity of the river was altered when the closely linked elements of the freshwater ecosystem, the floodplains, wetlands and riparian zone were disconnected from the river channel, affecting the river's ability to restructure and regenerate itself through its natural functions. The river is now confined to a concrete channel and is no longer capable of maintaining its health, which is crucial to maintain system resilience and functional integrity. The river could no longer purify water, act as a buffer for floods or provide a place of sanctuary where residents could find spiritual revival and enjoy recreation. The stream modification weakened the adaptive capacity of the river when: it weakened the river's ability to maintain ecological diversity and health; restricted the river to adapt to seasonal changes in flow; reduced ecosystem services; and weakened the river's ability to self-organise and regenerate.

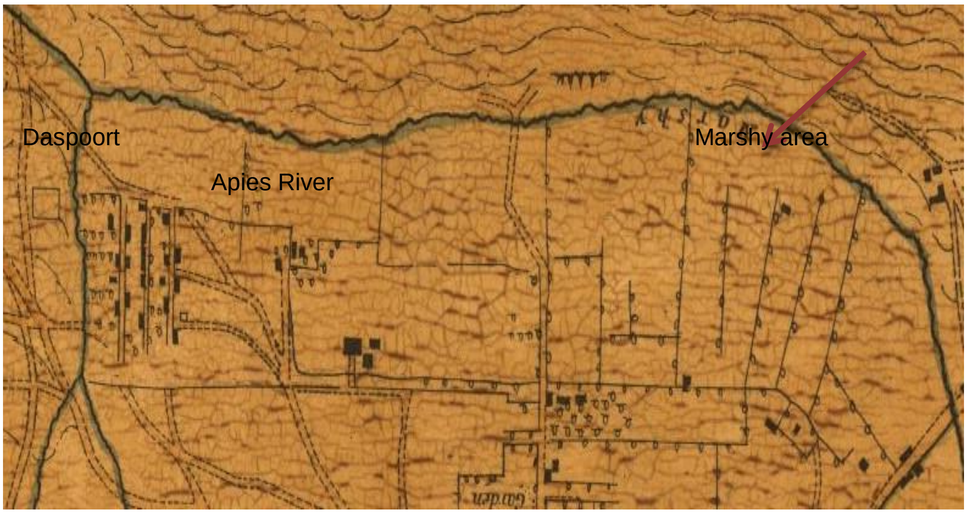
Another aspect of resilience which has been reduced by the canalisation is the ecological variability of natural seasonal flow, which sustained the riparian vegetation and helped to store water in the floodplain, which now can no longer happen, particularly in the quaternary catchment A23D.

The Council did not respond in a flexible manner to the flood disaster in 1909, because the decision was made without proper understanding of the dynamics of the freshwater system. The response to the flooding also did not combine and apply different types of knowledge and learning, which resulted in loss of the value of the natural freshwater system and loss of advantage to both the natural system and the city. Instead of compromising development in the floodplain, the freshwater system was compromised.

c) Press disturbance: degradation of wetlands :

Another press disturbance affecting the diversity and health of the freshwater system was the disregard for the wetlands in these two quaternary catchments. Wetlands were degraded and in some cases have been lost completely compromising the diversity of the freshwater system.

A report to the City Council in 2007 required rehabilitation of wetlands to be carried out without affecting surrounding land users (Grundling & Venter, 2007:70). But if rehabilitation of wetlands is confined by the built infrastructure around it instead adapting development to suite the natural processes, it means that the ecological processes are compromised for the sake of land use, ecological variability is not strengthened and ecological processes is not incorporated into planning and therefore cannot support positive resilience. Positive resilience in the SES requires planning which integrates natural processes, allowing them to continue to function in a natural way, so that ecosystems can deliver services in support of an optimally resilient SES.



Source: Adapted from: Maps Digital Collections, African Historical, 2009

Source: Google earth V 7.1.2.2041, 2015a

Figure 63: Marshy area next to the Apies River in 1880 (top) and how it looks today, serving as the Daspoort Sewage Plant (below)

Development taking place in wetlands has been noted since 1888 when, as described in section 4.3.7, James Clark's nursery was established in a reclaimed wetland area which later became the suburb of Riviera (Bolsmann, 2001:183-186). There is also the construction of the Daspoort sewerage plant, as illustrated in Figure 63, which was constructed in a wetland area in 1913 and is still operational today.

For wetlands to have an impact on the water quality in the watershed, wetlands must cover 2-7% of the total area of the watershed (Brauman, Daily, Duarte & Mooney, 2007:80). The wetlands contained in the quaternary catchment A23D cover 0.8% of the catchment area, and 50% of these wetlands are under threat or in need for rehabilitation (Grundling & Venter, 2007:69). It is not clear what the percentage of wetland cover is in the quaternary catchment A23E. It is therefore clear that current wetland coverage in A23D is not sufficient to contribute significantly to the improvement of water quality.

d) Press disturbance: land use change and increase in non-permeable surfaces:

Another gradual perturbation in the water catchment area was the increase in hard, non-permeable surfaces, which changed the Apies River catchment's natural indigenous plant diversity into hard, impermeable, built up-areas and structures.

When there is development in a floodplain, it affects the natural dynamic movement of water flow between the river and its floodplain, which is designed by nature to store water and to attenuate floods. Land close to a river's edge is more affected by floods than land further away. Over decades there was an increase in the non-permeable surfaces in the water catchment area. The wide gravel roads of Pretoria became difficult to navigate during the wet season because of stormwater and gradually these roads all became compacted, tarred roads served with subsurface stormwater drains, which channelled the water directly towards the river. This resulted in a higher incidence of flash floods, and polluted floodwater, which was collected and drained from the hard surfaces in the city into the subsurface floodwater systems and into the Apies River's concrete channel which diverted the water out of the urban centre.

Figure 64, Figure 65, and Figure 66 show how the permeability of catchments A23D and A23E has been changing over the decades. In 1879 the permeability of the water catchment was 99.2% and by 2006 this had decreased to 53.3% (and of this, 4.8% is cultivated land) (University of Preoria, 2014). What is happening in Pretoria is similar to what is described by Spirn (1984:130), that due to an increase in sealed earth such as pavements, buildings and tarred roads in urban areas, the rain that falls creates greater surface water runoff than the same amount of rain falling on a natural landscape and the impermeable surfaces prevent water penetrating into the soil. The slower water flows to rivers and streams, the less chance there is for flooding and the better the groundwater recharge. There is a direct correlation between an increase in urban expansion and an increase in the frequency amount and magnitude of flooding (*ibid*.130). In order to deal with the increase in surface water flow in Pretoria, the excess water had to be directed away and the first stormwater drains were built in 1906. According to Spirn (1984:131,133,134) stormwater sewers do not reduce the amount of water, they simply relocate the water from one place to another causing not only floods downstream but also increased water pollution. Urbanisation can increase mean annual floods by as much as six times (*ibid.*130).

The increase in development and in non-permeable surfaces in the areas close to the river caused the impact of flooding to increase as well. As described in section 4.5.5, the floods in

Pretoria in January 1978 and January 1996 were of the same magnitude as the floods in 1909. However, the impact of the later floods was much higher because of the increase in development close to the river (Van Veelen *et al*., 2004:4-18)

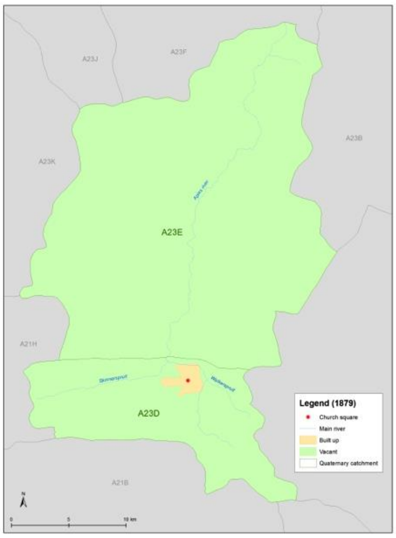
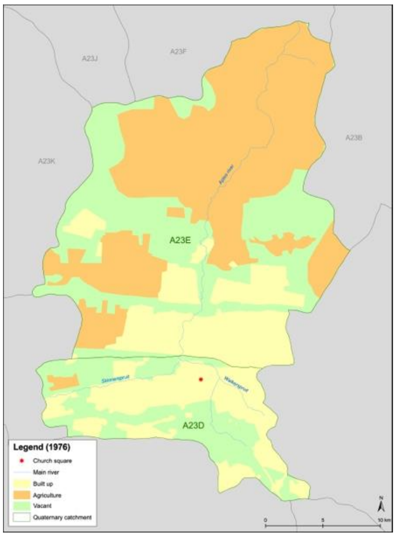
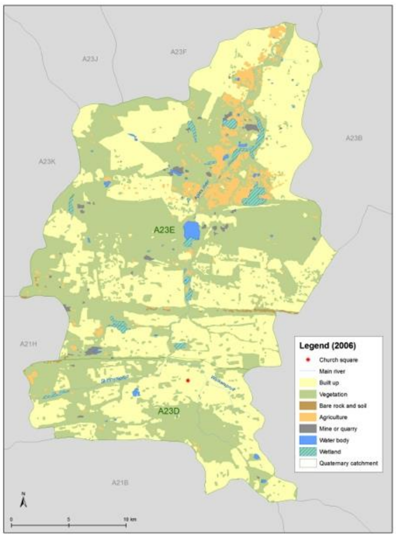
		

Figure 64 (Compiled by: UP, 2014a) By 1879: The total built-up area during this time was 0.8 % of the total Water Management Area (WMA). The remaining 99.2% of the WMA was largely undeveloped.	Figure 65 (Compiled by: UP, 2014b) By 1976: The total built-up area during this time increased to 25.8% of the total WMA with 74.2% of the WMA being undeveloped (agriculture as part of the 74.2% undeveloped land covered 40.5% of the WMA). Most of the development occurred right next to the river's edge infiltrating the once natural floodplain of the area.	Figure 66 (Compiled by: UP, 2014c) By 2006: The total built-up area during this time increased to 46.7% of the WMA, with 53.3% of the WMA that is undeveloped (4.8% of the WMA is cultivated land).

Figure 64: 1879 land use in the Apies River quaternary water management areas

Figure 65: 1976 land use in the Apies River quaternary water management areas

Figure 66: 2006 land use in the Apies River quaternary water management area

e) Pulse disturbance: flooding :

Due to uninformed planning, flooding in the Apies River was caused by a combination of the following:

- Stream modification which increased the amount of water and the speed of the water in the system.
- An increase in non-permeable surfaces in the catchment.

- Developments in the floodplain of the river.
- Stormwater pipes increasing the volume of water carried in a short period of time to the river system.

Figure 67: Apies River in flood (9 January 1909) affecting houses (Source: Anon, 2013q)

The natural ecological variability of freshwater systems was not recognised as an integral functional part of the urban infrastructure of Pretoria and as a result development encroached onto the floodplain of the Apies River ignoring the natural flow dynamics of the river and interfering with and causing a reduction in the ecological variability of the river, reducing its health, diversity, adaptive capacity and resilience. Developments that are located in the floodplain of a river will be flooded and this is what occurred in Pretoria in 1909. Sections of the river/and or its tributaries were already canalised in 1905 (four years before the floods in 1909) and this could have been a factor in the increased water in the river. It is ironic that according to the Mayoral minutes of 1909, it was believed that the floods in 1909 would have been much worse were it not for the already installed channel and stormwater drains. Thirdly, the stormwater drains which were constructed in 1906 to channel water to the nearest natural watercourse, increased the amount of water in the river during a rainstorm. Collectively all these factors contributed to the weakening of the river's ability to manage and control its own ecological functions and therefore increased the incidence and risk of flooding.

Pretoria developed and expanded along and across the Apies River and its floodplain for 54 years (1855– 1909) without development restrictions or a regulatory framework in support of the dynamics of the natural functions of the freshwater system. Then in 1965, the National Water Act (Section 169 of Act 54, RSA, 1956) introduced the requirement that the 1:50 year flood line be indicated on proposed township plans. Although the Pretoria City Council determined some 1:50 year flood lines in 1973, it did not include the Apies River (BKS (Pty) Ltd, 1998:3). It was only in 1975 that the Provincial Gazette Notice Number 1220 required that no building be built within the 1:50 year flood line of a natural watercourse. Pretoria therefore developed without restrictions on development within the flood lines of the Apies River for 120 years (1855–1975).

From a resilience perspective there was a lack of tightness of feedback when it took Pretoria City Council 66 years (1909–1975) to restrict development close to freshwater systems i.e. when the provincial legislation came into place in 1975. Tightness of feedback refers to feedback loops within variables in the system, which need to be fast enough to alert timeously that the system could cross a threshold and enter another state or potentially collapse (Resilience Alliance, 2010:7,35,51).

Since the flooding in 1909, the incidence of floods progressively increased. The increase in flooding coincided with the increase in non-permeable surfaces in the water catchment. The recorded flood incidents in the different eras are as follows:

- First era, Apies River natural era (1855–1909): 3 flooding events recorded over the 54 year period.
- Second era, Apies River era of stream modification and disconnection from the urban fabric (1910–1970): 9 flooding events recorded over the 60 year period.
- Third era, Apies River era in which attempts were made to reverse the disconnection between the Apies River and the city's built infrastructure: (1971–2014): 8 flooding events recorded over the 43 year period.

It is not in the best interest of the ecosystem or the social system to allow development on a floodplain (Spirn,1984:132). However, this is what happened in Pretoria. From a resilience perspective, there was a lack of feedback and it took many decades for the Council to put flood line restrictions in place. The importance of supporting ecological variability as a characteristic of resilience was also ignored when incompatible development encroached onto the floodplain of the Apies River, as structures and infrastructure inside the floodplain prohibit ecological variability and undermine resilience.

1.10 General and specific resilience in the Apies River

The governance system of Pretoria focused on specific resilience. It created a flood management system for the Apies River through the canalisation, thereby concentrating on the resilience of one of many variables in the freshwater ecosystem. According to Walker and Salt (2006:120, 121), focussing on the specific resilience of one part of the system can undermine the resilience of other parts of the system, thereby compromising the capacity of the whole system to deal with unpredictable disturbances. This is what happened with the Apies River SES. The canalisation of the section of the Apies River which runs through the CBD made this section of the river very efficient in transporting stormwater away. However, this specific resilience weakened the functional integrity of the Apies River as a natural ecological system and resulted in the loss of many other functions of the river. It also increased flooding downstream of the CBD. It can therefore be seen that the Apies River gained specific resilience but lost its general resilience, the latter, which according to Walker and Salt (2006:121) supports diversity, modularity and redundancy, and a system's capacity to deal with unforeseen disturbances and circumstances.

1.11 Conclusion: Lessons learnt from the historical analysis

The first main lesson learnt from the historical analysis is that the abundance of urban freshwater systems is not ensured in the long term if there is no local government in place or if there is a local government in place but it governs in an inflexible and non-transparent way. This is supported by Haarhoff, *et al*. (2012a:18), who state that history has taught us that even a good source of water requires strong municipal governance to sustain the quality and the supply of water. From the historical analysis of the Apies River is it clear that local governments respond to pulse disturbances (such as flooding) but do not act on press disturbances (such as developments in floodplains) which are the long term hidden pressures affecting the trajectory of a system.

Secondly, the historical analysis highlighted the importance of maintaining a tightness of feedback in the SES in order to be able to detect potential slow drivers of change and so manage disturbances before they negatively affected the freshwater system. The latter was evident in the historical analysis when several incidents of delayed responses to pollution in the Apies River negatively affected the quality of the freshwater system and the health of the community.

The third lesson learnt is that urban freshwater systems and the SES are negatively affected by ecological ignorance such as planning decisions that are made without an understanding of how freshwater systems function and without including natural functioning freshwater system as an integral part of planning and development proposals. According to Folke *et al.* (2002:438) this ecological ignorance and lack of knowledge of natural systems have a negative effect on the well-being of societies and undermines resilience This can be seen where developments occurred uncontrolled on the floodplain of the Apies River over a period of decades without compromise and where stream modification was applied as a ‘’solution’’ to pulse disturbances of flooding. It is also evident that once a system’s trajectory has been changed by canalisation it is almost impossible to change the system back to its original state as a naturally functioning freshwater system.

These lessons describe the main drivers of change which activated press and pulse disturbances in the Apies River SES. Press disturbances happen slowly, subtly and over a long period of time, gradually infiltrating and eroding a system, and are usually difficult to trace and track (Collins et al. 2011:352). Should the slow press disturbances such as stream modification, incompatible development encroachment onto the floodplain have been addressed, the pulse disturbances, such as floods and pollution in the Apies River freshwater system, would have been avoided. According to UNESCO (2003:16), resilient cities need to, amongst others, minimise pollution effluent and control the abstraction of water, something that did not happen in Pretoria.

According to Carpenter *et al.* (2001:779), by increasing the resilience of one aspect of the system, you can weaken the resilience of another part of the system. This is also what happened in the Apies River freshwater system when the adaptive capacity of the Apies River was weakened by the management decisions of the SES governance system which addressed flood attenuation through canalising the river. In doing this it weakened the connection between the built environment and the Apies River and the connection between the river and its natural components resulting in the compromise of the functional integrity of the river and affecting the general resilience of the Apies River freshwater system.

However, things can be done differently in future. The next section sets out ways of creating a stronger connection between the SES and the freshwater system, creating resilient cities that benefit from healthy freshwater ecosystem services.

CHAPTER 6 - CONCLUSIONS AND RECOMMENDATIONS

1.1 Conclusions

1.1.1 Achieving the problem, goal and objectives of the study

The problem that this study investigated is the change in connection between freshwater ecosystem services and humans in the urban context and how this poses a threat to the resilience of SESs. The study further explored how the connection between freshwater systems and urban infrastructure can be improved in future to contribute towards creating a positive urban resilience.

The main research question of the study was: How does the change in the connection between humans and freshwater ecosystem services in the urban context affect the resilience of the urban SES?

The main goal of the study was to understand how the change in the connection between the Apies River freshwater ecosystem and the City of Tshwane has affected the resilience of the Apies River as part of the Tshwane SES in the quaternary A23D and A23E catchments. The secondary goal of the study was to develop a better understanding of what caused the dysfunctional connection between the Apies River and the built infrastructure.

In order to achieve these goals, the study aimed to meet the following objectives:
Objective 1: To determine the resilience or the ability of the freshwater system to adapt to change through identifying the trigger events that caused major change in the system from one era to another, as evident in the historical profile.
Objective 2: To determine the undercurrents (press disturbances) of the system driving changes in resilience over time.
Objective 3: To identify the obvious patterns of the trigger events (pulse disturbances) which brought about change, based on the information in the historical timeline.
Objective 4: To determine the pattern of cross-scale interactions that was also relevant to the focal system.

The analysis of the adaptive capacity of a section of the Apies River over time was based on the approach as set out by the Resilience Alliance (2010:19,21), and included:

a) Three spatial scales forming part of a historical profile (horizontal axis), which included important key historical disturbances.

b) Different historical periods were defined as eras between historical regime shifting points which marked changes in resilience of the section of the Apies River.

c) Cross-scale events, which influenced the focal system (Apies River quaternary catchments A23E and A23D), were demonstrated which caused the crossing of thresholds and changes in resilience over a period of 159 years.

The historical overview explored the pattern of historical disturbances and the drivers behind them, how the system responded to these disturbances and what effects these changes had on the state and resilience of the freshwater ecosystem. By exploring the changes, the crossing of thresholds and the different states through which the system moved were revealed. Three eras were identified in the time period of the study. In the first era, the Apies River was still in a natural state. In the second era, the Apies River was modified and channelled, and in the third era the state of the Apies River system was only partly changed through a shift in governance and regulations. The study unveiled the patterns of change and showed what made the Apies River pass over a threshold, changing the resilience of the system such that the system now functions with new characteristics and behaviour. It described the driving forces that triggered the changes. Changes that occur in a system reveal the vulnerability of the system indicating the system's reduced capacity to adapt to disturbances and change, and are a measurement of the resilience of the system. By understanding the dynamics of the system and identifying the slow variables driving negative change in a system over time, better decisions can be made and appropriate interventions implemented before a system crosses a threshold, thus strengthening the general resilience of the system.

1.1.2 Main disturbances affecting the resilience in the Apies River freshwater system as part of the SES

The study concludes that the main disturbances in the Apies River freshwater system were the establishment of human settlements and the increase in population, which then resulted in development driven by ecological ignorance, affecting the functioning of the ecosystems in the catchment. The following slow pressures defined the manner in which development occurred in Pretoria in relation to the freshwater system:

a) The absence of strong local governance: Pretoria had no local council for the first 48 years of its existence (1855–1903). This meant that the city's infrastructure needs were neglected and not responded to, despite early warnings. In resilience terms, this meant there was an absence of tight feedbacks resulting in the crossing of thresholds before they were detected. The absence of a local government limited social capital i.e. trust, well-developed social networks, the capacity to respond to disturbances and adaptable leadership (Walker & Salt, 2006:147). The local councils which have governed Pretoria for 106 years (1904–2010) also did not observe some important principles of resilience such as flexibility and innovation, qualities required for positive resilience in an SES and failed to adequately address the deteriorating water quality, diminishing water quantity, aggravated by an increase in water demand.

b) Ecological ignorance: Failure to value freshwater systems and to understand the multiple functions of dynamic freshwater ecosystems which forms the “bloodstream” of larger ecosystem networks within a water catchment area. According to Walker and Salt (2006:146) a resilient SES would strengthen and incorporate ecological variability instead of controlling or suppressing it and would understand and appreciate ecological functions. In a system displaying positive resilience, ecosystem services will form an integral part of sustainable planning decisions and development proposals and will contribute to human well-being (*ibid.* 148).

The effect that the disturbances had on the Apies River system was that the part of the river which flows through the CBD now has only specific resilience in that it has become a stormwater channel directing water away from the urban areas during the rainy season as quickly as possible. The Apies River in this section has lost its general resilience and its ecological functions as a natural river system, a place for recreation and spiritual fulfilment, a regulating system that attenuates floods and a provisioning system that supplies fresh water to the community.

1.1.3 Reduced adaptive capacity in the Apies River freshwater system

The Apies River system’s resilience, and it is assumed then also that of the SES, was negatively affected with the reduction in the system’s adaptive capacity, making the system more vulnerable to change. The adaptive capacity of a system depends on the capacity to: a) learn how to live with transformation and unpredictability; b) learn how to support diversity in order to allow the system to restructure and regenerate; c) combining different types of knowledge and learning and; d) create opportunity for self-organising and regeneration (Berkes *et al.,* 2002:345, 355).

The closer a system is to a threshold, the weaker the resilience of the system and the easier it is for the system to cross the threshold into a new regime. When there are tight feedbacks in the system, management interventions can intervene in time moving the current state of the system away from the threshold of change. Slow feedbacks, which were typical in the Apies River system, throughout its history, prohibited the detection of thresholds in time before the system changed into another state of functioning.

The Apies River freshwater system's adaptive capacity was reduced over time. This loss of resilience is evident in terms of:

a) The weak capacity in the SES to learn how to live with transformation and unpredictability: This can be seen in that canalising of the Apies River which was perceived to be the best way to prevent flooding — hiding the river away in a straight concrete casing, instead of adapting the urban layout to the dynamics of the ecological and natural processes to benefit the natural, social and economic systems of the city.
b) Lack of supporting diversity in the Apies River SES: The Apies River's adaptive capacity was negatively affected when it lost its natural diversity. This happened when the river was converted into a concrete stormwater channel. The more diverse a system is, the healthier the systems and the more capacity the system has to respond and adapt to change. The diversity of the river has been most affected in the section flowing through the CBD where the river has been dramatically altered. The loss in diversity of the elements of the Apies River ecosystem, which includes the riparian zone, floodplain and wetlands, reduced the river's functional integrity and the provisioning of freshwater ecosystem services. Due to the loss of diversity, the river can no longer provide seasonal flood regulating functions, purification of water or aesthetic qualities for spiritual and recreational purposes. The degree of diversity in freshwater systems is also directly linked to the health of the river and the SES. The canalisation of the Apies River in the CBD reduced the river's response diversity but increased its efficiency as a stormwater drain. Efficiency, according to Walker and Salt (2006:120), is a short-term opportunity gain at the cost of resilience. In terms of the Apies River, the short-term gain was that flood and stormwater management in the city was functioning effectively, but the long-term effect was that a naturally functioning freshwater system was transformed into a negative state of resilience, a degraded system deprived of its multiple functions and unable to provide ecosystem services to the inhabitants of Pretoria. According to Walker and Salt (2006:120) managing resilience requires weighing up the short-term gains, which result in regime shifts and contain costs in terms of crisis management, against the long-term enhancing of resilience.

c) There is little scope for regeneration of the Apies River to a point where it can regain its functional integrity: The river cannot self-organise and regenerate as it is now contained in a concrete bed with tightly built infrastructure right up to the river's edges. The conversion of the river to a channel was supported by landowners and the community in Pretoria, but the costs of regenerating a natural river again are, according to the Council, too high and a task impossible and impractical (Pretoria City Council, 1992:2). According to Walker and Salt (2006:150), enhancing and controlling isolated components of a broader system reduces the resilience and the diversity of options in the functioning of the system — this is the opposite of resilience thinking. The City Council, in response to a pulse disturbance of flooding in the Apies River, opted for the isolation of one of the components of the system i.e. to optimise its efficiency as a stormwater channel, degrading the overall resilience of the freshwater system. But opting for greater efficiency which calls for simplifying the system, brings a decline in the resource base and does not contribute to positive resilience as it reduces the system's diversity and options to respond to disturbances, reducing the systems capacity to deal with change. Greater vulnerability increases the likelihood of the system crossing a threshold, and once a threshold is breached, it is not easy to shift back (Walker & Salt, 2006:123,141,149). Resilient systems are dynamic and always changing in order to maintain resilience and their ability to withstand shock. No dynamic system has an optimally efficient state (*ibid.* 141).

d) There was a lack of knowledge and learning in the system: There was a failure to apply different types of knowledge and learning, such as combining and applying experience and experiments, before formulating a response to the flooding in 1909. No other options, except to canalise the Apies River, were considered.

1.1.4 Principles of resilience missing in the Apies River system

From the historical narrative it can be concluded that the following principles of resilience were missing in the Apies River freshwater system, affecting the quality of the connection between the ecosystem and the built environment:

c) Lack of tight feedback in the SES: Pretoria has a history of poor local governance. As a result, the SES lacked tight feedback. In the context of resilience thinking, tight feedback is necessary to build the adaptive capacity of a system and to detect the system moving towards thresholds. In the case of Pretoria pressures on the system were not acted on in time. Pollution of the drinking water took 36 years to be addressed (1877–1913) and, once a sewerage system was in place, there were still long delays between reports of malfunctioning of the sewage works and steps to resolve the situation. In addition, it took the Local Council 64 years to promulgate regulations to manage development in relation to flood lines (1909–1973). In total Pretoria functioned in the absence of flood line regulations and guidelines for 118 years (1855 – 2014).

d) Lack of flexibility and innovation in the system: The history of Pretoria shows a lack of flexibility and innovation. This lack was particularly evident in the response of the Local Council to the flooding of the Apies River in 1909. The response to the flooding were not flexible and did not search for innovative solutions, but rather opted to transform the river into a stormwater channel. From a resilience perspective, a flexible and innovative response to the flooding would have been to recognise the natural functioning freshwater system as a valuable asset and learn how to coexist with it as part of the urban built environment.

e) Failure to protect the ecological variability of the river: The Apies River lost its diversity and its connection to riparian areas and wetlands - vital elements which enabled the river to expand and contract in its natural seasonal flow patterns, to maintain a healthy freshwater system as a provider of clean water and to act as a natural buffer against flooding.

f) Lack of support to, and recognition of, freshwater ecosystem services as part of the urban structure, offering valuable benefits: Pretoria chose to design the city against the deeper ecological structures of the freshwater system, working against the processes of nature instead of with nature. When this happens and a city develops out of alignment with its natural systems and developing as if they do not exist, a city needs to put in effort and energy (usually in terms of costly engineered solutions) to push against the natural deeper structures, which will continue to reassert themselves (Spirn, 2011:18). Planning decisions, throughout the history of Pretoria, did not support the freshwater ecosystem as an integral part of the development of Pretoria.

1.2 Recommendations, and suggestions for future research

1.2.1 Recommendations: how cities can be more connected with their freshwater systems by doing things differently in future

Pressures of population, development, pollution, increased water consumption, and climate change are a continuing threat to freshwater ecosystems. This study set out to learn from the past about why things went wrong in order to make wiser decisions in terms of the management of disturbances on freshwater systems in the future. The following recommendations summarise some principles that have emerged from this history of water governance in Pretoria. If these principles can be applied in the governance of urban freshwater systems in the future, it will be possible to create resilient SESs with a quality connection between human settlements and their freshwater ecosystems.

a) In order for natural systems to promote the resilience of an SES, the deeper structures that formed and shaped the current natural systems need to be understood, respected and supported in all new planning and development proposals. Cities should be aware of the slow press disturbances, which can change the quality of freshwater ecosystems, limiting their benefits for human well-being.
b) Natural freshwater systems should be viewed as connected and dynamic systems which form part of a greater ecological system, namely a water catchment area. These freshwater systems, which manifest a high degree of ecological variability, and the diverse services that they provide, should form a quality connection to, and an integral part of, the urban infrastructure through which they flow.
c) Governance should be flexible and innovative in order to deal with and manage the ecological variability of natural systems and how these link to the urban infrastructure.
d) There should be tight feedback in the SES in order to detect thresholds in the freshwater system well in advance, and in so doing, prevent disasters.
e) Cities should not regard natural freshwater ecosystems as separate and disconnected from the urban system, but rather as an integral part of the city, making it possible for freshwater ecosystems to function in their natural state as part of the urban built infrastructure. In order for cities to retain a functional connection with their freshwater systems, it is important to understand the link between healthy freshwater systems and their benefits to humans, as stated by Allan and Castillo (2007:12). In other words, according to Folke (2003:2027), it is important to understand the context and functioning of freshwater systems as the bloodstream of the biosphere, providing for both human and ecological needs. Once this value is established and the functions of freshwater systems are understood can the integration of the built infrastructure into the ecological spatial footprint take place.
f) An understanding of the history of the system is required in order to appreciate important variables and press disturbances in the system's resilience and its potential thresholds of change.
g) A regulatory framework is needed that supports the integration of naturally functioning freshwater ecosystems in the city, both in terms of regenerative design and as part of new planning.

h) The ecological requirements of a freshwater system as a water user itself need to be taken into account and balanced with human freshwater needs. In order to achieve this balance, it is necessary for compromises to be made in human dependence on and consumption of freshwater, to ensure that the ecological functioning of freshwater systems remains healthy and able to provide continued support services to both nature and humans.

i) Cities should be aware of the drivers and the ''unseen'' press disturbances behind pulse disturbances when dealing with issues such as floods in order to address the causes behind these disturbances and prohibit further disaster in the future.

j) The general resilience of a system is compromised when there is a focus on the resilience of only part of the system, called specific resilience. Compromising general resilience degrades the adaptive capacity of the system, i.e. its ability to cope with change and disturbances.

k) In order to create resilient freshwater systems, healthy freshwater systems need to be sustained according to Baron *et al*. (2003:12,14) this can be done by: recognising that humans and nature are interdependent and that social and ecological requirements need to be balanced; view fresh water within the context of a larger landscape system comprising of multiple ecosystems, such as a watershed; restore wetlands, lakes and rivers based on ecological principles; maintain functionally intact freshwater systems rather than embark on restoration efforts later; and ensure that the biodiversity and natural variable flows of freshwater systems are maintained and protected.

l) It is important to acknowledge that adequate water quality is important for healthy freshwater systems and can be achieved by protecting healthy riparian systems, healthy tributaries and functional wetlands, which reduces the impact of land based activities in the watershed (Nel *et al.,* 2011:4) and the prevention of toxic pollution (Resilience Alliance, 2002a).

m) In order to maintain a balance between ecological and human freshwater needs, a catchment–based ecosystem management approach should be followed which ensures the integration of water, land use and ecosystems as dynamic interactive systems, compromising human behaviour where necessary to strengthen freshwater ecosystem resilience and healthy freshwater services to both man and nature (Falkenmark, 2003:2037).

n) Ecosystem management at a watershed scale can provide the opportunity to design cities that are responsive to nature through sensitive planning and which keep ecosystems functioning in a healthy state able to provide the necessary ecosystem services on a continual basis. Planning should be done in such a way that natural systems are strengthened to enhance their capacity to cope with disturbance (Resilience

Alliance, 2002). In order to achieve this, it is necessary to have flexible, transparent government institutions to promote the management of freshwater systems in a multi-sectoral way (Nel *et al.,* 2011:4,14).

o) Cities can be more responsive to freshwater systems by recognising how urban settlement patterns respond to the natural drainage systems, by addressing the density of impervious surfaces of the urban form and by recognising the drainage and flood control system (Spirn, 1984:130). Cities can also greatly reduce their risk of flooding by determining the regional and seasonal pattern of rainfall, the extent of the floodplain within a city and the degree to which the floodplain is developed (Spirn, 1984:133). Considering these factors in planning can avoid many negative effects of urban water systems.

p) In terms of design interventions to enhance the functioning of urban freshwater systems, urban stormwater and wastewater should be managed by using natural systems that encourage groundwater recharge and healthy aquatic habitats. Examples of natural systems include the development of rain gardens, the use of wetlands, bio-filtration swales, and green roofs (Rottle & Yocom, 2010:50). The functions of fresh water in the city can be strengthened through natural open space corridors, an increase in urban forests, green roofs, improved filtration, rainwater harvesting, water storage and increased wetlands (Pedersen Zari, 2012:59).

1.2.2 Considerations for future research

It is suggested that future research should consider:

a) Comparisons of the differences in cost (ecological, financial and social) when a freshwater river system is not integrated into the urban context versus when the freshwater ecosystem is integrated and supports the “green infrastructure” of the urban fabric.

b) To explore how a regulatory framework, incorporating tools such as bylaws and development constraints and incentives, can support the incorporation of the natural functioning of freshwater ecosystems as part of the city structure in terms of regenerative planning and design.

c) Develop a pilot project based on spatial modelling, which examines how freshwater can be incorporated as an asset to the SES in newer developments such as Mamelodi and Atteridgeville, in order to avoid decisions based on the ecological ignorance of the past. This will include developments that recognise that freshwater ecosystems need to be protected and restored and kept healthy as part of a connected system consisting of reservoirs, streams, rivers, wetlands and underground aquifers that need to supply freshwater to the residents of these areas and which form part of complex ecological systems within a larger water management area. The footprint of developments that take the ecological functions of freshwater systems into account will look different than the footprint of settlements that develop without embracing the natural systems. These freshwater-sensitive developments will consider and protect the position of flood plains and wetlands and will include permeable surfaces to reduce storm water runoff to the adjacent streams, respecting the importance of the slow permeability of water to feed the underground water system, which is necessary to supply the base flow of the river. Recognising that freshwater systems are an asset to the SES and understanding how freshwater systems function will encourage the protection and restoration of streams, rivers and wetlands based on ecological principles.

d) Develop a framework for urban water catchment management plans based on ecological planning and ecological management principles to restore existing urban freshwater systems as far as possible to their natural state, connected to other ecosystem services and the urban fabric in the catchment. Such water-catchment-based ecological frameworks should also be developed to direct proposed urban developments to ensure that the patterns of natural freshwater systems are incorporated and validated as part of development proposals.

e) Develop a tool for cities to easily identify, through historical assessments, the slow-moving press disturbances in the system which will over time affect the adaptive capacity and positive resilience of the freshwater ecological systems upon which the cities' well-being depends. Such a tool should assist in providing solutions and future management strategies that can enhance the adaptive capacity of freshwater ecosystem services within the context of the SES.

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APPENDICES

Appendix 1: Timeline Apies River

Date	SIGNIFICANT EVENTS	Apies River				Local	National	International
		Flooding	Hydrological Modification	H20 quality	H2O quantity			
Apies River: Natural era (pre 1855 - 1909)								
1825/26	Mzilkazi (Matebele) settled in the area by the Magaliesberg (Cashane mountains) chasing the Bakwena tribe (Western Sotho) people away.					■		
1830	Travelling explorers recorded arriving in Tshwane.					■		
1840	Voortrekker settlers from the Cape arrive in Tshwane.					■		
1855	16 November, Pretoria officially declared a town with the first erven set out in the vicinity of Church Square situated in the elbow of the Apies River, and the first nine "hartbees" houses were built.					■		
	Construction of a holding dam at the Fountain Valley springs and water furrows to the town. Due to bad workmanship the water furrows had to be reconstructed in 1860 (Haarhoff *et al.*, 2012b:770).		■					
1857	Apies River's first appearance on a map, called AapRiver (Van der Waal, 2000).					■		
1858	Water furrows running along the main streets supply water to central Pretoria from the Fountains Valley (Van der Waal, 2000).				■			
1860	Pretoria declared as the seat of government (The City Council of Pretoria, 1955:150).					■		
	Local water regulations forbade the use of water from the furrows before it entered the town; pollution of the water was also prohibited (Haarhoff *et al.,* 2012b:770).			■				
1864	In May, a local Council was established to take care of much needed municipal services. However this Council was disbanded in September of the same year as the national government refused to supply the Council with the necessary revenue (Haarhoff *et al.,* 2012b:772).					■		
	As a result of the need to maintain the water in the furrows free from pollution and unfair use, a water superintendent was appointed (Haarhoff *et al.,* 2012b:770).			■	■			
1870	First large plots established along the Apies River (east of Du Toit Street and north of Boom Street). Mills built along the Apies River at Arcadia Drift in Church Street, Dr Savage Street and at Daspoort (Van der Waal, 2000).					■		
	The water superintendent's services needed to be supplemented with additional support from contractors and convicts (Haarhoff *et al.,* 2012b:770).			■	■			
1877	12 April, First British occupation of the Transvaal lasting until August 1879.			■				
	The British occupation resulted in an increase in population from 1,500 to 2,000 due to military and business activities (Haarhoff *et al.,* 2012b:773).					■		
	August, the furrows were in an unhealthy disease-ridden state smelling of sewage (Haarhoff *et al.,* 2012b:773).			■				
	Second failed local Council in Pretoria — this time people did not accept the Council because it was forced on them by the British military government.					■		
1879	End of the first British occupancy of the Transvaal.					■		
1880	16 December, start of the First Anglo Boer War.					■		
	Pretoria regains independence from British rule which lasts until 1899.					■		

Date		Apies River				Local	National	International
	SIGNIFICANT EVENTS	Flooding	Hydrological Modification	H20 quality	H2O quantity			
	The Apies River is documented as Apanjis River on the British Compass Sketch plan compiled by the Great Britain Army Royal Engineers.					■		
1881	23 March, end of the First Anglo Boer War.					■		
1883	1 May, Paul Kruger sworn in as President of the Transvaal (South African Republic) (Van der Waal & Associates, 1999:5).						■	
1887	Lion Bridge was built (as an iron bridge) over the Apies River at the Church Street crossing (Vorster, 1994:30), it was later rebuilt in concrete.		■					
1886	6 March, heavy rains described as a miniature Noah's Ark flood which caused the Apies River to come down in a mighty roar; the worst flood in previous 12-14 years (Swanepoel, 2012:[1]).	■						
	The Transvaal Witwatersrand Gold Rush.					■		
1888	1878-1888 Victoria Bridge completed across the Apies River at Jacob Mare Street. It was rebuilt in 1912 as a concrete bridge (Van der Waal & Associates, 2000:25).		■					
	First two jacaranda trees imported from Rio de Janeiro, planted at Myrtle Grove (Van der Waal & Associates,1999: 5).				■			
	Paul Kruger becomes president for a second term (Van der Waal & Associates, 1999:5).						■	
	Renewed pressure for a local government in Pretoria as a result of poor health and contaminated water in the furrows and the wells and a lack of a sewerage reticulation system. This resulted in a temporary Council established nine years after this (Haarhoff *et al.*, 2012b:777).						■	
	Cesspools were forbidden (Haarhoff *et al.,* 2012b:781).			■				
1889	Breakout of enteric fever in Pretoria due to pollution in the water furrows (Haarhoff *et al.*, 2012a:20).					■		
	Pretoria Water Works Company Limited was established to provide water for Pretoria. A collection chamber for the two fountains was built leading water into the town through steel pipes (Haarhoff *et.al.*, 2012:20).					■		
	The Pretoria Water Works Company Limited wanted to introduce water meters for individual users and increase the price the water. However, this was met unfavourably with a petition by 1,060 residence (Haarhoff *et al.,* 2012b:774).				■			
1891	Water connections established to buildings in the CBD (Van der Waal & Associates,1999:5).					■		
1893	Sewerage reticulation system still lacking and erven and furrows polluted as a result of inadequate sanitation (Haarhoff *et al.,* 2012b:775).			■				
1894	The Lion Bridge was officially opened on 11 June after it had to be rebuild due to erosion by stormwater. (The rebuild started in 1890) (Vorster, 1994:30).		■					
	Road compaction started with the first steamroller in operation (Van der Waal & Associates, 1999:5).			■	■			
1895	President Paul Kruger declared Groenkloof, in Fountains Valley where the fountains of Pretoria are situated, a protected area on 25 February. (Dippenaar, 2013, p. 23).					■		
1897	Poor sanitation and lack of wastewater reticulation contaminated the water in the furrows, which served as drinking water for the houses. This caused a high incidence of disease and an increase in the death rate in the city (Haarhoff *et al.,* 2012b:775).			■				
	The Tram Bridge was built over the Apies River in Esselen Street, a narrow iron construction. It was later widened to accommodate an electric tram and in 1939 modified to accommodate motorised transport (Andrews,1986:24).		■					
	Pretoria established a one-year temporary Council, followed by a second temporary Council in 1899 to address the water and sewerage infrastructure backlog (Haarhoff *et al.,* 2012b:777).					■		

Date		Apies River				Local	National	International
	SIGNIFICANT EVENTS	Flooding	Hydrological Modification	H20 quality	H2O quantity			
1899	October, second British occupation of Pretoria (1899-1902) and the start of the Second Anglo Boer War against Britain.						■	
	A section of the Apies River is incorporated into the National Zoological Gardens (Van der Waal, 2000).					■		
	Winston Churchill (special correspondent to the Morning Post, later prime minister of England) crossed the Apies River at the Skinner Street footbridge at night on 12 December in his escape from the Staatsmodel School (Van der Waal, 2000). The river was referred to as the mighty Apies then.						■	
1902	31 May, Peace of Vereeniging which ended the Second Anglo Boer War against Britain (Van der Waal & Associates, 1999: 5).						■	
	Start of the Transvaal Colony with British rule of the Union of South Africa (1902–1910).						■	
	The Fountains Valley water scheme is expanded with a concrete aqueduct built by the British Army and the Findley Reservoir built south of the railway station to ensure water supply to suburbs like Arcadia and Sunnyside (WAMTechnology CC, n.d.).				■			
1903	Severe flooding occurred, heavier than in 1909, but the impact was further out of Pretoria.	■						
	First democratic town Council elected after the war, almost 50 years after Pretoria was established, with powers to collect taxes in order to create an income base to improve development in Pretoria (Haarhoff *et al.*, 2012b:778).					■		
1904	Pretoria's population = 36,700 (WAMTechnology CC, n.d.).					■		
	The lack of sanitation and drainage in Pretoria during 1904 was becoming progressively worse, as revealed in a municipal health report later in 1907 (Haarhoff *et al.*, 2012b:781)			■				
1905	Canalisation started of the three rivers in Pretoria CBD (Haarhoff *et al.*, 2012b:781).		■					
1906	The construction began of a network of subsurface, brick-built stormwater drains in the inner town in order to divert surface water away to the natural watercourses. This was completed in 1911 (Haarhoff *et al.*, 2012b:778).			■	■			
1907	In order to improve the bad state of water provisioning in Pretoria after the war, a large-scale project was launched to improve the water mains to transport water to users in the town (Haarhoff *et al.*, 2012b:780).					■		
	None of the water in the 75 wells in use in Pretoria during this time tested suitable for drinking water (Haarhoff *et al.*, 2012b:780).			■				
	Municipal health report revealed the risk of the polluted water in the furrows as a serious danger to health (Haarhoff *et al.*, 2012b:781).			■				
1909	9 January severe flooding in Pretoria regarded as a national disaster when three people died and many lost their belongings when the Apies River changed into a powerful mass of water (Van der Waal & Associates, 2000:24).	■						
	The medical officer of health's concern at the health risk of the polluted water in the open furrows continued (Haarhoff *et al.*, 2012b:781).			■				
Apies River: Era of disconnection (1910-1970)								
1910	Apies River canalisation of the section between Vermeulen Street and Lion Bridge (1910–1911) (Van der Waal & Associates, 2000:24).		■					
	End of the Transvaal Colony and British occupancy; the Union of South Africa is established with Pretoria the administrative capital.						■	
	Apies River canalisation of the section between Esselen Street and Victoria Bridge (1910–1912) (Van der Waal & Associates, 2000:24).		■					
	Lion Bridge in Church Street, a bridge across the Apies River that was opened in 1894, is upgraded, the wooden deck was replaced by a macadamised surface and sidewalks were built (Van der Waal &		■					

Date		Apies River				Local	National	International
	SIGNIFICANT EVENTS	Flooding	Hydrological Modification	H20 quality	H2O quantity			
	Associates, 2000:24).							
	Esselen Street Tram Bridge across the Apies River completed **(**1909-1910) (Van der Waal & Associates, 2000:24).		■					
	Subsurface stormwater infrastructure and electrical cables were installed in the middle of Church Street, and stormwater duct built out of bricks (Vorster, 1994:30).		■					
1911	Canalisation of the section of the Apies River between Lion Bridge and Esselen Street (1911–1912) (Van der Waal & Associates, 2000:24).		■					
	Pollution in the Apies River detected. Subsurface stormwater drains, which during dry seasons were used as wastewater outlets from the CBD, Arcadia and Sunnyside caused pollution of the water of the Apies River. This caused concern about the health and state of the river (Municipality of Pretoria, 1911:95, 96).			■				
	The construction of a network of subsurface, brick-built stormwater drains in the inner town completed (Haarhoff *et al.,* 2012b:778).			■	■			
1912	A row of date palms were planted along the Apies River channel (Van der Waal, 2000).		■					
	Upgrade of wooden footbridge across the Apies River at Skinner Street (Van der Waal & Associates, 2000:24).		■					
	Victoria Bridge, which was completed in 1888 across the Apies River at Jacob Mare Street, was replaced with a concrete arch bridge (1911-1912) (Van der Waal & Associates, 2000:25).		■					
1913	The first sewage plant was built at Daspoort (Haarhoff *et al.*, 2012b: 781).			■				
1914	Severe flooding recorded (City of Tshwane, 2006:1).	■						
1915	Flooding recorded (Van Veelen *et al.,* 2004:4-18).	■						
1917	9 March it was recorded that he springs in the Fountains Valley experienced a yield problem, which caused fluctuation in the delivery rate which was attributed to the pumping of underground water by the East Rand Mining Group's operations (Municipality of Pretoria, 1918:24).				■			
1919	Canalisation of the section of the Apies River between Vermeulen Street and Proes Street (1919–1920) (Van der Waal & Associates, 2000:24).		■					
1921	Proes Street Bridge across the Apies River completed (1920–1921) (Van der Waal & Associates, 2000:24).		■					
1923	Severe flooding similar to that of 1909 accompanied by devastating hailstorms. This resulted in the increased use of concrete for building and houses in response to the loss of roofs from the hailstorm (Van der Waal, 1996a:3).	■						
	Bon Accord dam completed downstream from Pretoria north of the Wonderboompoort, serving mainly as source for irrigation (Dippenaar, 2013:39).		■					
	Pretoria's daily water consumption was 21.48Ml, which was close to the 23 Ml/day yield from the Fountains (WAMTechnology CC, n.d.).				■			
1927	Severe flooding recorded (City of Tshwane, 2006:1).	■						
	November, the Council urged to evaluate other sources of water for supplementing the water supply to Pretoria (WAMTechnology CC, n.d.).				■			
1928	Due to over-exploitation of the Fountains water supply, a water metering system was introduced in Pretoria in 1923 and completed in 1928 (Haarhoff *et al.,* 2012a:23).				■			
	The farm Rietvlei was bought in order to build the Rietvlei dam which was completed in 1934 (Dippenaar, 2013:31).				■			
	Flooding recorded in January (Van Veele *et. al.,* 2004:4-18).	■						

Date	SIGNIFICANT EVENTS	Apies River				Local	National	International
		Flooding	Hydrological Modification	H20 quality	H2O quantity			
1931	January flooding recorded in Pretoria (Van Veelen *et al*., 2004:4-18).	■						
1932	Canalisation of the section of the Apies River from Hove's Drift to Prinshof completed (1931-1932) (Van der Waal & Associates, 2000:24).		■					
	Hove's Drift Bridge over the Apies at Dr Salvage Road completed (1931-1932) (Van der Waal & Associates, 2000:24).		■					
1933	Willow Road Bridge was built across the Apies River (1932-1933) (Van der Waal & Associates, 2000:25).		■					
	Rietvlei dam was completed to supplement the urban water supply (Dippenaar, 2013:39)					■		
1935	Boom Street Bridge in Marabastad across Steenhoven Spruit completed **(**1934-1935) (Van der Waal & Associates, 2000:24).		■					
	Canalisation of the section of the Apies River from Proes Street to Hove's Drift (1934-1935) (Van der Waal & Associates, 2000:24).		■					
	Pretorius Street Bridge across the Apies River completed **(**1934-1935) (Van der Waal & Associates, 2000,:24).		■					
1937	Apies River canalisation from Victoria Bridge to Rhodes Avenue completed (1936-1937) (Van der Waal & Associates, 2000:24).							
	Struben Street Bridge in Marabastad across Steenhoven Spruit completed (Van der Waal & Associates, 2000:24).		■					
	Rhodes Avenue Bridge across the Apies River completed **(**1936-1937) (Van der Waal & Associates, 2000:25).		■					
1938	Apies River canalisation from Rhodes Avenue to Willow Road completed (1937-1938) (Van der Waal & Associates, 2000:24).		■					
1939	Tram Bridge over the Apies River in Esselen Street was modified to accommodate motorised transport (Andrews, 1986:24).		■					
	November flooding in Pretoria (Van Veelen *et al*., 2004:4-18).	■						
	World War Two began.							■
1940	Severe flooding recorded (City of Tshwane, 2006:1).	■						
	Between 1939-1940 Schoeman Street bridges across the Apies River and Walker Spruit were built in concrete by JD van Tilburg & Son, replacing the original steel bridges which were built when the Apies River and its tributaries were canalised (Van der Waal & Associates, 2000:24).		■					
1943	Pretoria established an agreement with Rand Water to import water to the area through pipes from Vereeniging, thus taking water from one water catchment, which drains to the Atlantic ocean, into Pretoria's water catchment which drains to the Indian ocean (Stadsraad van Pretoria, 1952:237).				■			
1945	World War Two ended.							■
1948	The National Party came into power and apartheid became the government policy.						■	
1949	Flooding, similar to that which was recorded in 1909, accompanied by devastating hailstorms (Van der Waal, 1996a:3).	■						
1955	Severe flooding recorded (City of Tshwane, 2006:1).	■						
1956	South Africa's first Water Act promulgated (Act No. 54 of 1956) (Ashton *et al.,* 2012:17).						■	
1962	November, Nelson Mandela arrested.						■	

Date	SIGNIFICANT EVENTS	Apies River: Flooding	Apies River: Hydrological Modification	Apies River: H20 quality	Apies River: H2O quantity	Local	National	International
	Political isolation for SA when the UN General Assembly requested member states to dismantle diplomatic, trade and transport relations with SA (SAHO, n.d.).							■
	The book *Silent Spring* by Rachel Carson was published which triggered the rise of the environmental movement (Ashton *et al.*, 2012:18).							■
Apies River third era: attempts to reverse the disconnection between the Apies River and built infrastructure (1970-2014)								
1973	The Pretoria City Council started to determine flood lines along the city's rivers and streams (Redelinghuijs, 1996:3).					■		
1975	National Water Act (Section 169 of Act 54 of 1965) required that the 1:50 year flood line be indicated on proposed township plans. Provincial Gazette Notice No.1220, required that no building be built within the 1:50 year flood line of a natural watercourse.						■	
1978	Severe flooding recorded at the Wonderboompoort (City of Tshwane, 2006:2).	■						
	The Water Act was amended to allow for flood management procedures (Redelinghuijs, 1996:3).						■	
1980	Lake Trevenna development plans abandoned (Van der Waal, 2000).					■		
1981	Canalisation of the Apies River was intensified and expanded in 1981 as a result of severe flooding in 1978 (Hefers, 1981).		■					
	October, cholera outbreak in the Apies River with 116 cases reported, caused by contamination from raw sewage due to an ineffective pump at the Hammanskraal Sewage Works. Most of the contamination was in Hammanskraal. Contamination stretched downstream from the Bon Accord dam up to Bophuthatswana (Stoltz, 1981).			■				
1985	Severe regional flooding recorded mainly in the flat areas of Akasia, Hammanskraal, Temba, Ga-Rankuwa, Soshanguwe and Mabopane (City of Tshwane, 2006:1).		■					
1990	Nelson Mandela released from jail.						■	
1991	Official ending of apartheid.						■	
1992	United Nations Rio Earth Summit takes place.							■
1994	12 February, Apies River experienced severe flooding with 62.3 mm of rain, over approx. 24 hours, affecting developments closest to the river edge such as the Wonderwaters Caravan Park in Wonderboom, Sunnyside and Fountains Valley (Gouws, 1994).	■						
	Magaliesberg Natural Protected Environment established where the Apies River runs through the Wonderboompoort (previously known as the Tweede Poort).					■		
	First democratic elections in South Africa.						■	
1995	23 October, establishment of the Action Apies River Working Committee (Van der Waal, 2000).					■		
1996	19 January, severe flooding in Pretoria, which caused major flow in a short period of time, but no human life lost. This motivated the Council to spend R90 million on stormwater management (Redelinghuijs, 1996:3).	■						
2000	Severe regional flooding recorded mainly in the flat areas of Akasia, Hammanskraal, Temba, Ga-Rankuwa, Soshanguwe and Mabopane (City of Tshwane, 2006:1).	■						
	Pollution: Large number of fish die in the Apies River.			■				
2004	The Apies River found to be polluted above recommended levels and the water not suitable for human consumption (Tshivhandekano, 2006:66).			■				
	Severe regional flooding recorded mainly in the flat areas of Akasia, Hammanskraal, Temba, Ga-	■						

Date	SIGNIFICANT EVENTS	Apies River: Flooding	Apies River: Hydrological Modification	Apies River: H20 quality	Apies River: H2O quantity	Local	National	International
	Rankuwa, Soshanguwe and Mabopane (City of Tshwane, 2006:1).							
2006	January, severe flooding in Pretoria (City of Tshwane, 2006:1).	■						
2009	Water quality concerns were raised due to contamination of the Apies River from the Rooiwal Sewage Plant, but no action was taken (Anon., 2011b).			■				
2010	Pollution in the Apies River affected several farmers north of Pretoria. Raw sewage was entering the river from the Rooiwal Sewage Works, due to faulty or inadequate pumps (Claassen, 2010a).			■				
2011	November, Apies River north of Pretoria declared a disaster area by the Department of Water Affairs due to contamination by raw sewage from Rooiwal leaking into the river due to lack of proper maintenance (Anon., 2011).			■				
	R11 million was allocated by the Council for the upgrade and maintenance of the Rooiwal Sewage Plant (Anon., 2011a).			■				
2014	January, severe flooding recorded in Pretoria	■						