APPLYING THE SOCIAL-ECOLOGICAL SYSTEMS FRAMEWORK TO UNDERSTAND IMPACTS OF FLOODING IN THE PALMIET RIVER CATCHMENT

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PREFACE

The research contained in this dissertation was completed by the candidate while based in the Discipline of Hydrology, School of Agricultural, Earth and Environmental Sciences of the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg Campus, South Africa. The research was financially supported by the National Research Foundation.

The contents of this work have not been submitted in any form to another University and, except where the work of others is acknowledged in the text, the results reported are due to investigations by the candidate.

Signed: (Supervisor)

Date: 26/08/2021

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DECLARATION: PLAGIARISM

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ABSTRACT

Accelerating urbanization in African cities is impacting the ability of urban ecosystem services to provide services to contribute to the wellbeing of people. Additionally, climate change presents increased urban risks such as the increased frequency and intensity of flooding. This thereby threatens human life and built infrastructure; and challenges the resilience of communities already strained by socio-economic challenges. Ecosystem services in urban catchments are poorly understood which further adds to the lack of understanding the value of natural resources in urban catchments and subsequently how to restore and protect vital natural resources in order to ensure ecosystem services delivery. The aim of the study is to understand how impacts of flooding decrease the resilience of the communities in the Palmiet River catchment located in Durban, South Africa, through applying the social-ecological system (SES) framework. The Palmiet River catchment is a dynamic and heavily urbanized catchment in which the Palmiet River extends 26km through its headwaters at an elevation of 510m flowing through the lower informal settlement at 18m elevation. The SES framework is an interdisciplinary approach to understanding biophysical and social aspects in a relational landscape – both of which can no longer be studied in isolation. The methodology of the study uses data collected from public community engagement forums to identifyspecific issues occurring within the catchment and understanding the roles of interested and affected stakeholders. Further, aerial photography images of the Palmiet River catchment from 1981 to 2016 were used to identify the rate of urbanization and terrestrial impacts; this data was additionally supported by drone images. A SES framework was applied for sub-sections of the Palmiet River catchment in order to develop a narrative for the total river catchment to improve understanding of societal actions of urbanization that impact the functionality of the Palmiet River. The findings of the study reflect that: 1) Flood events are occurring more frequently, and more peopleare at risk as the influx of people within the catchment increases and the land use/cover changes. 2) A collaborative social system with a strong governance unit exists within the Palmiet catchment. This has facilitated conversations amongst resources users and actorsin the rehabilitation of the resource system. This could potentially serve as a springboard for identifying viable areas for ecological infrastructure investments. 3) The social system has increased resilience within the catchment – however, this may change as flood events continue to increase in intensity and frequency. 4) The Palmiet River is a dynamic social-ecological system that presents challenges as well as opportunities for sustainable and integrative catchment management. The SES framework provided a tool to evaluate the social and ecological systems

through which to assess thecurrent limitations for the Palmiet River to regulate flood events. 5) It was lastly necessary to identify ways in which sustainable urban design systems and ecological infrastructure could be used as a part of catchment management strategies to rehabilitate and enhance ecosystem services. It was concluded that the ecosystem services once offered by the Palmiet River catchment have been compromised byunprecedented rates of urbanisation, particularly impacts of growing informal settlements in the lower parts of the catchment as well as industrial areas in the upper parts of the catchment.
***Keywords**: ecological infrastructure; ecosystem services; social-ecological systems framework; urbanization*

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ABBREVIATIONS

CoI	Community of Innovation
CPD	Climate Protection Department
EI	Ecological Infrastructure
ES	Ecosystem Services
MEA	Millennium Ecosystem Assessment
AoI	Area of Interest
RDP	Reconstruction and Development Programme
SES	Social-Ecological System
TEEB	The Economics of Ecosystems and Biodiversity
UEIP	uMngeni Ecological Infrastructure Partnership

CHAPTER 1: INTRODUCTION

1.1 Background for the study

Accelerating urbanization in African cities directly and indirectly impacts the functions and processes of urban ecosystems; which compromise the ability of ecosystem services to sustain life and functions in urban areas (Dodman *et al*., 2017; Inostroza and de la Barrera, 2019; Mngumi, 2020). There are fundamental knowledge gaps on the impacts of urbanization on the functions of ecosystem services, particularly in the African context (Turok and Borel-Saladin, 2014; Güneralp *et al*., 2017; Wiederkehr *et al*., 2020). This rise in urbanization on the African continent has been rapid in recent years compared to global rates of urbanization (Güneralp *et al*., 2017; White *et al*., 2017). The expansion of cities is dependent on continuous flows of ecosystem services from neighbouring non-urban ecosystems to support and sustain essential urban functions (Inostroza and de la Barrera, 2019). Furthermore, rapid urbanization in African cities is closely associated with a lack of spatial planning which is exacerbated with increasing informal settlements, urban poverty, inadequate housing, and the lack of basic services (Kombe, 2005; Turok and Borel-Saladin, 2014; Mngumi, 2020). Other key factors typically contributing to this delayed yet increasing rate of urbanization in African cities are a combination of political unrest and deeply rooted socio-economic challenges (Güneralp *et al*., 2017; White *et al*., 2017). This has impacted the nature in which resultant city growth and available city planning affects the natural environment (Turok and Borel-Saladin, 2014; White *et al*., 2017).

In general, increased urbanization is associated with an increase in impervious surfaces and reduction in vegetation in addition to rapid land use/cover changes (Güneralp *et al*., 2017). This leads amongst other impacts to frequent flood events in urban catchments resulting in severe risks to people, settlements, and the economy just to name a few (Muller *et al*., 2009; Turok and Borel-Saladin, 2014). Various flooding impacts and risks exist such as the loss of informal housing, water quality issues, soil erosion, damage to homes and public infrastructure, disruptions to livelihoods and the spread of diseases (Moser and Satterthwaitte, 2008). These impacts and risks vary disproportionately at a global scale and are especially concerning for developing nations such as in African cities. The uncertainties in the impact of climate change further exacerbates these risks in African cities that are more prone to challenges in effectively responding to the predicted frequency and intensity of natural hazards (Muller *et al*., 2009; McDonnell and MacGregor-Fors, 2016).

Water and sanitation networks and infrastructure in many African cities such as Durban, South Africa, are severely strained, often beyond municipal capacity to respond to the rapid and unplanned urbanization as alluded to above. This, therefore, also leads to an increasing demand on resources to cater for a growing urban population and poses abundant pressure on local government for ensuring human welfare in cities while preventing a loss in natural ecosystems and further, compromised environmental services (Hasse *et al*., 2014; Turok and Borel-Saladin, 2014). It needs to be noted here that the Intergovernmental Panel on Climate Change (IPCC) continuously cautions on the interference of humans with the climate system leading to heightened and frequent extreme weather events such as excessive rainfall leading to urban flooding (Geneva, 2013). This, therefore, brings attention to the need to better unpack how urban ecosystems function and provide services to people, in addition to the limitations in the performance of ecosystem services (ES) due to growing human influences in a fast-evolving world (Hasse *et al*., 2014; Martin-Lopez *et al*., 2017; Van den Heuvel *et al*., 2020).

Urbanization is an essential driver of land use/cover changes (particularly in the urban zone) which influences the supply and demand of ES (García-Nieto *et al*., 2018). ES in urban catchments are poorly understood and challenging to quantify (Costanza and Kubiszewski, 2012; Inostroza and de la Barrera, 2019). Consequently, this further adds to the lack in the understanding of the value of protecting natural resources in urban catchments (Costanza and Kubiszewski, 2012; Inostroza and de la Barrera, 2019; Mngumi, 2020). Furthermore, one of the greatest challenges is to adequately capture the way in which contemporary patterns of urban development are shaping flooding risks in African urban areas (Van Rooy, 2006; Dodman *et al*., 2017). Poor and ineffective urban planning in cities has altered valuable ecosystems. This is considered an urban metabolism to describe the interdependencies and dynamics within cities and their ecosystems (John *et al*., 2019). Additionally, many African cities face an increasing amount of backlog in infrastructure investment and lacking service delivery which continues to lead to further issues of pollution, severe flooding impacts and overconsumption of resources (Turok and Borel-Saladin, 2014; White *et al*., 2017). This, therefore, highlights the necessity for the knowledge of urban risks – particularly the nature and measure of these risks in the context of poverty, increasing urban population and climate change (Turok and Borel-Saladin, 2014; Dodman *et al*., 2017).

The concept of natural ecosystems is evolving beyond a traditional undisturbed environment to one which encompasses the integration of people and technology (Haase *et al*., 2014). The degradation of the natural environment and ecosystems in African cities is a shared reality that presents a platform for collaborative efforts in changing the environmental trajectory between

people and the spaces people choose to occupy (Kiunsi, 2013; Mngumi, 2020). Therefore, the physical landscape and its emerging risks need to be studied in relation to the activities occurring in that landscape. Urban landscapes present a multitude of complexities that are constantly evolving as social-economic activities of people simultaneously change (with) the environment (van den Heuvel *et al*., 2020). The prestigious 2019 Nobel Prize Winners in Economics, Ester Duflo and Abhijit Banerjee discard the generalized and formulaic approach of thinking about the (urban) poor in their book: Poor Economics (Duflo and Banerjee, 2011). The Nobel prize winners advocate for the poor not to be reduced to being studied from a perspective of being solely pitied or used for political propaganda. But instead, they be given platforms to share their unique knowledge and narratives that inherently contribute to understanding their physical and social context in greater depth (Duflo and Banerjee, 2011). Therefore, inclusive engagement with different members in society presents the opportunity to investigate different existing social and biophysical systems that are simultaneously at play within a catchment and city at large, and how best to study the progression of ecosystem services offered within the catchment system.

Quantifying the value of ecosystems and their ES is challenging. This is due to limited analytical tools and methods. Another contributing factor to this challenge is the existing spatial and temporal complexities of ecosystems (Inostroza and de la Barrera, 2019). Environmental and social challenges do not exist in silos; they are interconnected and adaptive complex systems which interact at multiple temporal and spatial scales (Berkes, 2017; Martin-Lopez *et al*., 2017; Selomane *et al*., 2019). These complexities are often characterized by inherent uncertainty, tipping points, connectivity, emerging properties such as resilience that cannot be predicted from investigating only parts of a system (Berkes, 2017). Unlike simple systems, it is difficult to describe complex systems such as social-ecological systems (SES) through a single perspective and using a standard analytical model (Berkes, 2017). The method of applying a social-ecological systematic approach aims to understand the interactions and relationships between the resource system and human system (Selomane *et al*., 2019). It is the people who live within these urban areas that are of interest here as they are influential in shaping the condition of the resource system and therefore the services offered from it. It is important to understand this interaction through space and time in order to co-design and encourage engagements to tackle challenges and transformation in space and time. Therefore, connecting social and ecological systems across spatial and temporal scales are key efforts to understand the relations between the biophysical sphere and the human system. Only when we gain insight into this highly complex and non-linear system can we enable ourselves to move onto a more sustainable

trajectory of development (Selomane *et al*., 2019). It is also in this way of thinking that Ester Duflo and Abhijit Banerjee advocate for research to focus on the type of evidence used to inform policy development; and the type of questions asked to address presented evidence (Duflo and Banerjee, 2011). It is the depth of deliberation and the changing perspective that can move us away from the technocratic approach and the analysis looking at and not into the urban system and its hinterland. In this study, the urban system will be investigated through various areas of interest to provide a broader view of the areas and activity within the catchment.

1.2 Rationale for the study

Contemporary research has gained momentum in expanding on how significant land use/cover changes affect the supply of ES (Allen, 2003; Turner *et al*., 2007; Burkhard *et al*., 2012; García-Nieto *et al*., 2018; Chen *et al*., 2020). Subsequently, the conversation on the investment in ecological infrastructure (EI) continues to be investigated (Cumming *et al*., 2017; Chen *et al*., 2020). EI is a term used to refer to natural and semi-naturally functioning ecosystems that provide water utility services that enhance, augment or replace services provided by built (grey) infrastructure (Lee *et al*., 2014; SANBI, 2014; UNEP, 2014). The investment of EI would address urban development challenges such as ecosystem regulation services e.g. rainwater runoff regulation (Chen *et al*., 2020). In this case, investment in the type of EI would be guided by the location and biophysical characteristics of the catchment to maximize the effectiveness of the selected EI (MacFarland *et al*., 2019). However, the investment in EI to support built infrastructure is reliant on functional ecosystems delivering such services to people (Cumming *et al*., 2017). It is therefore necessary to investigate existing connections and interactions between social systems and ecological systems in a catchment. Such system thinking has gained increasing attention over the last twenty years (Colding and Barthel, 2019) as the path to conceptualizing the linkages of both systems has proven valuable and experimental across various disciplines. The concept of SES was first coined in the seventies and later conceptualized into a framework (Ratzlaff, 1970; Berkes and Folke, 1998; Colding and Barthel, 2019). The concept of SES is defined broadly but has been simplified as a system of people and nature or as a system that includes societal (human) and ecological (biophysical) subsystems in mutual interactions (Harrington *et al*., 2010; Thomas *et al*., 2012). Again, this points us to the realisation that the links in the SES are not always causal or linear but can be relational and adaptive without necessarily always following logic. With that, each system that is investigated becomes unique and does not necessarily yield results that can be up- or out-scaled.

Flooding is driven particularly by the increased frequency and intensity of rainfall events, and consequently amplifying the threats to human life and built infrastructure (Nur and Shrestha, 2017). Although research on flooding in African cities has increased in recent years, it remains crucial to understand whether people possibly are becoming more resilient while experiencing more severe flooding as the realities of climate change become more evident (Agbola *et al*., 2012; Nkwunonwo, 2016; Nur and Shrestha, 2017; Salami *et al*., 2017). Resilience is defined as the capacity of a system to withstand disturbance during change in a manner that still allows a system to retain its structure, functions, character, and feedbacks (Walker *et al*., 2004; Berkes, 2017). The spatial distribution of flooding impacts beyond the increase of events and their severity are attributed to climate change and to patterns of land use and state of natural vegetation (Dalu *et al*., 2018). In developing countries such as South Africa, drastic land transformation, climate change, land degradation, invasive alien species and hydrological alteration are a threat to ecosystems (Turpie *et al*., 2017). The key challenge therefore lies in finding integrated water resource management strategies that incorporate a balance between ecosystem protection and sustainable human resource use (Vörösmarty *et al*., 2010). This is further explored by expanding on the resilience required in urban development through integrative approaches that link the relationship between urbanization, urban growth, urban governance, and ecological degradation in sub-Saharan African cities (Fraser *et al*., 2017; Sutherland *et al*., 2019). Topographical household location is another contributing factor identified when assessing flooding impacts, especially when looking at the destruction and loss of households in informal settlements (Dalu *et al*., 2018).

The intense impacts of flooding in African cities is attributed to poor urban planning and climate change (Nkwunonwo, 2016). Flooding impacts are exacerbated by the growing occupation of floodplains, increased runoff from impervious surfaces and silted drainage systems (Douglas *et al*., 2008). Poor urban planning amongst other governance challenges contributes towards the (dis)placement of informal settlement dwellers in African cities and their exposure to higher risks of flooding (Adelekan, 2010; Jabeen *et al*., 2010). High flooding risks associated with urban expansion in areas such as wetlands should be preserved (Adelekan, 2010). This contributing factor to low-income groups being situated in unsafe areas as a result of limited living options is exacerbated further during flooding events (Douglas *et al*., 2008). Flooding increases various vulnerabilities of communities - which are already strained by socio-economic challenges particularly evident in African cities (Nur and Shrestha, 2017). As a result, it is important to strengthen linkages between climate change adaptation and development tackling the associated

risks (Awuor *et al*., 2008). This therefore begs for a debate on how vulnerable communities or systems can gain resilience to flooding impacts in the context of minimal resources available.

The concept of ecosystem services (ES) can assist in unpacking the relational system seen in SES applications where systems interact and form each other continuously. ES are direct and/or indirect contributions and benefits of the natural environment to human well-being (Schröter *et al*., 2014; Crafford, 2015). Buffering flooding in various ways is an example of this. In a study conducted by Dalu *et al*. (2018), it was found that the topographical position, land cover pattern and the proximity of people to water bodies collectively contributed to the physical impact of flooding risks. The study concluded with the recommendation to explore EI as part of the adaptation response to minimize flooding impacts. The consequence of land use change and the increased dependence by vulnerable people on natural resources is also considered (Dalu *et al*., 2018). This dependence not only includes ecosystem services such as natural vegetation acting as a flood mitigation measure but extends to the vulnerability and exposure of people to flooding (Palmer *et al*., 2009; Dalu *et al*., 2018; Ferreira *et al*., 2020). This is an outcome of colonial institutional disposition and political instability in some African cities (Güneralp *et al*., 2017). Considering this, the co- dependency of people and governance systems, and functional ES is identified (MEA, 2005). This realization, although lacking an extensive influence in national policies on urbanization in Africa, still requires for local strategies that promote liveable and valuable lives (Güneralp *et al*., 2017).

Present land use change is a concern in reducing the capacity of ecosystems to sustain long-term productivity from local to global scales (Foley *et al*., 2005; Ashley *et al*., 2020). The competition for access to natural resources is a challenge, especially with changing land use in urban catchments (Carpenter *et al*., 2009; Cardinale *et al*., 2012). In this case, an urban catchment refers to an area located within the surroundings of a (metropolitan) city or town. It is also important to outline the scale of the (sub-) catchment in relation to the available natural resources and users in the catchment. Substantial advances in land use change science have been recognized in studies and as a result contribute to understanding the dynamics in human-environment systems (Grêt-Regamey *et al*., 2017). However, research has not been fitting for mainstreaming research outcomes into decision-making and implementation. This, therefore, presents a challenge for decision-makers in a diverse urban landscape in responding with innovative approaches and fostering transformative solutions; specifically in developing countries with a lack of resources (Turner *et al*., 2007; John *et al*., 2019; Ashley *et al*., 2020; Bedinger *et al*., 2020; Ndebele-Murisa *et al*., 2020).

Human impacts on freshwater ecosystems continue to result in decreasing supplies of safe clean water mostly due to increasing pollution on inland watercourses (Vörösmarty *et al*., 2005; Liu *et al*., 2015; Ashley *et al*., 2020). The direct links between increasing urbanization and ES provision have not been widely investigated (Inostroza and de la Barrera, 2019). A growing body of knowledge advocates for further research into SES that may support future investment in ecological infrastructure to address sustainable development goals (Cumming *et al*., 2017). The physical state of a river can be used as an indicator of ecosystem condition (Liu *et al*., 2015) as the functionality of ecosystems is a combined result of abiotic variables such as hydrology, pollution and sediment load (Breuste *et al*., 2015). Increases in temperature and changes in rainfall affect natural habitats as well as physiological adaptation and phenology of freshwater species, which consequently alters the dynamics of freshwater ecosystems and with that the resultant ES (Doak and Morris, 2010; Liu *et al*., 2015). The dynamics of freshwater ecosystems in an urbanised landscape remain poorly understood in terms of restoring ecological processes and functions in urban spaces (Elmqvist *et al*., 2015). By the year 2030 it is estimated that approximately 60% of the world's population will be urbanised (Elmqvist *et al*., 2013; Lee *et al*., 2014a; Elmqvist *et al*., 2015). This coupled with additional factors - such as climate change impacts, calls for enhanced resilience and functional ES in urban systems (Elmqvist *et al*., 2015; Liu *et al*., 2015). There are various types of ES that exist to highlight human dependency on the biosphere, but the most common grouping of ES is: provisioning services, regulating services, cultural services and supporting services. This will be defined and further explored in Chapter 2. In essence the type of benefits ecosystems provide people are classified into one of these above groups (MEA, 2005). The natural environment continues to be over-exploited and degraded partly resultant due to the lack of understanding the value of regulating ES (Carpenter *et al*., 2009; Crafford, 2015). The role of ES in advancing sustainable development goals highlights the importance of meeting environmental and societal goals through cross-sectoral cooperation and planning, as per The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (Diaz- Reviriego *et al*., 2019; Van den Heuvel *et al*., 2020).

Several frameworks have been developed to study SES over time. The SES framework is a tool in which to develop an interdisciplinary understanding of the interaction between the use of a natural resource system (such as a river) with the various processes occurring simultaneously or sequentially on that particular resource system dominated by human use and decision-making (Oström, 2007; McGinnis and Ostrom, 2014). The application of SES frameworks is constantly evolving to account for complexities in interactions between various systems. It is important to note the availability of physical and socio-economic data to support parameters in frameworks

used to investigate SES (Gain *et al*., 2020). In closing, the rationale for this study is therefore, to apply a SES framework to explore the impacts of urbanization on the systems present in an urban catchment as well as the role ES can play in reducing vulnerabilities or increasing resilience of users within the system. The parameters in the application of the SES framework are essential in supporting the information, possible investment and overall improvement of the catchment and the livelihoods of people.

In striving for sustainable development, it is becoming increasingly important to maximize services that are freely given by the natural environment to improve livelihoods of people and restore the natural environment. This pursuit therefore demands forward-thinking that is inclusive of all systems that contribute to forming a holistic urban system. The following section expands on the rationale of this study through the outlined aims and objectives.

1.3 Aims and Objectives

The aim of the study is to understand how flooding risks impact the resilience of the Palmiet catchment through applying the social ecological systems framework. The main research question is therefore: How can a SES framework help us understand societal actions of urbanization that impact on the functionality of the Palmiet River and further, how has this influenced resilience against flooding?

The objectives of the study are to:

1. Identify what ecosystem services exist in the Palmiet catchment, and how these could enhance catchment management with a specific focus on flooding.

2. Construct a social-ecological systems model for the Palmiet catchment.

3. Identify how the social-ecological system in the Palmiet has evolved over time and the impact on the hydrological functions of the Palmiet River with a specific focus on flooding.

4. Identify the value and potential of ecological infrastructure investments for the Palmiet catchment to achieve resilience against flooding.

1.4 Structure of Dissertation

This document presents a review on past literary works to set a background and motivation for this project and its approach of investigation. The literature review in Chapter 2 is composed of subsections that aim to expand on the recurring themes of the project and concludes by setting the objectives to support the aim of the study. The methodology follows in Chapter 3 by

introducing the study area and the steps taken to achieve the results of the study. These results are presented in Chapter 4. The discussion is presented in Chapter 5. Chapter 6 concludes the research findings of the research and possible gaps and needs for future research studies.

CHAPTER 2: LITERATURE REVIEW

The impacts of human activities have largely altered global patterns of ecosystem processes as countless ecosystems globally are shaped by humans and their (mis)usage of land (Ellis and Ramankutty, 2008). Therefore, the co-evolution of people and natural systems has led to pervasive anthropogenically modified ecosystems (Ellis and Ramankutty, 2008; Mauerhofer *et al*., 2018). Maintaining ecological integrity is essential for sustainable development and instilling the resilience of natural resources (Alberti, 2010; Vörösmarty *et al*., 2018; Sutherland *et al*., 2019). However, maintaining ecological integrity remains a challenge; such solutions need to ensure sustainable use of natural resources whilst improving human livelihood and sustainable development (Vörösmarty *et al*., 2018). Viewing this in the context of cities is specifically challenging as patterns of urbanization impact severely on ecosystem dynamics by means of complex interactions and mechanisms that connect urban activities and their spatial organization to land cover change (Alberti, 2010; Des Roches *et al*., 2020). Additionally, human systems affect ecosystem function necessary to support important services in urban areas (Alberti, 2010; Hermoso *et al*., 2018; Des Roches *et al*., 2020). The properties that define a catchment's ecosystem such as climate and geomorphology operating at a global scale influence factors such as hydrology, which is typically non-linear and slow-changing (Martin-Lopez *et al*., 2017). The spatial scale of these biophysical factors determines the ecological properties and the size of ecosystems which are often analysed at the more localised catchment scale which is the integrated water resource management based preferred unit (Martin-Lopez *et al*., 2017). Although the boundaries of ecosystems are open to energy transfer to and from their surrounding ecosystem, they are entirely enclosed by the boundaries of another ecosystem (Bailey, 1987; 2009). Social systems, on the other hand, are interconnected by connections across global and local scales (Martin-Lopez *et al*., 2017). The temporal scale, specifically in the case of South Africa with a history of apartheid legacy adds a level of complexity in unpacking the biophysical and social systems that exist within a catchment (Angelstam *et al*., 2017). This complexity lies in that the spatial planning and access and proximity to natural resources and built infrastructure or basic service delivery during Apartheid was established and defined by racial groups which has carried lasting impacts in current biophysical and social systems. This is also challenging to address outside a socio-political context (Angelstam *et al*., 2017). Integrating these dynamic systems presents a challenge because of this connectivity that goes beyond a physical boundary or landscape. The size of a catchment is therefore crucial in understanding the interaction of the SES. Additionally, ecosystem services, as detailed in this chapter play an integral role in defining the

productivity of a resource system. The SES framework is a tool used to frame the SES in a catchment and offers perspective to the role of ES offered in conjunction with people in a catchment. The literature review is therefore comprised of sections that build on the importance of the proposed research project and concludes with an evaluation of the literature that reinforces the validity of this study.

2.1 Ecosystem Services

Ecosystem services (ES) are broadly defined through various viewpoints from a range of disciplines but are defined by the Millennium Ecosystem Assessment (MEA) as the aspects of ecosystems actively or passively utilized by people to substantiate human wellbeing (MEA, 2005; Fisher *et al*., 2009). ES are responsible for connecting nature to people (Grizzetti *et al*., 2016; Des Roches *et al*., 2020). The significance of natural capital and ES was highlighted in the early 2000's as a form of supporting human wellbeing (Grizzetti *et al*., 2016). Early recognition of the concept of ES in the seventies led to increased interest in further studies on ES (Schumacher, 1973; Ehrlich and Ehrlich, 1981; Ehrlich and Mooney, 1983; Braat and Groot, 2012). Since then, the conversation surrounding the significance of natural capital and ES has gainedmomentum. The understanding of ES has evolved through literature and framed thinking surroundingthe social, cultural, physical, and economic value of the natural environment (Costanza *et al*., 1997;Norgaard, 2010; Turpie *et al*., 2017). This has therefore, contributed to classifying or grouping various typesof ES to a certain extent. ES are complex and often interrelated in their functioning (*viz.* Chapter 2.1.1) and consequently, have received slightly varying classifications over time (*viz.* Chapter 2.1.2).The use of ES within a framework is a growing body of work in scientific environmental literature and has received many variations in methodologies used to improve understanding of ES (Guerry *et al*., 2015). ES as a framework previously did not provide quantitative or spatially explicit information to decision makers regarding the likely outcomes of human developmental actions on ecosystems and their interactions at multiple scales (Reed *et al*., 2013). Findings show that earlier studies struggled to assess and quantify ES due to the restrictive information on the topic (Guerry *et al*., 2015).

The relationship between human wellbeing and ES can be debated. An article by Raudsepp-Hearne *et al.* (2010b) titled *Untangling the Environmentalist's Paradox* explores the relationship between human wellbeing and ES. The conclusions in this article, note that human wellbeing has improved at a global scale while a decline in ES has been found. This is despite contrary findings by the MEA (MEA, 2005). This then consequently challenges the benefitsto preserving and enhancing ES if the relationship to human wellbeing is questionable (Daw *et al*., 2016). However, the relationship between the benefits of ES and human wellbeing has becomeclearer over time and has led to intensified efforts in improving human actions to reverse declines in ES to improve environmental

conditions and human wellbeing. Clarity in this relationship has contrastingly raised concerns on how ecosystems will respond to gradual or abrupt changes (such as climate change and urbanization as examples) and that greater effort in understanding resilience from local to global scales is needed (Guerry *et al*., 2015; Sutherland *et al*., 2019).

The concept of resilient SES sustaining ES when disturbed is addressed by many researchers with the consensus on the fact that more adaptable management and innovative interventions in EI solutions are needed where more integrated dynamic systems approaches are researched to understand existing complexities in SES (Folke *et al*., 2010; Biggs *et al*., 2012; Reyers *et al*., 2013; Guerry *et al*., 2015). This is further explored in Chapter 2.4 where the range of ES which are usually associated with upstream landscapes make for an ideal social-ecological system case study in terms of highlighting land use interactions therein (Reed *et al*., 2013). However, this does not negate studying downstream landscapes as SES as often populations increase and impact the natural landscape more severely.

2.1.1 Ecosystem services: functioning and thresholds

It is argued that the functionality of an ecosystem is a system's ability to sustainably provide value and benefits from the physical environment to society (Wallace, 2007; Perez-Verdin *et al*., 2018). Knowledge on the functions of ES has gained immense popularity particularly due to increased human population and subsequently the increased demand for natural resources (Picket *et al*., 2001; Chowdhury *et al*., 2011;Yu *et al*., 2012; Du Toit *et al*., 2018).

Other important aspects to consider when studying ES are ecological thresholds and the mapping of ES (*viz* Chapter 2.2). Ecological thresholds help to understand how SES work and change over time. Ecological thresholds are defined as the point at which there is a rapid disturbance in an ecosystem. A disturbance may also be a slight change in an environmental driver that, however, produces a large impact or response in the ecosystem (Groffman *et al.*, 2006). Thresholds are not easily identifiable as they operate at various spatial and temporal scales. Ecologicalthresholds are important measures that inform the state of the natural environment. An example of ecological threshold measures in a freshwater SES to improve water resource management is the evaluation of river health. The ecological threshold to monitor river health is usually done by quantifying water quality variables affecting the presence of macroinvertebrates (Sultana *et al*., 2020). This is a guideline to assess the impacts people have on the environment and whether the environment is coping or malfunctioning due to any external stressors. Identifying ecological thresholds at the onset can prove to be difficult especially when linked with urbanization and population growth. Many factors are introduced at the interface of functioning ecosystems that co-exist with humans. Long-term consequences exist for not understanding the role of ES as more dependence is added by growing societies on these services

(Reed *et al*., 2013). Although ES are unpredictable in responding to change in SES, it is necessary to ensure that a tradeoff for one ESdoes not inadvertently compromise the delivery of other important ES (Reed *et al*., 2013; Perez-Verdin *et al*., 2018). Therefore, ES present the opportunity to improve catchment management through multiple objectives and decision-making that create trade-offs between competing ES and stakeholders responsible for their provision and delivery (Reed *et al*., 2009; Reed *et al*., 2013). Here it becomes important to monitor the social as well as the ecological system in order to understand the feedbacks andinfluences that occur between the systems.

2.1.2 Categories of ecosystem services

Different classifications of ES exist however the most widely used are applied based on TEEB (The Economics of Ecosystems and Biodiversity) and MEA (MEA, 2005; TEEB, 2010; TEEB, 2011; Haines-Young and Potschin, 2011). The four most common groupings of ES are categorized based on the TEEB (2011) classifications defined as:

1) Provisioning services – include services such as energy, raw materials, food, water, and medicinal resources.
2) Regulating services – services provided by ecosystems acting as regulators such as carbon sequestration, water purification, flood regulation, climate regulation, and disease control.
3) Cultural services – benefits to people from ecosystems through providing aesthetic, recreational, spiritual, or educational services.
4) Supporting services – indirect services needed to produce and maintain other services such as nutrient recycling, soil formation and water purification. These services allow ecosystems to provide regulating services.

These ES are important in urban landscapes in that provisioning services for example,constitute fresh water regulating the flow and purifying water. This is necessary in urban catchments where often the reduction of vegetation influences the quantity of available water. Cultural and supporting services are found to be more difficult to assess and quantify, however their role in functional ecosystems is as vital. It can be argued that functional regulating ES particularly play a huge role particularly in cities where freshwater ecosystems are vulnerable to rapidly increasing threats of human influences (Cilliers and Siebert, 2012). Protecting freshwater ecosystems is not only a concern of focus on water quality but available freshwater quantity as well. Regulating ES is one of the least understood yet possibly the most valuable services offered by ecosystems (MEA, 2005; Crafford, 2015). Regulating services include moderating extreme events such as floods. In urban landscapes, ecosystems act as a buffer against extreme natural events wherein wetlands absorb water from flood events and trees stabilize slopes. The role of regulating ES such as flood regulation on downstream freshwater ecosystems serves an important function to be studied in order to find tools that enable us to

understand the human and natural systems that co-exist in cities - and how best to manage these intertwined systems. The reliance of bulk water supply measures from upstream channels and dams possibly influences the lack of protection and focus on downstreamrivers. Therefore, urban landscapes where multiple stakeholders are involved in decision-making processes offer a platform for investigating and improving the governance of ES trade-offs.

2.1.3 Identifying and assessing ecosystem services indicators

A common approach to assessing ES is using proxy variables such as land cover/land use which provide a visual conceptualization of ecosystem processes and services through modelling (Seppelt *et al*., 2011). It is noted that the data used in ES studies varies, with a large proportion of studies using secondary data and a smaller portion of studies using primary data based on observation and measurements (Seppelt *et al*., 2011; Busch *et al*., 2012). ES research in South Africa has contributed to global knowledge in identifying and assessing studies of the value of ES (Sutton and Costanza, 2002; Seppelt *et al*., 2011; Malinga *et al*., 2015; Malinga, 2016; Keeler *et al*., 2019; Clements *et al*., 2021). The value of ES, however, has predominantly been assessed from an economic standpoint (Busch *et al*., 2012; Gómez-Baggethun and Barton, 2013). Researchers have used this economic standpoint as concepts of EI and ecological economics continue to evolve (Costanza *et al*., 1997). Bagstad *et al*. (2013) provide an extensive summary of tools for assessing ES, which details various approaches depending on the ES study site in review.

Research findings indicate that ES research is still a fragmented field and the methodological approach to investigating ES remains challenging in integrating biophysical data, ES trade-offs, stakeholder involvements and social data (Carpenter *et al*., 2009; Fisher *et al*., 2009; Seppelt *et al*., 2011). Global and international initiatives are increasingly merging municipal goals with conservation goals as part of meeting sustainable development targets of cities (Breuste, 2011). This, furthermore, demands for intricate sets of methodologies, discourses and planning tools across various scales that encompass resilience of social and ecological systems. A ‘value pluralism’ perspective in which the valuation process used in SES encompasses multiple, often-contradictory valuation languages, and therefore providing more than one metrics (Gómez-Baggethun and Barton, 2013). This is also the founding principle of the SES framework proposed in McGinnis and Ostrom (2014). DEFRA (2007) outlines an introductory approach to valuing ES. This guide by DEFRA (2007) outlines five steps in the valuation of ES:

1. Establish the environmental baseline

2. Identify qualitative assessment of the potential impacts of policy options in ES

3. Quantify impacts of policy options in specific ES
4. Assess impacts on human welfare
5. Value changes in ES

Quantifying ES is done through various perspectives; ecological, socio-cultural and economical (Pickett *et al*., 2001; Burkhard and Maes, 2017; Du Toit *et al*., 2018). The ecological perspective of assessing ES addresses the health of a system using indicators such as diversity and integrity. The socio-cultural perspective addresses the significance of a system to humans using indicators such as cultural identity in relation to ES (Groot *et al*., 2010). The paper by DEFRA (2007) encompasses an economic background and remains useful as a guideline in identifying and assessing ES. The economic perspective of ES is directly related to the value of ES contributing to the economy (DEFRA, 2007).

2.2 Mapping Ecosystem Services

Mapping ES is a useful task for landscape planning as spatially quantifying an ecosystem provides an indication of the ecosystem condition and services provided at temporal and spatial scales (Malinga, 2016; Burkhard *et al*., 2013). Identifying ES is a precursor to mapping of ES and thereafter assessing ES in an area of interest. This makes the analysis of ES and the possible changes thereof simpler. The basis of mapping and modelling ES is based on the availability of information to analyse spatial distribution of multiple ES at various spatial scales (Maes *et al*., 2012). Various approaches exist on techniques and models to mapping ES (Egoh *et al*. 2012, Martínez-Harms and Balvanera 2012, Maes *et al*. 2016; Crossman *et al*. 2013). However, there is no standardised method to the selection process for ES assessment as previously stated in Chapter 2.1.3. It is noted that the criteria used in selecting an ES will have an impact on the outcome of the assessment (Bagstad *et al*., 2013). Baring this in mind, various criteria is used for selecting ES for studies such as (Malinga, 2016):

1) Literature reviews (Anderson *et al*., 2009)
2) Available data (Raudsepp-Hearne *et al*. 2010, Queiroz *et al*. 2015)
3) Case specific needs, issues, and trends (Fischer at al., 2011)
4) Local and national policy goals (Wendland *et al*. 2010, Fisher *et al*. 2011)
5) Representation of ES categories (Posthumus *et al*. 2010, Raudsepp-Hearne *et al*. 2010, Queiroz *et al*. 2015)

6) Integrated knowledge of stakeholders (Posthumus *et al*. 2010, Raudsepp-Hearne *et al*. 2010, Queiroz *et al*. 2015)

The criteria used for selecting ES can be used to build on data for knowledge into ecological systems and human systems in landscapes where ES and ecological conditions are to be assessed. The mapping process should be as inclusive as possible with regards to all dynamics in the landscape.

ES mapping tools have evolved as technological advances have too (Troy and Wilson, 2006). However, information used in mapping ES depends on the audience targeted through scientific and policy platforms; it is a determining factor to the type, suitability of approach and extent of mapping that can be done (Troy and Wilson, 2006; Dearing *et al*., 2014; Burkhard and Maes, 2017). The integration of numerous tools for mapping ES ranges from desktop applications to sensor, web-based or mobile devices. Appendix A provides a list on the most common ES mapping tools (Burkhard and Maes, 2017).

2.2.1 Selecting ecosystem services to map in a system

As previously mentioned, a range of approaches and methods exist to map ES. A simple approach is by deriving information on ES directly from land use/cover (Maes *et al*., 2012). Approaches to ES are also determined on the spatial scale of the study site or system, (primary or secondary) data availability and where the emphasis is on the assumed existence of ES rather than the quantification of the supply of ES (Maes *et al*., 2012). Furthermore, it is most ideal to use primary data (particularly for quantifying provisioning services) as it is the most accurate information. However, such information is typically scarce for regulating, supporting and cultural services. Researchers often resort to the use of proxies to quantify these services through derived model outputs such as modelled runoff as an indicator for water provision (Maes *et al*., 2012). Furthermore, three approaches for mapping ES can be identified through the following methods: benefit transfer, community value method, and social-ecological assessments of ES (Martínez- Harms and Balvanera, 2012). To elaborate on the aforementioned approaches for mapping ES, the benefit transfer approach relates monetary value to historical records of land cover types; the community value approach is a spatial analysis of social values and the social-ecological assessments approach models the spatial relationship between measurable ecological and social variables such as land-cover and population, respectively (Martínez-Harms and Balvanera, 2012). The social-ecological assessments approach is deemed the most diverse and follows the methodology below (Martínez-Harms and Balvanera, 2012):

1. Identifying type of ES to be mapped

2. Identifying the type of sources of information to be used to map ES

3. Identifying the spatial scales at which to map ES

4. Classify the type of method to be used to model and map ES under the social-ecological approach

2.3 Ecological Infrastructure

The use of ecosystems as infrastructure is being first proposed in 1984 at an urban planning technical meeting of the Man and Biosphere Programme (UNESCO, 1984; Da Silva and Wheeler, 2017). Recent studies indicate that further research is needed towards assessments of the quantitative value of ES for effective policy formulation and decision-making regarding water resources planning to occur (Chan *et al*., 2006; Gret-Regamey *et al*., 2008; De Groot *et al*., 2010; Angelstam *et al*., 2017; Van Oudenhoven *et al*., 2018; Clements *et al*., 2021). The investigation of alternative solutions to secure water resources for growing cities remains on-going as part of integrated water resource management. Furthermore, solutions to securing and protecting water resources are often scenario based and cannot necessarily be applied globally. Many studies and models are evaluated in the quest to find suitable and sustainable applications to securing water resources. Much debate has formed the shift to investigating greener solutions rather than depending solely on built infrastructure to securing water resources (Wu, 2010; Mguni *et al*., 2016; Sutherland *et al*., 2016; Venkataramanan *et al*., 2020; Choi *et al*., 2021).

Urban populations are growing at a rate that can no longer solely depend on dams only – especially with the unpredictability of climate change impacts in South Africa (Muller, 2007; Muller *et al*., 2009; Angelstam *et al*., 2017; Sutherland *et al*., 2019). This precedes research into EI to promote healthier landscapes with functioning ES whilst increasing water security. Water security in this context is defined as the capacity of a population to protect adequate amounts of water resources at an acceptable quality for sustaining livelihoods and preserving ecosystems in the present society (Vörösmarty *et al*., 2010; Grey *et al*., 2013). The concept of urban EI requires understanding of ES and the stability and security of ecosystems in urban landscapes (Li *et al*., 2017).

Environmental legislature in South Africa has been praised for its progressive and innovative strides to maintain EI through collaborative and integrative forms (Angelstam *et al*., 2017; Cumming *et al*., 2017). However, investment into EI and the widespread implementation and management of innovative environmental policies and legislature fall short. Examples of EI discourses in South Africa include the then Department of Environmental Affairs' Natural Resources Management and Environmental Protection and Infrastructure (EPI) programmes; including the Working for Water programme and the Working for Wetlands sub-programme which restored 970 wetlands across the country, to name a few (Angelstam *et al*., 2017). Examples of the implementation of EI in South

Africa has largely been through programmes that leverage public and private sector resources such as in the Natural Resource Management programme and stewardship programmes (Cumming *et al*., 2017). It can be argued that EI application in South Africa has largely been focused on rural areas and upper catchments characterized by wetlands (Mander *et al*., 2017; Sigwela *et al*., 2017; Hughes *et al*., 2018).

2.4 Social-Ecological Systems

Social-ecological systems (SES) are essentially landscapes that are viewed holistically to understand the human and environmental components and their interlinkages of a landscape simultaneously. Global changes in the condition of the environment have rendered a large interest in connecting trends, causes and consequences of localized SES which are typically observed at broader scales (Magliocca *et al*., 2015; Magliocca *et al*., 2018). River catchments are established as one of the most interesting SES due to the proximity of human activity to rivers (Gari *et al*., 2015). The risk, vulnerability and robustness of SES is studied to determine the ability, resilience, and transformability of a system to adapt to change (e.g. Walker *et al*., 2004). The social aspect is complex in terms of depicting SES models and frameworks as human decision making and behaviour are often based on a multitude of factors such as politics, economics, anthropology and sociology to name a few (Angelstam *et al*., 2017; Schlüter *et al*., 2017). This therefore makes it difficult to quantify social aspects, revealing gaps in logic particularly pertaining interactions with the natural environment (Schlüter *et al*., 2017). The future of the ecological aspect for this reason is becoming increasingly challenging to predict as increasing human populations deteriorate the environment.

The SES framework by Ostrom (2007) provides a guideline and tool inaddressing both social and environmental aspects of a system in space at a specific period. The framework as described in Chapter 2.4.1 can also be utilized in analysing ES offered, ES trade-offs and the resilience of a system to withstand shocks (Walker *et al*., 2002; Carpenter *et al*., 2009). The following subsections define the SES framework concept by Ostrom (2007), in addition to providing examples of applications of the framework. The aim of this section is to broaden the understanding of SES by elaborating on concepts that are interlinked using frameworks such as resilience and ES trade-offs.

2.4.1 Social-ecological system framework

The topic of social-ecological systems is incomplete without mentioning the MEA (MEA, 2005) in its focus and spearhead for analysing SES; which has gained extensive encouragement in scientific and policy communities (Carpenter *et al*., 2009). The MEA has played a significant role in shifting the paradigm surrounding SES thinking which has led to the SES framework (Ostrom, 2007). The SES framework by McGinnis and Ostrom, (2014) is depicted in Figure 2.1.

The SES framework provides flexibility for improvement of the understanding of various scenarios and concepts from an array of disciplines that each have unique technical languages that still require interpretation into a common language (Ostrom, 2009; McGinnis and Ostrom, 2014). A framework assists in collecting, analysing, and organizing theoretical and practical information (McGinnis and Ostrom, 2014). This is particularly useful in dealing with complex social aspects that are intertwined with the environment. The SES framework aims to be neutral to theory from various disciplines to evaluate information in an unbiased manner (McGinnis and Ostrom, 2014). Although this has been the intent of the SES framework in theory; remaining neutral is not always possible in its application. The fundamental basis of the framework is the presumption that people (whether individually or collectively) can make conscious choices that can produce significant outcomes in society (McGinnis and Ostrom, 2014). Furthermore, it is important when applying the SES framework that it remains as reflective to those living within the system as possible.

As with many approaches in research methodologies, applying the SES framework has associated pros and cons. Many concepts can be used to analyse various types of SES (Brock and Carpenter, 2007; Rockström *et al.*, 2009; McGinnis and Ostrom, 2014). The ability to apply the SES framework to analyse different theoretical concepts is considered a pro; however, it also tends to render a different understanding from theoretical perspectives which may cause confusion and contradict itself in attempting to remain neutral in theory as previously stated (McGinnis and Ostrom, 2014). The core of SES is understanding the interdependent social and environmental linkages and the changes thereof which require multi- and interdisciplinary knowledge contributions (Ostrom, 2007; Partelow, 2018).

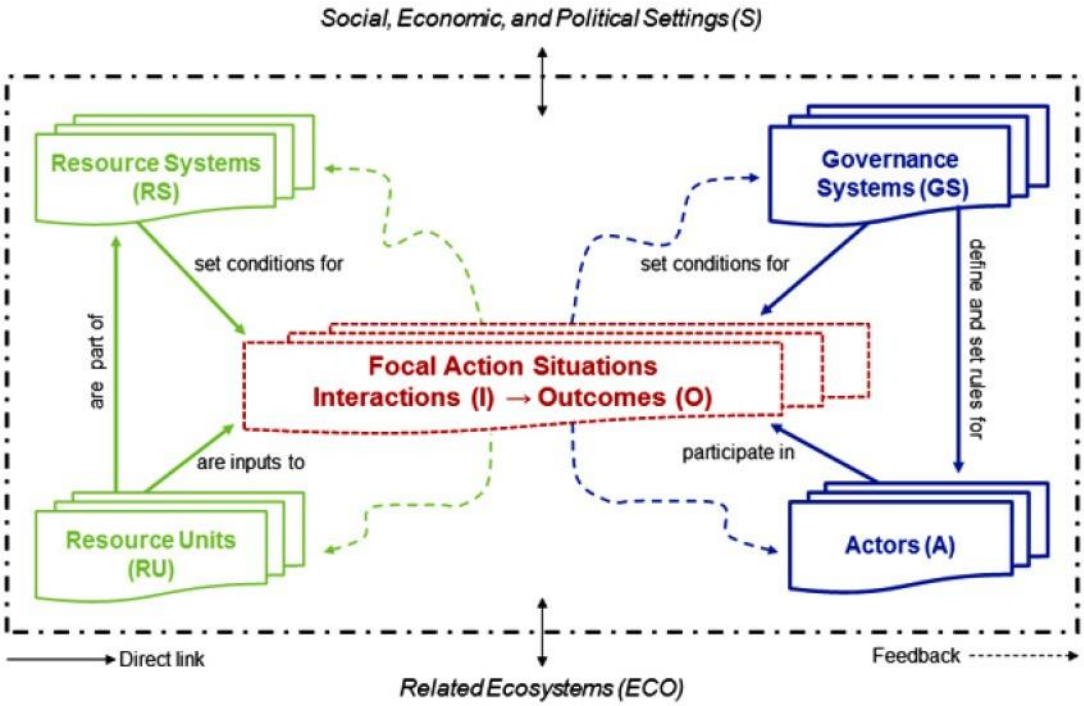

Figure 2.1 Social-ecological systems framework (McGinnis and Ostrom, 2014)

The framework depicted by Figure 2.1 which is adopted from McGinnis and Ostrom (2014) is purposely designed for application to a clearly defined domain of common-pool resource management situations in which resource users extract resource units from a resource system (McGinnis and Ostrom, 2014). The SES framework builds on the Institutional Analysis and Development (IAD) framework and has been modified over time (Ostrom, 2007, 2009, 2011; McGinnis and Ostrom, 2014). The SES framework is composed of multiple tiers. The first-tier category is denoted by solid boxes, i.e. resource system, resource units, governance systems and actors (McGinnis and Ostrom, 2014). These are recognised as the highest tier variables, which then contain second tier categories. Second tier categories contain multiple variables that can be selected based on the SES being studied. Appendix B provides examples of these second-tier variables that are used as input for studing the SES. The solid arrow denotes action situations that occur as inputs and are changed by actions of the second- tier category into outcomes (McGinnis and Ostrom, 2014). These tiers of interactions produce and react to knowledge systems. Thus, the role of management is vital in ensuring resilience to SES to generate ES (Breed, 2015). The dashed arrow denoted feedback occurring from action situations to each first-tier category (McGinnis and Ostrom, 2014). The feedback between the environment and people is recognized as being uncertain, unpredictable, and complex which are limiting in confidence when assessing a system, y*et al*so representative of reality.

The surrounding dashed-and-dotted line focuses on the entire SES as a logical whole but acknowledges external influences from related ecological systems (McGinnis and Ostrom, 2014). Research surrounding the SES framework attempts to identify concepts, pathways, and indicators of sustainability in various spatial scales between the human-nature relationship (Ostrom, 2011; Partelow, 2018). The SES framework uses diagnostic tools to explain the necessity of a paradigm shift in analysing environmental issues. The framework, however, has been advanced by new research questions which challenge the complexity of the application of the SES framework through mixed methodologies (Ostrom, 2009; Ivankova and Plano Clark, 2018; Li *et al*., 2020).

Various case studies on the use and application of SES research in different parts of the world exist. The Community Conservation Network Research (CCRN) present a guideline for analysing social-ecological systems (Berkes *et al*., 2014). In this guideline the most common keys to constructing an analysis for SES include: 1) a focus on the integration of the natural system, the human system and the governance system as well as 2) consideration of scale, level and resilience of the system (Berkes *et al*., 2014). Assessing the first point can be done through various ways. Staying true to Ostrom (2009), the integration of the natural, human and governance systems in this case is depicted as 'the resource system' which encompasses the natural system; and 'the governance system' which encompasses the human and governance systems. Using this basis, the resource system provides ecosystem services used and is managed by the governance system (Ostrom, 2009).

The SES framework has caused much debate in the objective to understand SES versus the relationship of systems that make up a single SES (Mao *et al*., 2016; Cumming and Allen, 2017; McGinnis and Ostrom, 2014; Partelow, 2018; Schlüter *et al*., 2019). There is no one answer to the approach of SES framework due to the connectedness of each system that produces an overall functioning SES. The discretion to apply the SES framework is on the user and the specific landscape or scenario in question (Ostom, 2007).

2.4.2 Urban landscapes as social-ecological systems

An ecosystem refers to the natural environment where people have an impact on the functioning of the natural environment's capacity to deliver ecosystem services. Cities are a global network of ecosystems in which people are part of the natural environment and subsequently natural processes (Bolund and Hunhammar, 1999; Carpenter *et al*., 2011). Human activities pose a threat to the natural environment and an interference with natural processes despite being a subsequent part of nature.

Urban ecological studies date back to the early to mid-twentieth century but there are still gaps in knowledge still existing today (Steiner, 2002; Pickett *et al*., 2011). Urban ecosystems have a focus

on urban climates, urban hydrology, biota and biogeochemistry of urban systems and their interaction with people (Pickett *et al*., 2011).) Urban design, urban sustainability and system resilience play a role in changing urban environments (Pickett *et al*., 2011). Urban systems serve as model systems for examining social and biophysical processes particularly in a world where more than half of the world's populations reside in urban areas (Collins *et al*., 2000; Redman *et al*., 2004; Grimm *et al*., 2008). This increasing migration of people into urban catchments has caused a disturbance in ecosystem dynamics as illustrated by Grimm *et al*., (2000) in Figure 2.2 below:

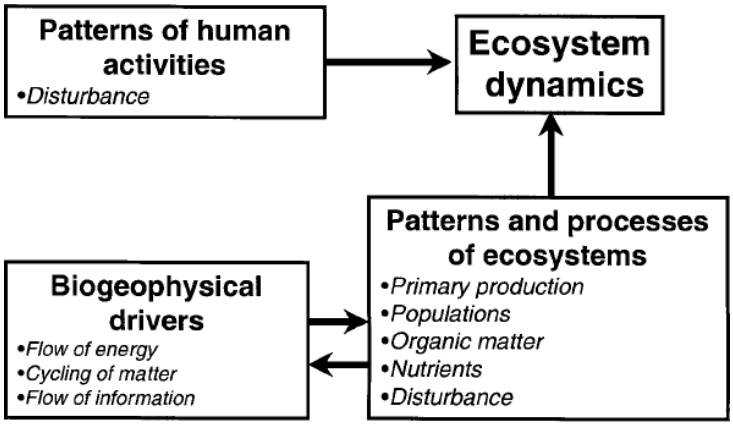

Figure 2.2 Social-ecological systems framework (McGinnis and Ostrom, 2014)

These interactions and feedbacks have direct and indirect impacts on ecosystem dynamics. The basis of Figure 2.2 aids in understanding the concept of urban ecosystem dynamics which can be applied to understanding SES (Figure 2.1) in urban catchments. The interconnectedness (social, cultural, and ecological systems) of urban landscapes demands for integrated and cross- sectorial responses to addressing global challenges. As depicted in Figure 2.2 disturbances through the patterns of human activities impact ecosystem dynamics. Biogeophysical drivers such as the flow of information in the biogeophysical interactions influenced by factors such as organic matter, nutrients or population drive and interact with overall patterns and processes of ecosystem dynamics. This serves as the governance system which plays a crucial role in managing and building resilience of a system (Ostrom, 2009; McGinnis and Ostrom, 2014)).

Furthermore, the thinking surrounding social-ecological systems particularly in urban systems is crucial for understanding politically sensitive situations whereby social demands may be at odds with ecological understanding and management of endangered ecosystems (Hand *et al*., 2018). New

methods and approaches are therefore imperative to addressing complex problems through crowdsourcing and data collection, to increase integration and dissemination of social-ecological research (Hand *et al*., 2018).

2.4.3 The role of ecosystem services in developing social-ecological systems framework

As elaborated in earlier sections of this chapter, ES play a vital role in the trade-offs and functioning of social-ecological systems. Carpenter *et al*. (2009) provide a paper for managing ES beyond the MEA to manage flows of ES and human impacts. Rapid urbanization and the increase in population in a landscape adds pressure and change to the dynamics of the ES in a system. In other words, drastic changes in land use potentially influence the resilience of a SES differently than an acute change in land use over a longer period. This concept of resilience is explored further in Chapter 2.4.4. The concept of SES is based on connecting ecological and social systems by two feedbacks (Opdam *et al*., 2018). Firstly, the perception of benefits (or ES) within the community from landscapes (or a system) and secondly, interventions taken regarding the landscape to ensure better value of these benefits or ES (Opdam *et al*., 2018). There is progress in the network thinking surrounding SES (Bodin *et al*., 2016; Opdam *et al*., 2018). This paradigm shift regarding network thinking of SES identifies patches and actors within the landscape as nodes and the connections between these nodes as links (Opdam *et al*., 2018). This inherently emphasizes the importance in the role of the governance system in facilitating and subsequently improving the relationship between people and the natural system.

2.4.4 Resilience of Social-Ecological Systems

The concept of resilience is largely explored through various perspectives and across many disciplines. Resilience is referred to as risk reduction (Sutherland *et al*., 2019). Studying the resilience of SES is undertaken with the aim to clarify a system's existing capacity and properties. The instability often found in SES is highlighted through the quest to understanding human-water relationships (Mao *et al*., 2016).

In a paper by Mao *et al*. (2016) to assess socio-hydrological resilience under change, an initial question is posed which subtly frames initial thinking of resilience: 'resilience of what in relation to?' This question can be used to underlie the very basis in applying the SES framework to better understand respective systems and establish as well as enhance preparedness to change in landscapes that are already vulnerable to impacts of e.g. climate change. The latter part of that very question posed by Mao *et al*. (2016) '…in relation to?' is also important on its own as it probes the need to distinctly define the system and the issue that affects or threatens the existing stability of the system in review. This question essentially is the starting point to problem identification and clarification. Cumming and Allen (2017) also support this starting point to SES analyses by additionally

suggesting the following key points to be followed: 1) define the system, 2) state the key elements of interest and their relevance and lastly, 3) explain how a particular problem arises.

Resilience serves as an organizing framework for social-ecological analysis but proves to be difficult to quantify or operationalize (Angeler and Allen, 2016; Cumming and Allen, 2017). Therefore, the resilience in SES research is presented as a systems ability to maintain its identity (Cunning and Allen, 2017). In addition to this, incorporating a focus on system identity thresholds can be used to connect management goals, empirical data, and resilience theory (Cunning and Allen, 2017). Lastly, it is important to note the link in the shift that occurs when the resilience of a system is exceeded with resulting consequences in the delivery of ecosystem services (or disservices) to people which may be difficult to restore (Cunning and Allen, 2017). However, this may provide an opportunity for new system elements and interactions to be introduced (Linton and Budds, 2014; Mao *et al*., 2016). An example is seen through Merrill *et al*. (2018) in which the water quality degradation impacts in a SES were studied and led to the development of a resilience framework that applies ES concepts to coastal SES affected by degraded water quality. The study presents the opportunity to improve effective SES research and the delivery of ES through the framework which is intended to be transferable to other geographic sites with different disturbances (Merrill *et al*., 2018).

2.5 Threats to Freshwater Ecosystems in South Africa

Catchments (or watersheds) connect and comprise of terrestrial, freshwater, and coastal ecosystems which execute various ES listed in Chapter 2.1 such as supplying and purifying freshwater; and providing protective habitats for fisheries and biological diversity. Freshwater ecosystems include rivers, streams, ponds, lakes and wetlands. Freshwater ecosystems are generally situated at the lowest points in the landscape (WWF, 2016). This also implies that freshwater ecosystems are receivers of water runoff and - due to human activities – also of waste, sediment, and pollutants (WWF, 2016). Freshwater ecosystems and mainly aquatic species habitats are highly sensitive to temperature and precipitation changes as well as upstream impacts. Water supply and sediment to stream channels drastically change when a catchment is urbanized. Urbanization and human activity have modified hydrological processes by replacing natural vegetated land cover with impervious surfaces (Konrad and Booth, 2002; Dow, 2007). Below is a list of some of the specific threats to freshwater resources (Dudgeon *et al*., 2006; Albert *et al*., 2021):

1. Over-abstraction of freshwater
2. Deteriorating water quality
3. Invasive alien plants

4. Urban development
5. Habitat destruction
6. Flow alterations

2.5.1 Land use change impacts on inland freshwater ecosystems

Land use change has been identified as the most important driver for alterations on the landscape over the last century (MEA, 2005). Landscapes are characterized by historical co-evolution of social systems and ecosystems (Blondel, 2006). Land use in urban environments tend to alter ecological characteristics by leaving irreversible impacts on the urban landscape (Postel and Thompson, 2005; Grimm *et al*., 2008). This is debated with examples from the cities of Phoenix, Seattle, and China where it was found that urban planning and land use policies played a major role in determining potential urban ecological impacts (Grimm *et al*., 2008). One of the biggest challenges for urban planning has been allocating and managing different land use types through EI planning (Lee *et al*., 2014). Urban ecosystems depend somewhat on physical ES, which has influences on land use decisions (MEA, 2005). The capability to influence land use decisions is essential in economic development as land use determines the growth and functionality of a city (Cilliers, 2010). Therefore, urban ecosystems are strongly influenced by political land use structures (Ernstson, 2013). ES are influenced by power relations among stakeholders within a catchment and management network structure (Kuslits *et al*., 2021). This forms the basis of a political discourse in an SES (Kuslits *et al*., 2021). The influence of politics is also recognized in terms of the amount of EI in urban development and urban ecosystems as concepts of resilience of SES (Folke, 2006). Politics in this context refers to not only the political parties in power, but the power dynamics at play amongst stakeholders that have control on the type of development that occurs in a particular region. This is particularly true for South Africa, having past restrictive apartheid period policies (Jiusto and Kenney, 2016).

2.5.2 Threat of urbanization on rivers

Over the years, engineering approaches have dominated decision-making of the water landscape in South Africa (Schulze and Stuart-Hill, 2017). As stated previously, urbanization and climate change present a challenge to urban development especially regarding water resource provision. Therefore, increasing resilience capacity particularly to the most vulnerable communities in the urban environment is essential (Sutherland *et al*., 2019). Planning, decision-making and stakeholder engagement in water governance are considered as soft approaches that ought to go together with

engineering and technological advances in sustainable development of water resources (Sutherland *et al*., 2019).

The response to the hydrological cycle continues to alter greatly over the past few decades due to human impacts, including infrastructural development on water resources and urban impervious landscapes. Alterations on the hydrological cycle call for a greater depth in understanding urban hydrology in the context of sustainable development its relation to ES as well as the specific role of urban citizens (Mao *et al*., 2012; Breuste *et al*., 2015). Cilliers (2010) reinforces that due to challenges of providing basic infrastructure, the need for protecting natural environments and enhancing EI is therefore often neglected. Because of such, there has been an on-going conversation in South Africa on the viability and benefits of investing in the value of ES (SANBI, 2014). Restoring and protecting natural ecosystems have been put forward as an alternative to provide cost-efficient and effective solutions to many of the challenges faced by today's society, such as climate change, disaster management and prevention, resilient cities and water resource management just to name a few (McCartney *et al*., 1999; SANBI, 2014).

2.5.3 Impacts of informal settlements on rivers

South Africa, as with many developing countries, is seeing a rapid growth in informal settlements in urban areas. Informal settlements are unplanned communities created by people particularly in search of jobs, education, and better opportunities in cities (UN-Habitat, 2003; Jiusto and Kenney, 2016). According to the Housing Development Agency (2013), informal settlements are defined as the unauthorised use and occupation of land whereby in most cases the construction standards do not comply with building regulations. It is estimated that approximately 20% of urban households in South Africa live in informal settlements and is expected to increase by 2045 (Closas *et al*., 2012; Housing Development Agency, 2013; Jiusto and Kenney, 2016). Limited resources and access to basic services result in shack houses being constructed along land on the urban fringe such as riverbanks, steep unstable slopes, flood-prone land and landfill sites (Holden, 2008; Jiusto and Kenney, 2016). Example from the city of Cape Town whereby 85% of the area of land occupied by informal settlements in 2009 was low lying and subject to flooding (Mels *et al*., 2009; Jiusto and Kenney, 2016). Similar findings exist in Brazil (Satterthwaite, 2011). Urban drainage is amongst one of the key challenges in urban planning associated with informal settlements (Armitage, 2011). Furthermore, urban drainage interventions need involvement from residents because they are the most active agents for change in their own environment.

2.5.4 Catchment management

Catchments are managed under various terms that speak to the same objective to restore and protect natural ecosystems. Rehabilitation and restoration of land-based ecosystems are highlighted as the key strategy to recover ES (Galati *et al*., 2016). The focus on the use of natural ecosystems is often cost effective and more sustainable as these strategies tend to take advantage of local solutions that follow temporal and seasonal changes of the ecosystems (Keestra *et al*., 2018). A systems thinking approach as the basis for nature-based solutions requires a system to be studied holistically as opposed to a reductionist approach and studying properties of individual elements (Pollard and Du Toit, 2008; Keestra *et al*., 2018). Natural systems adapt to their environment which is inclusive of influences from the climate, inhabitants, and management (Chorley and Kennedy, 1971; Keestra *et al*., 2018).

The use of nature to restore natural behaviour of the environment and ES of River systems is a common goal for river restoration projects. Figure 2.3 captures the use of ES as a guideline to long-term solutions for hydrological risks and land degradation. Figure 2.3 separates strategies based on soil solutions and landscape solutions. Landscape solutions particularly focus on the concept of connectivity much like the SES framework whereas e.g. soil solutions aim to focus on increasing soil function. Based on Figure 2.3, flood regulation for example is an ES that can be enhanced through measures that trap sediment and restore wetlands. This solution promotes infiltration and flood risk measures that decrease the speed of water during flood events.

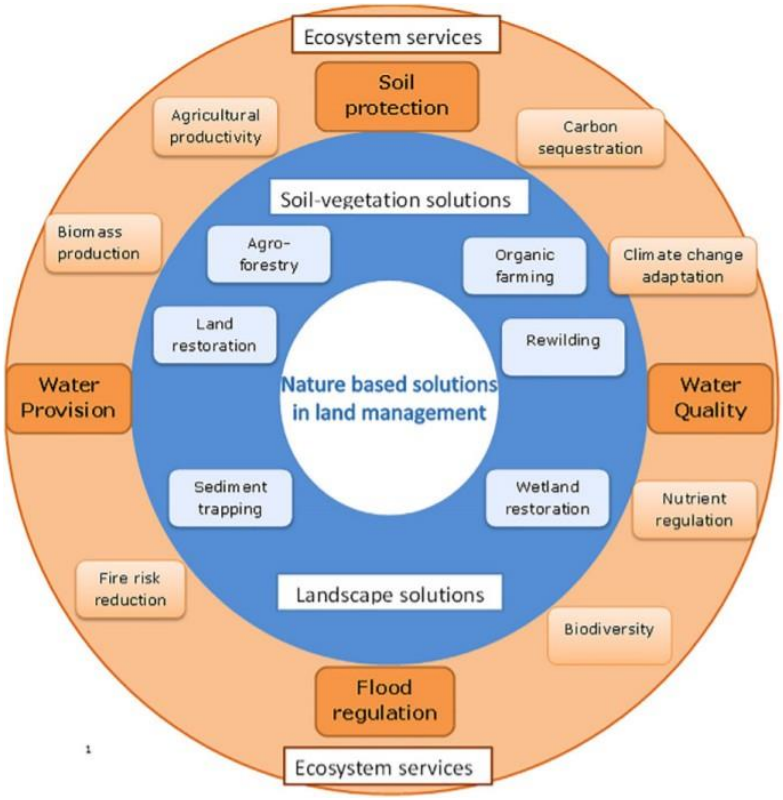

Figure 2.3 Types of catchment management solutions based on ecosystem services (Keestra et al., 2018)

2.5.5 Urban Flooding

Hydrological studies are evolving beyond traditional scientific methodologies to inclusive studies that integrate various approaches in social sciences disciplines. Urban flooding continues to be a growing phenomenon worldwide (Ashley *et al*., 2005). The cause of urban flooding impacts is beyond the simple justification of resultant climate change impacts and various patterns of precipitation but is also an attribute to contributing urban growth, growth of informal settlements in flood plains and increased impervious surface (Ashley *et al*., 2005). Flood events can also be shocks or disturbances to SES particularly in cities that are rapidly expanding with growing populations.

2.6 Evaluation of Literature

It is evident that the protection of freshwater ecosystems on an urban catchment is vital especially with increasing urbanization in African landscapes. To successfully protect freshwater ecosystems in cities, a more realistic and integrative approach is necessary. Additionally, the inclusion and enhancement of ecological infrastructure is becoming increasingly essential to support built infrastructure in growing urban environments to ensure water security to societies and to sustain the provision of ecosystem services. Water challenges in South Africa are further heightened and more apparent amidst economic and social development issues. The risks to water security and what that means to ES can be challenging. Flooding for example, poses an evident social and economic risk in which case intervention is required to manage this risk particularly to the most vulnerable in society (Muller *et al*., 2009). Measures to manage this risk include catchment rehabilitation and management and infrastructure investments. To initiate EI solutions, the current state of the environment and the factors that influence that environment need to be addressed. This introduces the need to incorporate both ecological and social systems in urban planning mechanisms. Furthermore, social, and hydrologic dynamics need to be understood better for efficient ES identification. Improving urban freshwater ecosystems has the potential to provide benefits such as flood mitigation and supporting human livelihoods.

There are research gaps in the interactions between societal interactions and biophysical processes in lower catchments particularly in South Africa. Social-ecological studies across various disciplines have a gap in methodological approaches to identify and analyse resource interactions. The SES framework (McGinnis and Ostrom, 2014) offers a foundation to build a better understanding of such

interactions. Additionally, the SES framework is a method for complex adaptive social-ecological systems to be analysed and with that understanding to inform planning and action. Furthermore, it is vital to keep research in line with contributing to sustainable development goals of protecting, restoring and sustainable use of terrestrial and freshwater ecosystems. Therefore, as elaborated in the literature review, there is substantial need to incorporate ecosystem-based adaptation into urban development surrounding freshwater ecosystems to promote effective integrated water resource management. The literature review presents an opportunity in protecting freshwater ecosystems amidst accelerated urbanization through ecosystem-based adaptation in the form of the SES framework. The potential for improvement of human livelihoods and ecological services provided by ecosystems requires understanding and safeguarding as part of landscape management. The literature review presents the selection and mapping of ES broadly through previous and more detailed work. However, as with many developing countries such as South Africa, the use of secondary data is still highly relevant as limitations in historical data exist. Interdisciplinary research in sustainability sciences is a growing field which presents a challenge to researchers particularly in applying concepts such as the SES framework. However, despite the challenges, many opportunities to unpacking water research complexities exist - to which the investigation of enhancing EI to increase water security is no exception.

Based on the reviewed literature, understanding freshwater ecosystems from the perspective of a lower urban landscape has proved to be complex due to the proximity and vast differences of land uses within a shared resource system. However, despite these complexities, the need to understand implications on ES provisioning exists. The growing influx of people to cities exacerbates issues of water security which further emphasizes the need for more approaches to understand water resources narratives in urban contexts. Also, the dynamics of watercourses cannot be studied in isolation from human impacts anymore which makes such studies imperative in present and changing societies.

Therefore, the aim of the study is to understand how flooding risks impact the resilience of the biophysical catchment as well as the communities living in the Palmiet catchment through applying the SES framework. The Palmiet catchment has been selected as the study site to tackling the research question due to data availability and a high level of activity occurring in the catchment. The following chapters address the following research question: How can a SES framework help us understand societal actions of urbanization that impact on the functionality of the Palmiet River and further, how has this influenced resilience against flooding? The selection of the study sites along with the objectives of the project are set out in the following chapter (cf. Chapter 3).

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CHAPTER 3: METHODOLOGY

This chapter introduces the study area, the methodological framework and outlines how data was collected and analysed to achieve the aim and objectives of this study.

3.1 Study Area

The Palmiet river catchment has been selected as the SES to be studied. It is located within the lower uMngeni catchment, in the Durban area within the Ethekwini Municipality region (Figure 3.1). Durban is located on the east coast of South Africa where summer rainfall occurs. This region is characterized by a humid and subtropical climate with warm summers (average temperatures of 28 degrees Celsius) and dry winters (average temperatures of 11 degrees Celsius). The Palmiet catchment consists of sedimentary rocks which include Natal sandstone in the western and central areas of the catchment and Dwyka, Ecca and Alluvian formation in the eastern areas of the catchment (du Preez and de Villiers, 1987).

The Palmiet catchment is part of a highly urbanised and immensely degraded landscape in the catchment. The Palmiet river catchment has been selected as a suitable case study because of the range of activities that occur around the Palmiet river. These activities include intense industrial developments in the upper catchment, residential households and informal housing. The river is impacted by increased nutrient and microbial loads as a result of declining water quality. Flood events are common, and transport accumulated waste from the lower parts of the catchment to the beaches (Moodley *et al*., 2016). The Palmiet catchment is dynamic in this reason and offers a platform to study the existing social- ecological relations and systems at play.

The Palmiet River extends from 29°47’6.0”S, 30°51’9.7”E to 29°48’16.5”S, 30°58’16.4”E. The Palmiet River is approximately 26km in length. The upper reaches of the river are elevated and characterized by industrial developments and high-middle income residential households. The river flows into the Palmiet Nature Reserve located at the middle of the catchment for approximately 6km. The lower reach of the Palmiet river runs through an informal settlement and through Springfield Industrial Park before entering the uMngeni River. It is important to note that the catchment is diverse in its degrees of wealth and inequality and as a result the challenges faced by communities within the catchment are vastly different. For example, the communities in the lower reach are confronted with a lack of access to service delivery and limited resources as a result of poverty in contrast to the communities in the upper catchment that reside in high-middle income households. Development around the Palmiet river catchment has severely impacted the river such that there has been a large

loss of valuable topsoil, health risks due to contaminated water and increased surface runoff, flooding and erosion of the riverbed and riverbanks (SANBI, undated).

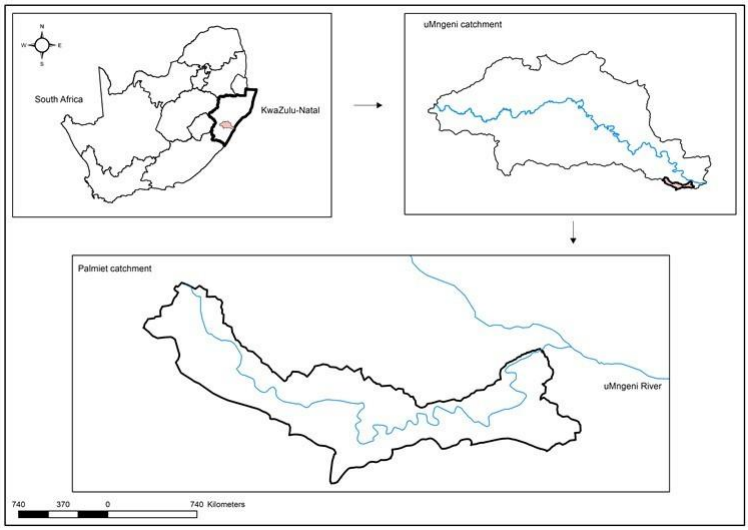

Figure 3.1 Palmiet catchment (Durban, KwaZulu-Natal, South Africa)

3.2 Methodological Approach

The methodology process is detailed in Figure 3.2 below and has been created to provide structure to the dissertation through consecutive steps that lead to relevant outcomes intended to address the aim of this paper. The methodology includes a biophysical approach and a social approach. Due to the nature of this study, it was important to find a path to navigate the available information coherently. Therefore, the methodology process begins with achieving the first objective which is to identify how ES enhance catchment management in the Palmiet catchment. This is achieved by participating in community engagement workshops and municipal meetings for the Palmiet catchment which are organized and facilitated by the Climate Protection Department (CPD) of the eThekwini Municipality. This aids in identifying various needs and concerns from various residents and stakeholders within the catchment. To conclude this first part, an evaluation of the collected information is done to reflect ways to merge the concerns of people on the ground with the implementation through municipal actions in policies and functions. Additionally, the ES identified through stakeholder workshop engagements within the catchment are mapped showcasing the biophysical outlook of the catchment. The next step in addressing objective 2 is constructing a SES model of the Palmiet catchment to understand the dynamics within the catchment. Thereafter, aerial photography images of the Palmiet catchment are obtained from the eThekwini Municipality with the application of GIS techniques to identify areas of significant change due to urbanization (objective 3). This step highlights how the SES changes over time and possibly shedding insight into possible investment of EI. Thereafter the final step involves achieving objective 4. The outcomes of

objectives 1-3 hope to highlight the resilience of the system to change including the influence of urban flooding on one of the Areas of Interest (AoI) selected. Drone maps are used to provide a detailed view of urban flooding impacts along the selected AoI. In conclusion, this methodological approach is intended to answer the main research question of the study in the discussion.

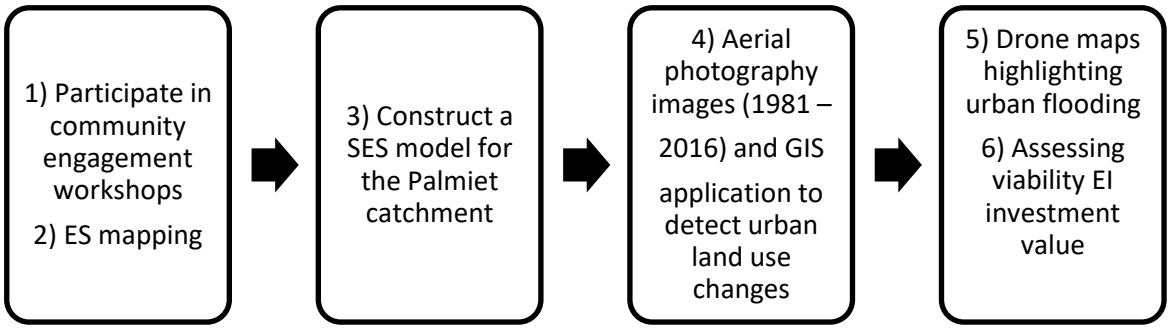

Figure 3.2 Research methodological approach

The social dimension of the research was investigated during a year long tenure as an intern at the Environmental Planning and Climate Protection Department (EPCPD) for the Ethekwini Municipality. Access to information and participation to meetings was permitted through this capacity which enabled attendance to municipal meetings held as part of the departments target in rehabilitating various catchment areas throughout the city of Durban. Meetings were attended by municipal official, researchers, community members and representatives of non-governmental organizations. These meetings were held at least quarterly over a period from 2016. Attendance to 5 public workshop engagements for the Palmiet catchment that were conducted by the Climate Protection Department (CPD) of the eThekwini Municipality. The CPD is a smaller team that is a subdivision of the EPCPD. The public workshops were intended for community members to voice their concerns surrounding service delivery from the municipality. These workshops were attended by municipal employees from CPD, the Water and Sanitation department and the Stormwater department within Ethekwini Municipality. Through attending these workshop engagements, information was obtained regarding the consensus of activities in the catchment and how residents are impacted across the catchment. The Palmiet Rehabilitation Project (PRP) stems from the uMngeni Ecological Infrastructure partnership (UEIP) which has been the source for data collection as there was existing ethical clearance within the research group. The PRP is a shared-governance project focused on addressing climate change adaptation. The project is coordinated by the CPD of eThekwini Municipality, who serve as the secretariat of the project. The project was initiated as a concept for a project for the UEIP. The UEIP is a partnership of a diverse group of organisations

from government, business, academia and civil society committed to finding ways of better integrating EI solutions into water resource management through collective participation and coordination of activities in the greater uMngeni River catchment. The partnership focuses on conservation, rehabilitation and restoration of natural systems within the Palmiet Catchment to improve community resilience. A Community of Innovation (CoI) forms a working group of core actors such as the Palmiet River Watch, eThekwini Conservancy Forum, Wildlands Conservation Trust, CPD and researchers from the University of KwaZulu-Natal and Durban University of Technology. The CoI in the PRP project was established to oversee implementation of an action plan, which was developed by a broader group of project stakeholders. The action plan is led by the CPD where a set of prioritised action items are split into three categories for project implementation: Governance; Bio-physical and Social. The action plan (Appendix C) continuously changes to address different needs once an action item has been completed

Information was accessed through attending CoI, UEIP stakeholder meetings and internal municipal meetings where minutes were taken with permission received during tenure as an intern. This information was captured and received throughout 2017 to 2019 as permission was granted for the enrichment of this dissertation. The meetings and workshops attended contributed to the identification of ES. Thereafter, biophysical data was assessed using a desktop study using ArcMap (version 10.5.1) and aerial photography images obtained from the Spatial Planning Branch within eThekwini Municipality. The aerial photography images obtained for the Palmiet catchment area date from 1981 to 2016 (35 years). One image per year was obtained. The images encompass various issues in different years such as patches of missing information and inconsistencies in seasonsfor which images were taken. Images selected were taken in the months of May and June. For this study, 6 years were selected during the 35-year period where images had enough land cover and aerial visibility information and consistent detail throughout the catchment. The years analysed were: 1981, 1999, 2007, 2011, 2015,and 2016. Drone maps were obtained through the University of KwaZulu-Natal's architectural department to highlight a flooding event (24 April 2019) in the informal settlement in the lower reach of the catchment. This was included as a way to substantiate the argument towards EI.

3.3 Identifying Research Sites

Research areas were identified within the Palmiet catchment based on the predominant activity occurring in the area to understand and evaluate the condition across the catchment in a simplified manner and eliminate assumptions of homogenous impacts occurring throughout the entire

catchment. The research areas were divided into the upper, middle and lower reaches of the catchment as the dominant activities occurring within each area are different yet contribute to the impacts and function of the overall Palmiet river.

Various land uses exist within an urban catchment. Therefore, the study site (Palmiet catchment) is divided into three research sites which are referenced as Areas of Interest (AoI). Figure 3.3 is a map depicting the location of each AoI in relation to the catchment and the river. Table 3.1 gives an account of the land use and relation of each AoI to the Palmiet River. The AoIs were identified and selected across the Palmiet catchment based on the differences in land uses and also due to social-economic standing at various parts of the catchment. The whole Palmiet catchment was studied for the biophysical functioning and ES then localised to consider the contextual background existing in different parts of the catchment. Three areas existing in the upper, middle and lower Palmiet catchment were identified as so-called Areas of Interest.

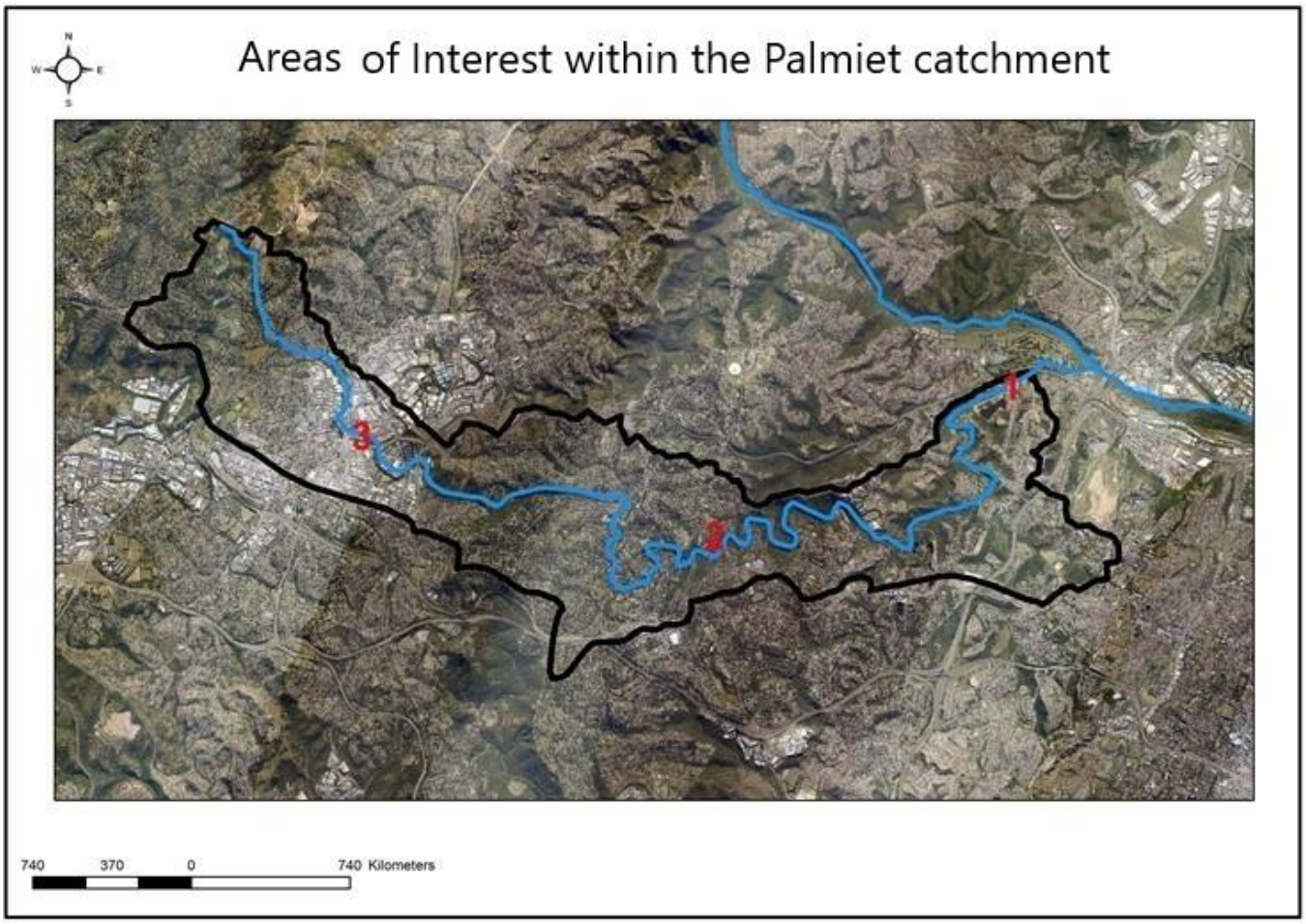

Figure 3.3 Selected Areas of Interest within the Palmiet catchment

Table 3.1 Background on Areas of Interest

AoI	Name of Area	Relation to River	Land Use
1	Quarry Road Informal Settlement	Lower Reach	Low-income residential area
2	Palmiet Nature Reserve	Mid Reach	Managed/Protected area
3	Pinetown/New Germany Industrial area	Upper Reach	Industrial

The three Areas of Interest (AoI) have unique physical characteristics. The upper catchment is defined by industrial and high-middle income residential land use, whereas the middle of the catchment is defined by a nature reserve, and the lowercatchment is defined by informal settlements and low-income residential land use. These main characteristics are the foundation to unpacking the ES offered at different points in the catchment. Each AoI is different and has changed over time with the increase in urbanization. Each AoI interacts with the next at multiple temporal and spatial scales and do not exist independently of the next. The SES framework is therefore a tool that is applied to understand the various interactions occurring within a system. The scales and uniqueness of the SES is complex and interconnected - although in this case it is all very closely related and sits under the same administration. As in SES, the complexities in each Area of Interest are characterized by inherent uncertainty, connectivity, resilience and tipping points.

The increasing impacts of flooding events within the Palmiet catchment demand for greater attention and a call for measures that will decrease the impacts of flooding on people and the surrounding environment. The ability within the catchment forflood regulation varies depending on the existing land use surrounding the part of the river and the natural state of the environment and type and/or condition of storm water infrastructure present. As mentioned previously, this interaction through space and time is necessary to co-design and encourage engagements to tackle challenges and transformation in space and time.

3.4 Social ecological systems framework

The approach taken in applying the SES framework in the Palmiet catchment is built on information from previous studies to understand the productivity of the Palmiet river, which is viewed as the resource system (Naidoo, 2016). Research by Naidoo (2016) aimed to explore the relationship

between the infrastructure, water quality condition and riparian zone within the Palmiet catchment. This study validates in its findings that the productivity of the Palmiet river to offer ES is diminished due to environmental degradation, declining rates of water quality, and a significantly modified river channel due to hard infrastructure influencing the streamflow rate (Naidoo, 2016).

A SES model of the Palmiet catchment was constructed to understand the system as it currently stands based on the information and perceptions of people residing within the catchment and physical land use changes throughout the catchment. A SES model of the catchment is aimed to support knowledge on measures suitable for the catchment to develop in a sustainable manner that supports the influx of people and protection of the river and natural environment. The principles of the concept as detailed in Chapter 2.4.1 have been abided to where the first-tier variables are the following: the resource system is the Palmiet River, the resource unit is the Palmiet catchment, the governance system is the CoI and the UEIP, and the actors are the actual people residing or working within the catchment. Furthermore, the second-tier variables (as expanded in Appendix B) are listed below for each first-tier variable:

- Resource System – Productivity of the system (RS5), Predictability of system dynamics (RS7)
- Resource Unit – Growth rate (RU2), Spatial and temporal distribution (RU7)
- Governance System – Government organization (GS1), Network structure (GS3)
- Actors – Location (A4), Importance/dependence of resource (A8)

The narrowing down of the second variables is for simplicity to facilitate understanding the impacts of urbanization on the Palmiet River. The focus of the SES framework are the interactions of the first-tier variables which lead to certain outcomes. The first-tier variables are deepened by underlying layers which present themselves as second-tier variables that expand the understanding of the first-tier variable itself. Two second-tier variables were selected based on the information available and to best describe the interactions occurring within the Palmiet catchment. Therefore, the main challenge in understanding the components of the first-tier variables was unpacking how the impacts of the second-tier variables impact the current condition of the first-tier variables.

The Resource System builds on previous research conducted to understand the productivity of the Palmiet River to offer ES. The Resource Unit is built upon the rate of urbanization and the spatial and temporal distribution thereof. Section 4.3 details the rapid rate of urbanization particularly since 2011

which is validated by literature regarding delayed yet rapid rates of urbanization in African cities. The Governance System is the role of the caretaker of the Resource System which is the eThekwini Municipality and their role withvarious stakeholders to implement strategies of change. This project team consisted of municipal employees from various departments such as: water and sanitation, housing, special projects, pollution, solid waste, stormwater and roads,architecture, health, parks, and the CPD. The University of KwaZulu- Natal was also part of this project team. Over time this network structure has gradually shifted since 2014 because of fragmentation and a lack of horizontal coordination within the municipal departments. The roles and distribution of tasks shifted. The CPD now provides the mainlead and facilitates coordination amongst relevant stakeholders. The action plan for the PRP was drafted by the CPD with the input of the CoI.

The actors are the people who reside and work within the catchment. The ability and willingness of the actors to change their actions and relationship towards the natural environment is dependent on their location and the importance/dependence of the resource. Table 3.2 details the index used to provide insight to each second-tier variable.

Table 3.2 Second-tier variable index

First-Tier Variables	Second-Tier Variables	Index
Resource System	Productivity of Palmiet River	Previous research on the Palmiet River
	Predictability of River dynamics	History of flooding events and current channel dynamics
Resource Unit	Urbanization Rate	Use of aerial photography maps
	Spatial and temporal distribution	Use of aerial photography maps
Governance System	Government organization	eThekwini Municipality
	Network structure	Multi-stakeholder participation
Actor	Location	Geographic information
	Importance/dependence of resource	Significance to people situated within the catchment

The focal action situation is based on the ES in review. The interaction of the systems to flood events and the relationship of the systems in response to the focal action situation are expanded further in this chapter 2.4.

3.5 Land Use Change

Land use change was detected through the use of aerial photography images. The visual images cannot be quantified through digitalization but remain useful in providing visual aid to recognize the changes that are physically occurring within the catchment. The information on the land use images was accessed through the Spatial Planning Branch within eThekwini Municipality for the Palmiet catchment area from 1981 to 2016 (35 years) as stated in chapter 3.2.

CHAPTER 4: RESULTS

This chapter presents the results of the study. The methodological approach (*viz*. Chapter 3.2) is followed to achieve these. An analysis of the results is presented within each sub-section of this chapter along the lines of the objectives and Figure 3.2.

4.1 Ecosystem Services for the Areas of Interest

Observations from the workshops and interactions between community organisations and the municipality, it became clear that there is great dependence on the role of the municipality and other stakeholders to address issues across the catchment through service delivery. However, the initiative of the larger UEIP project to enhance ecological infrastructure aims to explore ways to enhance and restore ecosystems and contribute to the uMngeni catchment. Table 4.1 lists the main concerns per AoI, raised in large public stakeholder engagements (May 2018) including residents and interested and affected parties of the Palmiet catchment. The response from the community engagement has been used as input to tabulating Table 4.1

Table 4.1 gives an indication of the main issues currently experienced and discussed within the various sections of the catchment. Increasing urbanization and the growing demand for service delivery has increased pressure for eThekwini municipality to address and deliver services to people. Various political structures such as local government parties (African National Congress, Economic Freedom Fighters and the Democratic Alliance) exist in the catchment and within municipal structures which add to the complexity of delivering services to people within the catchment and the city of Durban at large. However, for the purpose of this study, the political component has been omitted as it exceeds the scope of the study. Interested and affected parties within the catchment have various issues of which the condition of the Palmiet river is a common denominator. However, even so, the outlook on the present condition of the Palmiet river varies within the catchment. An individual's outlook and relationship with the river is related to their location and standpoint as can be seen by the issues raised in Table 4.1. For example, people situated in AoI 1 may view the water resource as a beneficial place to discard grey water yet, also as a threat during heavy rainfall events which have led to floods that have destructed homes and led to the deaths of people. At AoI 2, the river is treasured and protected for conservation purposes to ensure and restore natural functionality of the river and protecting species that depend on the health of the river. Minimal human activity occurs at AoI 2. The pollution at AoI 2 is significantly less than the other points within the catchment.

At AoI 3, the river is not necessarily valued for its ecological significance but instead (in some cases) misused as a dumping channel (e.g. in parts of the informal settlements), of which the impacts of such are carried down through to the bottom of the catchment. To a certain degree, the ES provided and utilized surrounding the Palmiet river also vary. For example, the provisioning service of water from the Palmiet River maynot be for human consumption at any point in the river. The water quality level at different points varies depending on the existing land use and human activity at that point. Therefore, the focal typeof ES was selected in the following manner depicted in section 4.4.

Table 4.1 Main issues within each Area of Interest in the catchment

AoI	**Main Issues Faced**
1	• *Water and sanitation:* Service delivery issues are a big concern to residents. There are two ablution blocks servicing the growing informal settlement. These ablution blocks are closed at night which is problematic. There is no piped water to each household but there arecommunal taps instead. • *Safety:* Crime and health hazards due to pollution are commonly experienced throughout the informal settlements. Electricity: Many illegal connections exist throughout the informal settlement which is also asafety hazard. There is no legal or proper electricity connections installed. Pollution: There is litter throughout the informal settlement. The Palmiet River is polluted withsolid waste dumped into the river (see Appendix C) • *Erosion:* The banks of the Palmiet River are eroded. This places great risk to settlements closestto the banks of the river. Flooding issues have resulted in the loss of homes and people.
2	• *Water:* Declining water quality and river health is a great concern along the nature reserve.
3	• *Water:* Pollution issues including effluent discharge into the Palmiet River have resulted inwater quality issues.

As noted in section 2.1.3, various ES are intertwined and influence each other. Table 4.2 depicts the types of ES that are perceived during the collection of information for this research study as dominant in each AoI based on the current condition of the river andsurrounding environment at that point. The dominant ES are outlined in table 4.2 below to be used in the mapping construction of the SES framework in section 4.2.

Table 4.2 Dominant ecosystem services per Area of Interest

Areas of Interest	**Ecosystem Services**			
	Provisioning	Regulating	Cultural	Supporting
1	X	X		
2	X	X	X	X
3	X			

Table 4.2 shows the dominant ES selected from each AoI in the Palmiet catchment. The most obvious provisioning service, dominant throughout the catchment is the water resource itself despite its physical condition. The reason for the dominance of the river is due to the potential to rehabilitate the area to restore and enhance EI as discussed and advocated for by the UEIP. Regulating ES are also assumed to be dominant in AoI 2 due to the potential for flood and climate regulation based on the abundance of plant species across the nature reserve and along the river. Cultural ES are dominant in AoI 2. AoI 2is a space for educational, recreational, and spiritual activities which therefore enhances the functionof cultural ES. Supporting ES are dominant in AoI 2 as it is the closest to being undisturbed in the catchment despite carrying pollutants through the river from the upper catchment. Lastly, much of the potential for all ES to thrive across the entire catchment has been reduced by human activities based on the main issued faced listed in Table 4.1.

However, much can still be done with the natural based solutions. The focal type of ES that will be highlighted in this study is the regulatory ES of flood regulation. Based on community engagements, it was highlighted that impacts of flooding are worsening even in the event of lighter rainfall events that should typically not cause sever impacts. During my internship for the municipality, a report was compiled based on the inputs of community engagements and municipal officials which can be

found in Appendix C. The flood regulation measures within AoI 1 are poor and further exacerbated by increased erosion of the riverbanks and the lack of vegetation surrounding the riverbanks. At AoI 2, for example, flood regulation is not as poor as it is in AoI 1 due to the dense vegetation that is present to reduce the velocity in the flow of rainfall. AoI 3 is an immensely impervious surface area and thus minimal areasfor infiltration exist. This in essence shows how widely different an urban catchment is and how theresponse to regulating ES vary across an urban landscape. As much as it may not be possible to completely implement measures of EI at all points within an urban landscape, it is evident that effort can be made to utilize the natural environment for catchment management as cities expand and face climate change impacts.

Recalling that the first objective of the study is to identify which ES exist in the Palmiet catchment, and how these could enhance catchment management with a specific focus on flooding. Knowledge regarding which ES are dominant and how they contribute to the wellbeing of people in a catchment assists in providing a theoretical starting point to informing decision makers which changes need to be addressed. Investment in EI is a good option to address flood regulation forexample. The Palmiet catchment offers ES that require nature-based solutions to addressing issues of degradation and impacts on people. ES therefore enhance catchment management by providing astarting point firstly through identifying which ES are dominant and secondly investigating strategies that could be investigated such as enhancing EI at certain parts of the catchment and through the application of sustainable drainage systems particularly in the lower parts of the catchment. Apart from the investigation into EI, there are small initiatives that are low cost and simple that can be done within the Palmiet catchment to increase the regulation of floods. Initiatives such as constructing trenches, ditches and ponds in the upper catchment are options that have been presented in discussions within the CoI including initiatives such as planting trees and vegetation throughout the catchment. The sustainability of these or any catchment management initiatives is dependent on the willingness of people to change their actions to be more environmental conscious. The dispersed socio-economic reality of people within this catchment is emphasized during stakeholder meetings where one is able to pick up the desires of people to shift to environmental consciousness but the limitations they face when there is socio- economic struggles that demand immediate response.

During the community engagements, it was noted that residents of the informal settlement would like a cleaner living environment but details such as not receiving refuge bags from the municipality lead to people littering. People resort to using shopping carrier bags for domestic refuge but these plastic bags end up dumped on the side of roads and walk ways waiting for municipal collections

which usually tend not to happen. These collections are scheduled to be weekly. Adopting a social-ecological approach includes social challenges that people face as part of catchment management strategies and in the case of the Palmiet, the involvement of the CPD and other departments in the municipality have taken recognition of this. Although all the issues highlighted in Table 4.2 are not always addressed effectively, the collaborative effort in catchment management ensures that these issues are still heard. Though issues are heard, there are still challenges in implementing solutions as municipal officials have expressed internal challenges with municipal departments being fragmented and lacking capacity to address many issues. A suggestion from this study is to address social and ecological issues within the catchment based on ES that the system offers. Through doing so, the social issues are constantly linked back to the environment. For example, one of the findings was an issue of no legal electrical connection in AoI 1. This issue does not have a direct environmental link; however, it can be approached from a perspective of provisioning services such as energy whereby efforts are shifted to investigating investments for low-cost solar panel use for electricity generation especially for off-grid settlements.

4.2 Social-ecological systems model for the Palmiet catchment

The ES input from Table 4.1 and 4.2 provided information in understanding the social and ecological condition of the Palmiet catchment. In applying the SES framework in the Palmiet catchment, Figure 4.1 illustrates a conceptual SES model for the Palmiet catchment where the first-tier variables have been defined for each system throughout the catchment during flood events. The analysis that exists in the Palmiet River catchment particularly after a flood event is advancing. The various systems within the catchment remain connected in a manner that is not common in other local river catchments. The system of the Palmiet catchment becomes largely flooded particularly along the river during a flood event. This has set conditions for poor flood regulation in that the system is not at a point where the river dynamics are resilient to minimizing impacts of flooding. The resource unit of the system, of which the spatial and temporal distribution of a flood event is impacted the highly urbanized catchment. This therefore renders the outcomes of the flood event having large impacts to people and their property. AoI 2 is largely extended with natural vegetation that is protected from urbanization but still produces minimal flood regulation as there is minimal impervious areas unlike AoI 1 and 3. The Resource System, (productivity of the river and predictability of system dynamics) due to urbanization and degradation in the catchment does not offer regulating ecosystem services to regulate floods in the way in which it has the potential to.

Therefore, the flooding because of the minimal regulating ecosystem services has high negative impacts throughout the catchment (AoI 1-3) due to the resource units and actors within the catchment. The governance unit in the catchment currently sets conditions to manage flooding events through action towards utilizing ES through initiatives within the CoI (such as early warning systems through the use of Whatsapp to communicate the severity of a flood from people in the upper catchment to people around the informal settlement). The people within the catchment are rapidly degrading the system through actions of pollution as described beforehand. Consequently, the ecosystems particularly in the upper and lower parts of the catchment show a significant decrease of ecosystem servicessuch as flood regulation in flooding events and water purification.

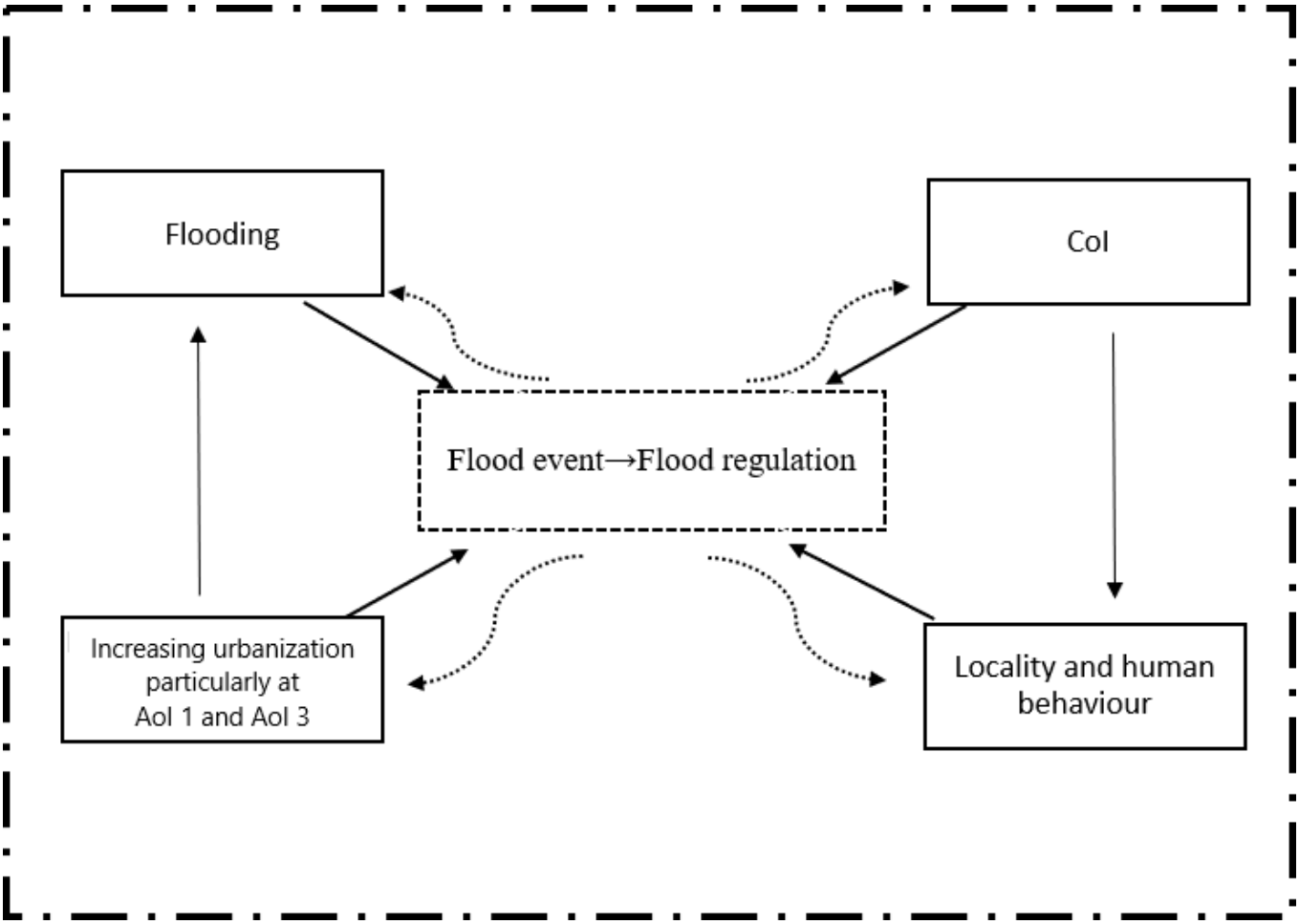

Figure 4.1 Social-ecological system for the Palmiet catchment

4.3 Aerial Photography to Detect Land Use Changes

For this section, historical aerial photography images were selected based on the purpose of conducting a visual analysis of the areasof interest. Limitations of historical data exist within the Palmiet catchment. The following land usechange images for each AoI are arranged and discussed per AoI.

4.3.1 Land use change for Area of Interest 1

AoI 1 is an informal settlement which has grown over the last 35 years. Figure 4.2 depicts the natural state of the lower Palmiet catchment with minimal human disturbance to the river. Vegetation cover is visibly present, and the Palmiet River has minimal visible influences from human development. With an influx of people into the Palmiet catchment, it can be seen in Figure 4.3 that there is a difference in economic standing by the type of settlements in the lower catchment. In 1999, post-Apartheid, issues of political and economic difference were still very much evident through settlement patterns particularly in Durban, KwaZulu-Natal. The lower Palmiet catchment which is in the Reservoir Hills suburb of Durban was predominantly an Indian community. As seen in Figure 4.3, there is a difference in the types of housing settlement. The bottom right of the image shows formal housing which has gradually expanded since 1981 (seen in Figure 4.2). The top left portion of the images depicts an informal settlement (Quarry Road) which has had a large environmental degradation impact on the Palmiet River from the late 1990's to present day. AoI 1 is therefore focused on the informal settlement for this reason. The rate of growthin this informal settlement in Figure 4.2 compared to Figure 4.3 can be attributed to the political change in South Africa. From 1981 to 1999 many people from rural areas in South Africa were finallyexperiencing the freedom of choice and unrestricted movement to urban areas in search of greater opportunities. The construction of informal settlement at such close proximity to the river (Figure 4.3) has led to various impacts of pollution to the river system.

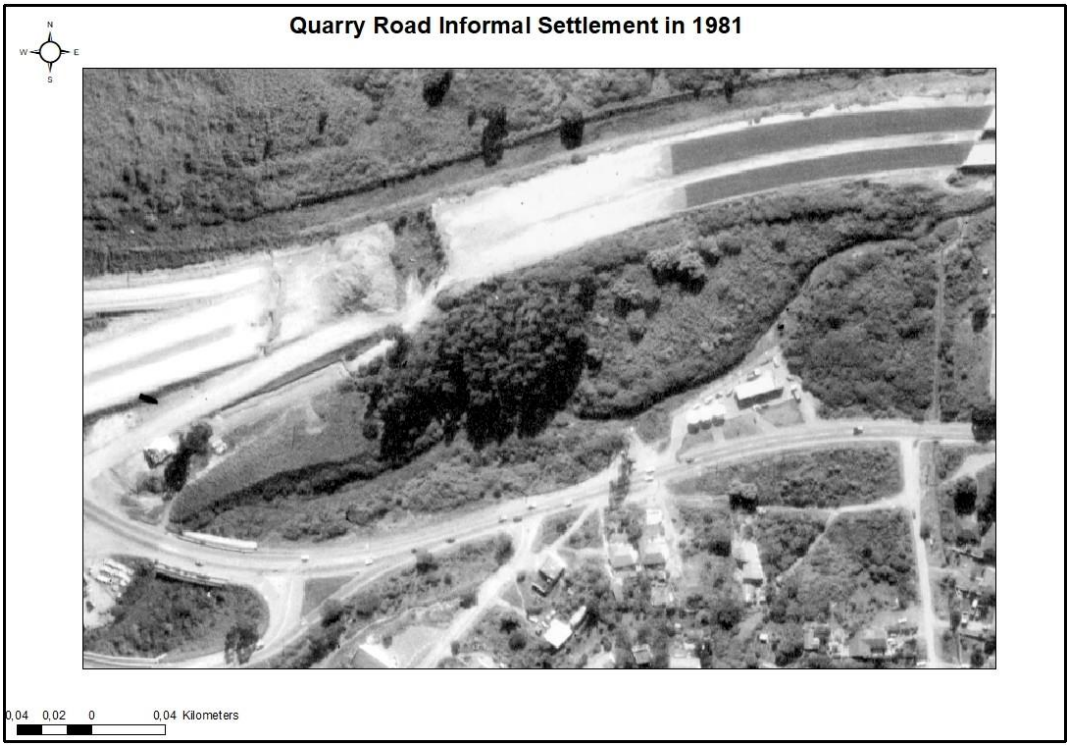

Figure 4.2 Quarry Road informal settlement in 1981

Figure 4.3 shows slightly more settlement on the north-eastern parts of the informal settlement compared to Figure 4.4 which is 8 years later. This decrease in settlements over time is possibly attributed to the allocation of RDP housing to residents of informal settlements as well as flooding events that occurred in 1999 (one event in February 1999 and one event in December 1999) which consequently destroyed structures built on the banks of the river (as depicted in Figure 4.3 and missing in Figure 4.4). As a result of the flooding events in 1999, the riverbed widened and a large loss of trees along the river occurred. Changes in informal settlements along the river at this particular point in the river from 1999 to 2007 were minimal.

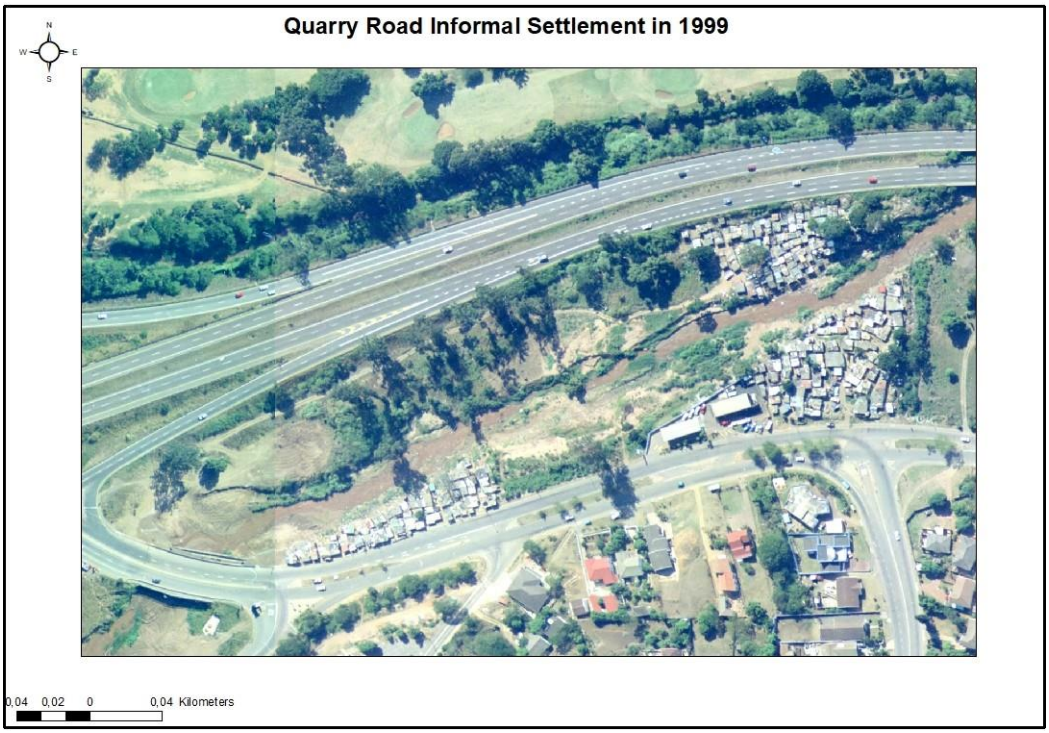

Figure 4.3 Quarry Road informal settlement in 1999

Figure 4.4 Quarry Road informal settlement in 2007

As with the case in Figure 4.3 and Figure 4.4, the growth of the informal settlement was gradual in Figure 4.5. However, Figure 4.5 depicts an increase from 2007 which as a result adds to the human impact on the river. Influx of people into the catchment and particularly informal settlements in the lower parts of the catchment began gaining momentum from 2011. The Quarry Road informal settlement is not the only informal settlement in the catchment, however for the purpose of the scope of this study it is the only informal settlement included.

As noted in the literature review, the rate of urbanization in African cities has been rapid. The growth of the informal settlement until 2011 has been gradual and the human impact on the river can be assumed to be minimal as fewer people resided to directly impact the river negatively. Figure 4.6 depicts rapid growth of the informal settlement compared to Figure 4.5. The informal settlements did not exist in the north westerly parts of the catchment in Figure 4.5, however in a span of 5 years, rapid growth of informal settlements in this part of the catchment can be seen in Figure 4.6. Furthermore, the proximity of the settlements to the river poses great threats to people living on the banks of the River. The rate of growth in this informal settlement is a cause for concern due to flooding risks as well as many challenges facing the municipality to provide services such as waste removal, electricity, piped water and sanitation. The geographic location of this informal settlement hinders the necessary implementation of these services as the municipalities have not formalized many areas of informal settlements as suitable living areas. Appendix C provides images of the conditions in Figure 4.6.

Figure 4.5 Quarry Road informal settlement in 2011

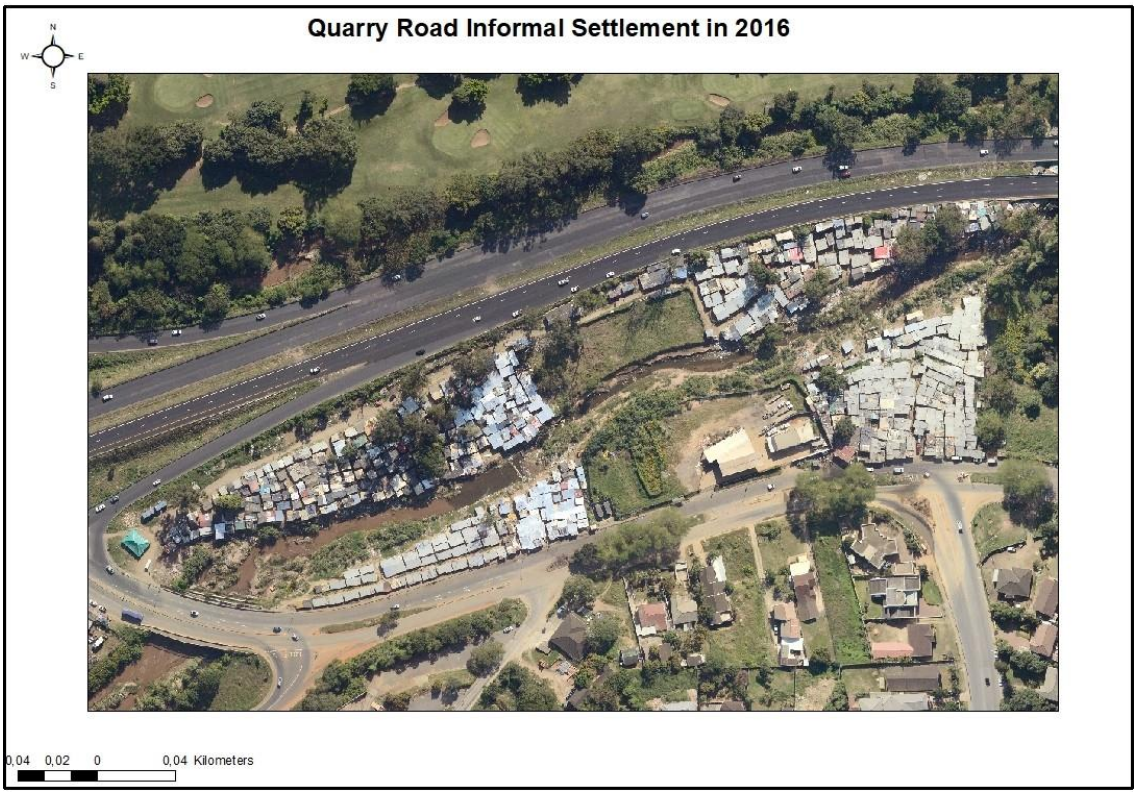

Figure 4.6 Quarry Road informal settlement in 2016

4.3.2 Land use change for Area of Interest 2

AoI 2 is the Palmiet Nature Reserve (PNR) of which 6km of the Palmier River passes through. The PNR is located in the Westville suburb of Durban in the middle section of the Palmiet catchment. Figure 4.7 – Figure 4.11 show slight changes in vegetation and human development surrounding the PNR from 1981 to 2016 particularly around along the Palmiet river. This is largely due to the protection and conservation of the PNR. However, the growth of industries in the upper catchment (AoI 3) have impacted the water quality in the Palmiet River into the PNR.

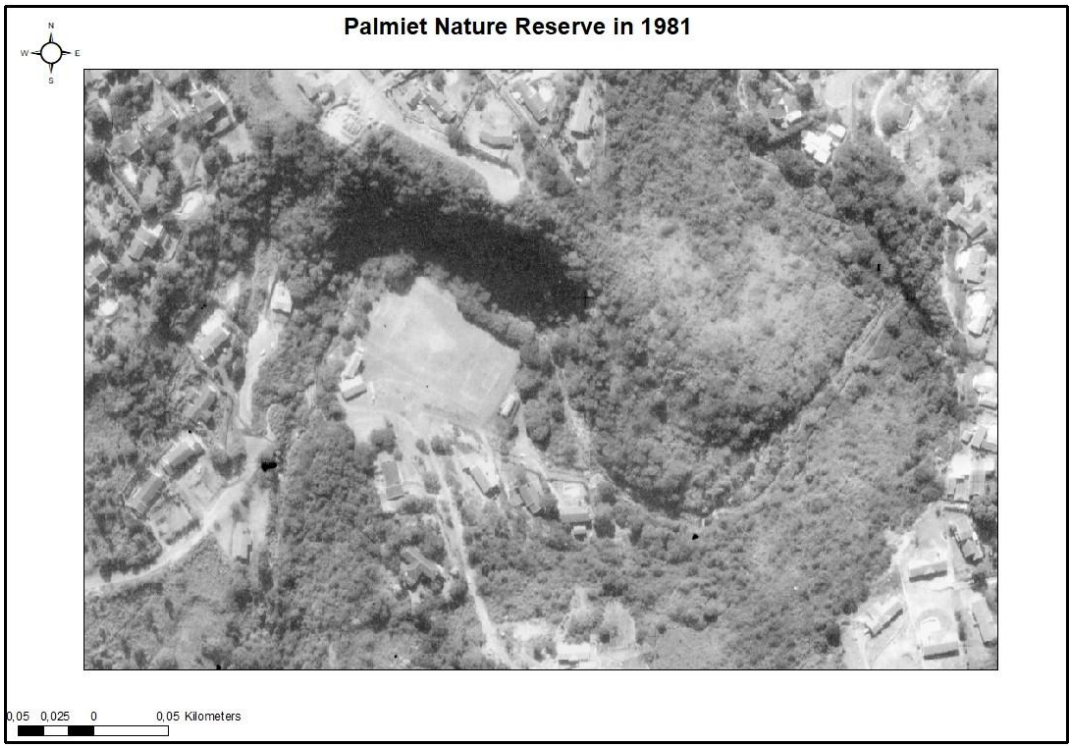

Figure 4.7 Palmiet Nature Reserve in 1981

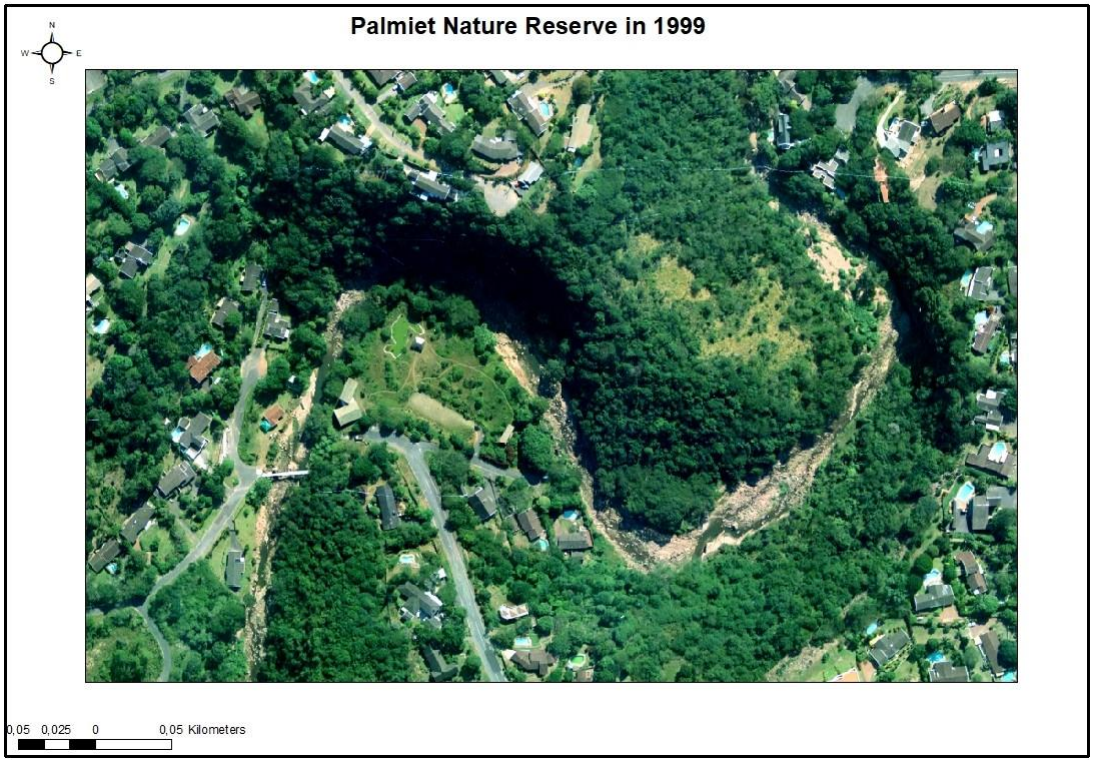

Figure 4.8 Palmiet Nature Reserve in 1999

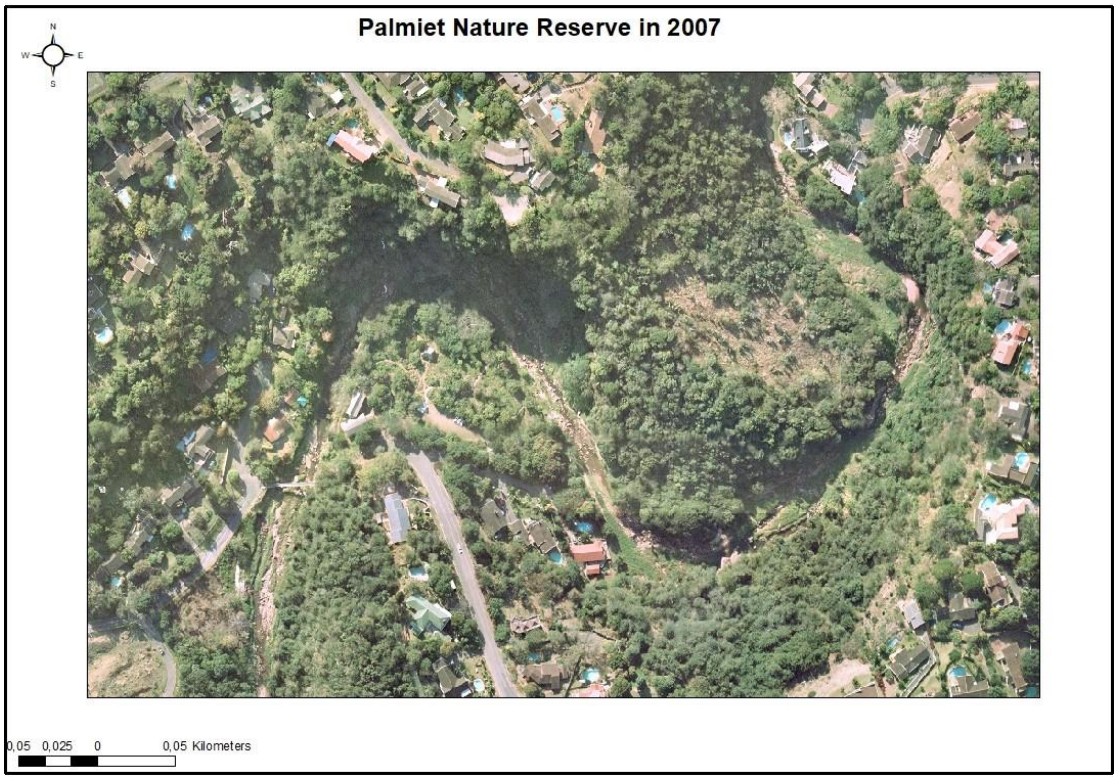

Figure 4.9 Palmiet Nature Reserve in 2007

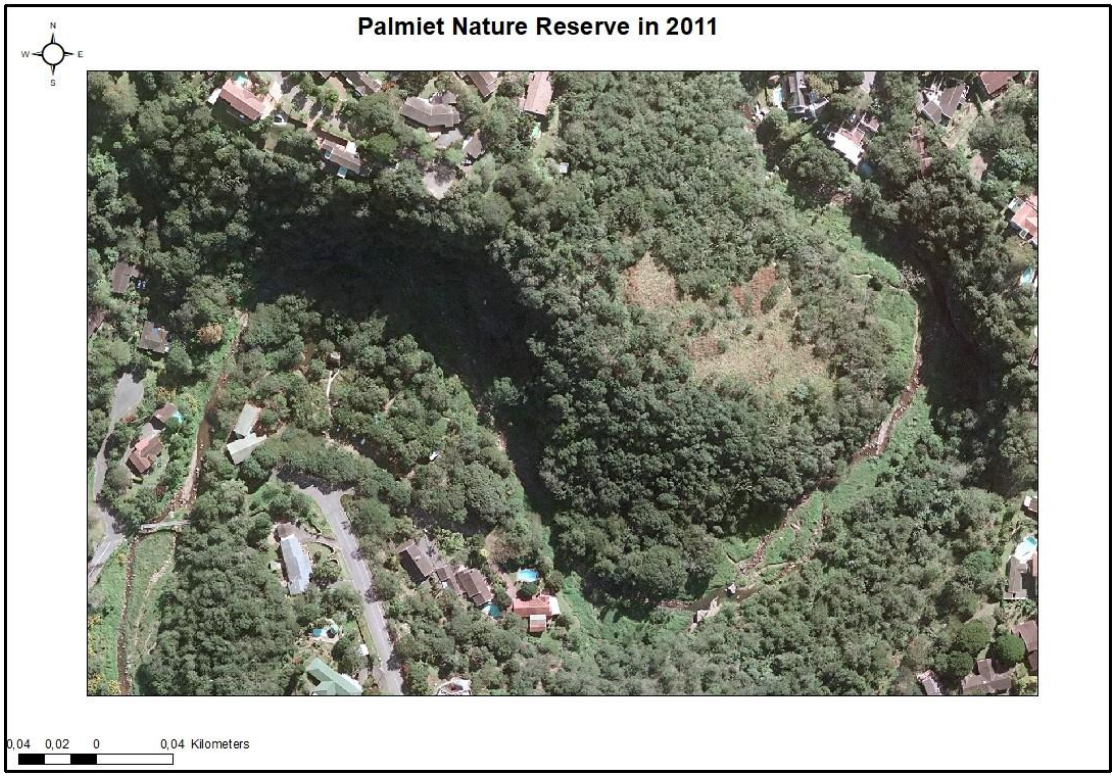

Figure 4.10 Palmiet Nature Reserve in 2011

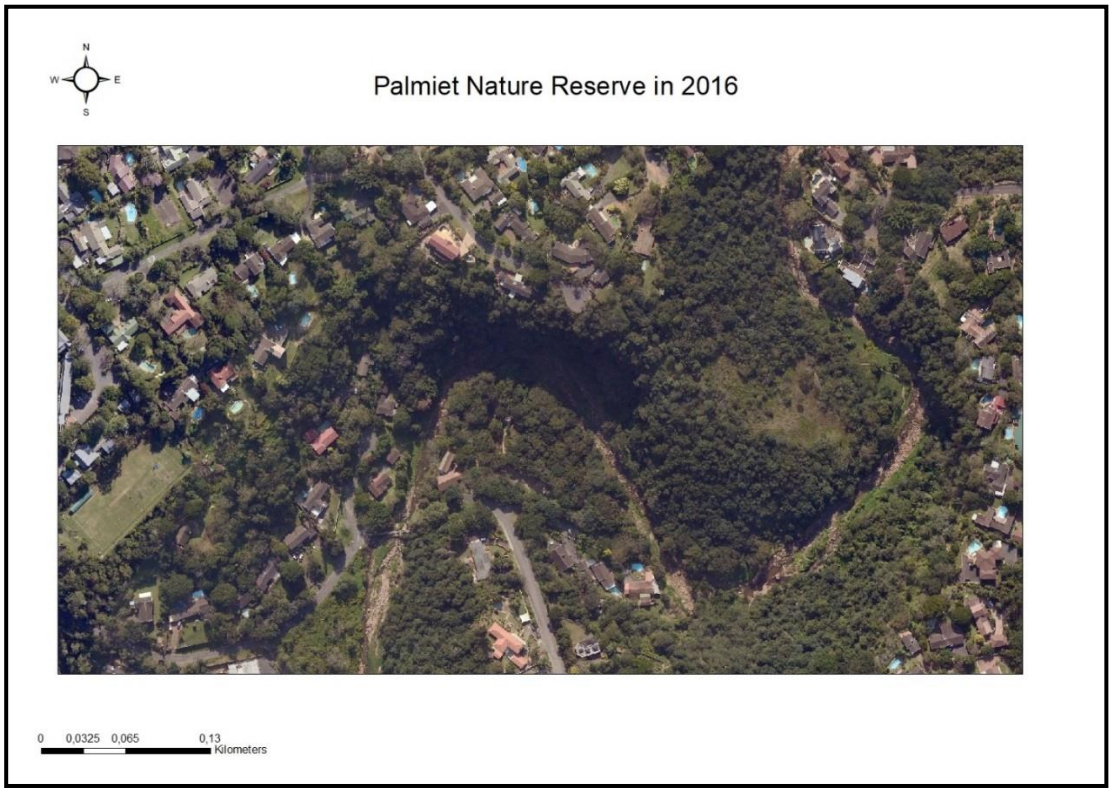

Figure 4.11 Palmiet Nature Reserve in 2016

4.3.3 Land use change for Area of Interest 3

AoI 3 is the industrial park located in the upper reach of the Palmiet catchment within the Pinetown and New Germany suburbs. The areal images below are for the years: 2007, 2011 and 2016. Information for 1981 and 1999 aerial photography images for the upper part of the Palmiet catchment was not found and therefore omitted in this section. However, changes based on images since 2007 show minimal changes in infrastructure along the Palmiet River despite declining water quality recordings. Vegetation changes (which weigh differently in the contribution to an ES) are also minimal throughout the industrial area. However, vegetation seems to be declining in the western region of the images as depicted in Figure 4.14.

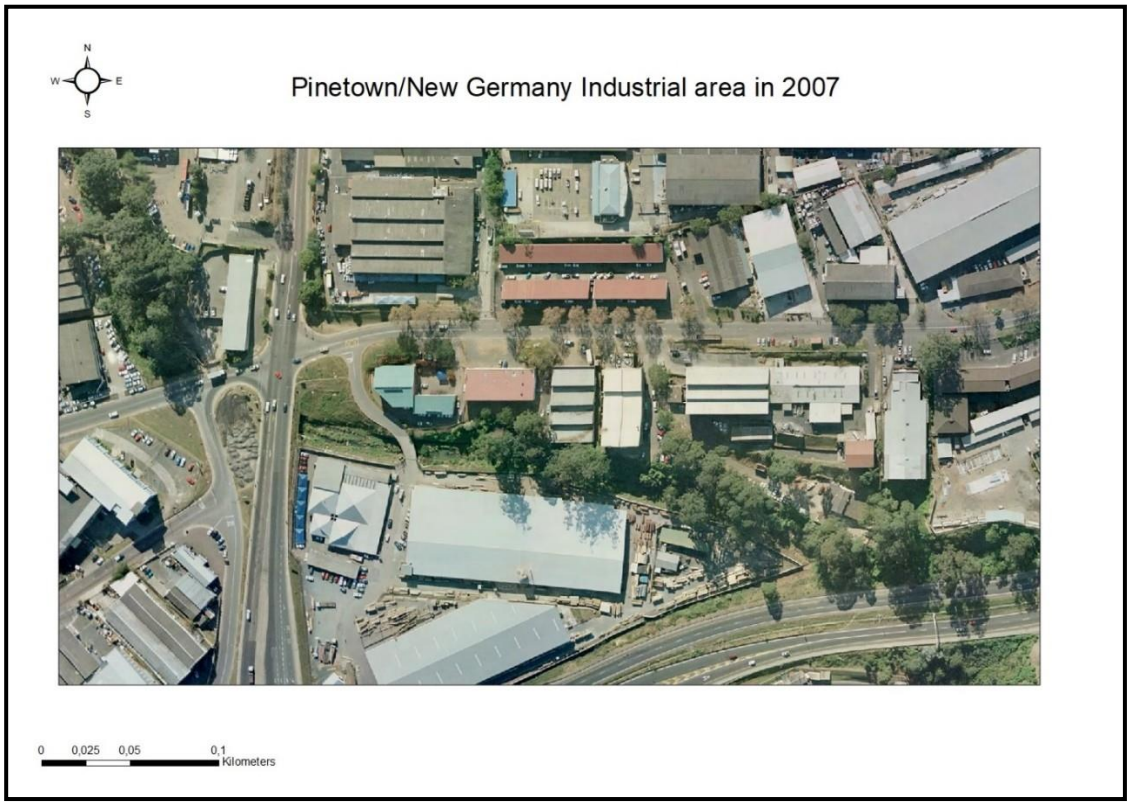

Figure 4.12 Pinetown/New Germany Industrial area in 2007

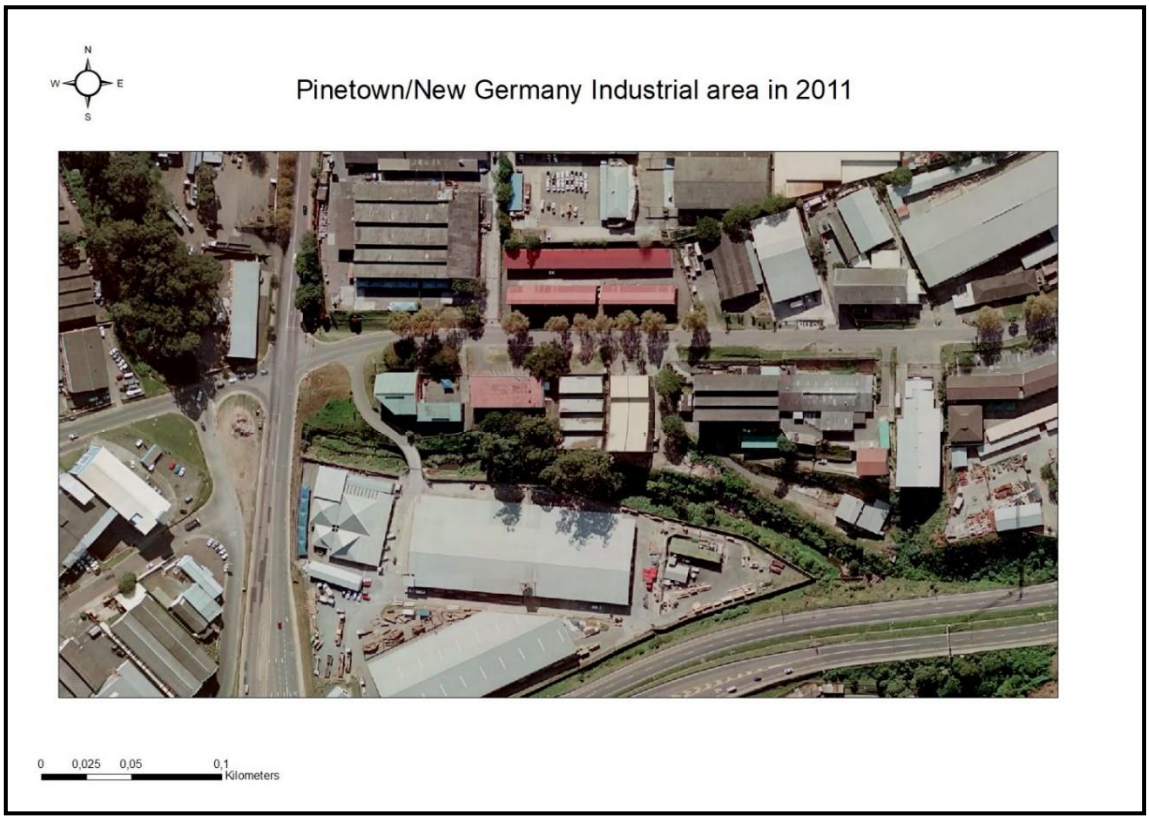

Figure 4.13 Pinetown/New Germany Industrial area in 2011

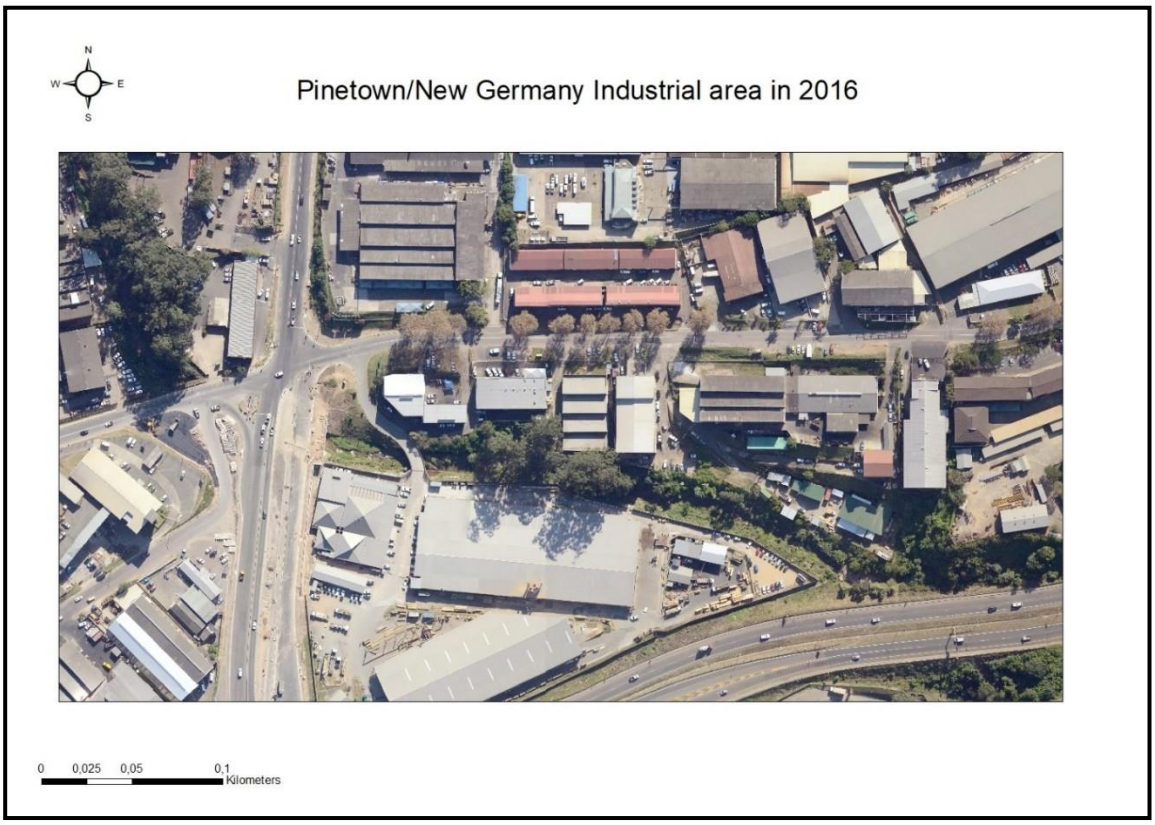

Figure 4.14 Pinetown/New Germany Industrial area in 2016

4.3.4 General analysis of land use change in the Palmiet catchment

As stated in the literature review, it can be concluded that growth in human population in African cities is occurring at a rapid rate to the detriment of environmental systems. This therefore requires interventions that are not only beneficial to accommodating people in cities in a manner that enhances the quality of life of people where they are not at risk of natural hazards such as flooding. This increasing rate of urbanization is also contributing to climate change risk in that people are increasingly at risk of natural hazards and unpredictable weather patterns due to cumulative impacts of human activities. The risks of climate change are largely felt by the urban poor who are already vulnerable, as in the case with AoI 1 (informal settlements), the resilience of the natural systems as well as people is becoming increasingly difficult to recover from shocks (Williams *et al*., 2018). AoI 2 (nature reserve) are at risk from climate change impacts in terms of species and biodiversity loss whereas AoI 3 (industries) risk the possibility of destruction of built infrastructure for example with increased flooding. With that said, the greatest AoI at risk of all the above remains to be the poorest and less resilient. The spatial distribution of urbanization in the Palmiet catchment according to the aerialphotography is occurring at the upper catchment and lower catchment. The middle of the catchment(AoI 2) remains unchanged in land use due to the PNR being protected. The temporal

distribution of urbanization in the Palmiet catchment has largely grown in the last 7 years but more specifically in 2013 to 2015.

The aerial photography images of the Palmiet catchment confirm the need to restore and rehabilitate the river and its associated ecosystem services especially with the rate of growing populations in African cities. Drastic changes have occurred in the lower reach of the Palmiet catchment. The city of Durban is experiencing a tremendous growth in informal settlements particularly in unsuitable areas that are not intended for residential purposes such as the case in the Palmiet. One of the greatest challenges facing the city regarding the uncontrollable rate of growing informal settlements, as mentioned earlier, is the provision of proper drainage systems, piped water, and adequate sanitation services. Besides the political influences of not addressing many of these issues, the city is reluctant to solving these issues due to the geographic location and the capital to provide services for free or at low rates to people who are mostly not in the financial position to contribute to the provision and maintenance of these services. These images show changes to the system over time and deduce the increased impacts of urbanization over time and the strain this puts on the river to go back to a healthy state.

4.4 Drone Images for Area of Interest 1

The drone images presented in this section are to highlight the impacts of a flood event that occurred on the 24th of April 2019. It can also be noted that one can see an expansion of housing within the informal settlement even in this short time period. This can be seen on the top left and top middle sections of the images. The eastern part of Figure 4.17 shows the reduced number of settlements because of the flood event. This is an unfortunate situation experienced in AoI 1 after flood events. The flood event in Figure 4.17 is approximately six months after the last flood event that occurred in October 2018. The people residing within Quarry Road Informal settlement prove to be optimistic in their attitudes to rebuild their homes and their lives during flood events, despite there being a greater opportunity for the resilience towards floods. The focal interaction situation of the catchment being flooded, and the outcome not being regulated and reducing risk to people and property is the reality of this AoI in Figure 4.17. The fourth objective of this study included: identifying the value and potential of ecological infrastructure investments for the Palmiet catchment to achieve resilience against flooding. It is proposed that with the addition of EI in the catchment, it would reduce the current impacts experienced after each flood event. This would reduce the velocity of the flooding and possibly reduce the impact of destruction to property and possibly negate the loss of lives. The Palmiet catchment already has an existing governance network that is committed to improving the

river and the ES offered within the catchment. This would provide a great platform for the management of EI within the catchment.

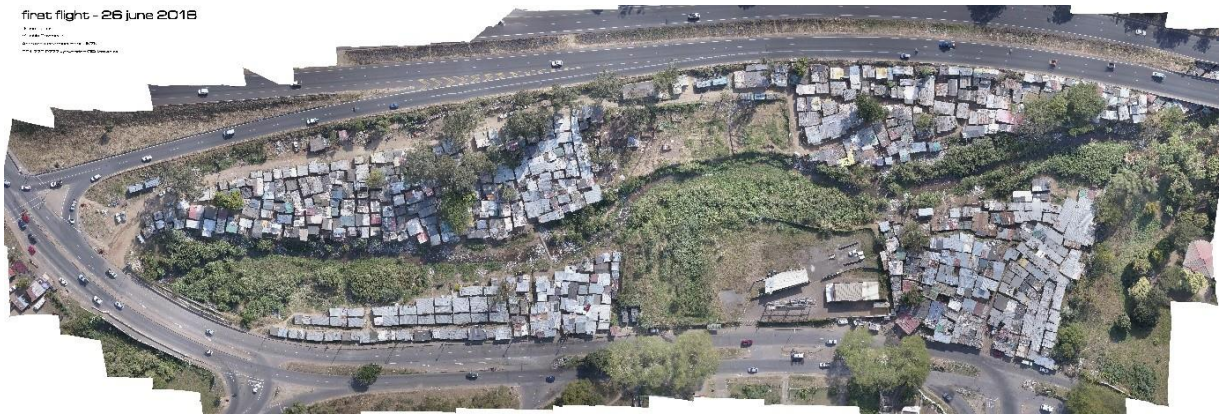

Figure 4.15 First drone flight (26 June 2018)

Figure 4.16 Second drone flight (11 September 2018)

Figure 4.17 Third drone flight (24 April 2019)

CHAPTER 5: DISCUSSION

The AoI's have been investigated as a contribution to the social ecological system of the Palmiet catchment presented unique risks and resilience to the resource system (Figure 4.1). This revealed that the experiences in the complexities of the ecosystem services present at different points in the catchment are different yet still very much connected. For example, the link to the Palmiet River and commonality of the provisioning ecosystem services. The risk to flooding (and potential of regulating ecosystem services) throughout the catchment has differing impacts to people depending on the existent land use and proximity to the resource system in each AoI.

The application of the social ecological systems (SES) framework has been found to be less impactful when applied to a large catchment. However, complexities in the systems approach were still challenging to conceptualize even in discussing the AoI systems individually and thereafter applying the SES framework to the entire catchment. The framework was found to not be suited conceptually for application across an entire large catchment. It is proposed that it may be better suited to be applied to one AoI instead of the entire Palmiet system. The interaction – outcome scenario of an ES such as flood regulation could be applied to each AoI. Each AoI has the potential to be studied as a SES independently before approaching a holistic SES for the catchment. Each AoI has intricacies that can been further studied as an entirely separate SES,which was not done in this study as it was important to show the relationship that exists through various systems within the entire Palmiet catchment. The relationship between each system is very interesting in the Palmiet catchment through which the strengths and weaknesses are easily identifiable. The Governance System has a strong focus on the informal settlement which has the greatest informationavailable in comparison to other parts of the catchment. Therefore, a detailed SES could have been constructed for this part which may not have been necessarily reflective of the social-ecological relations for the entire catchment. For catchment management to be effective through policy and implementation, the interaction outcome scenario should be applied throughout the catchment and the impacts assessed throughout. The relationship for the various systems within this framework is often co-dependent for change which is understandable in a complex SES such as the Palmiet. Initially, the assumption made was that the construction of the SES for the Palmiet catchment would be straight-forward, but this provedto be challenging in the uncertainty that exists around predicting people's actions. Another finding was the diversity of the SES as one moves through the catchment and down the river which then brought about the realization to choose and investigate at a smaller scale and thus use a bigger resolution for all the collected information and data.

The interdisciplinary and transdisciplinary approach to the application of the SES framework proved challenging especially in framing the social aspects even when using a defined second-tier. Although the political aspect has been omitted for the purpose of this study's application of the SES framework, it is important to mention the role which it plays addressing the required resilience needed to regulate flooding in the catchment. The political aspect is broad and addresses the power dynamics and interactions at play between various societal actors regarding a specific issue. Although omitted in this study, the political aspect is an important factor to be considered for effective change within social-ecological dynamics which should be studied in further research studies. The collaboration of actors within the Palmiet catchment is remarkable in organizing the existing governance structure for the initiation of sustainable and functional social-ecological systems. Suchorganization of interested and affected parties is not commonly found throughout many urban catchments. The results gave insight to the change in land use/cover over time and how the rapid rate of changeis impacting the ability of the Palmiet River to regulate flood events. This rapid change therefore prompts solutions such as investment into ecological infrastructure to cater for growing populations.

Lastly, through this study it was found that the impact and collaborative efforts of people are essentially the determining factor to bring changes to the management of the catchment management such as a waste recycling initiative. Therefore, it is important for the actors in the catchment to be more resilient to shocks in the system using nature-based solutions. Although the perception of the river might vary depending on individual standpoints regarding the Palmiet River, the shared common goal for healthy freshwater ecosystems drives the CoI to continue addressing challenges faced within the catchment. Greater law enforcement is needed particularly in the upper reaches to regulate pollution and decrease poor water quality on the river. Urbanization is a challenge which needs to be addressed through urban planning and Armitage *et al*. (2009) share an investigation of greywater solutions in informal settlements in Cape Town that could be applied to the case of the informal settlements of the Palmiet catchment in the interim to reduce negative impacts to the river. Examples of these greywater solutions could include soakaways, drum filter, and improved informal drainage system. Growing research on water sensitive design and sustainable drainage systems (SuDS) in Cape Town, South Africa offers a great platform on strategies to enhance ES and ecological infrastructure in cities. The Palmiet catchment could potentially be a great study site to explore SuDs.

CHAPTER 6: CONCLUSION

Rapid urbanization is a reality faced by many African cities in addition to increasing social challenges such as informal settlements, access to adequate water and sanitation services amongst many other socio-economic burdens. The assistance of strained government structures is often challenging considering political loyalties which further hinder the progression of catchment management. The Palmiet catchment provides an interestingly complex yet refreshing view of a collaborative social system involving interested and affected parties from various organizations and residents. This is a true reflection on the efforts required to effect change and create positive social and ecological impact. The information within the social system is a testament to the shared vision to achieving a rehabilitated Palmiet River and improved living conditions for all residents. This shared vision ultimately contributes to the goal to decrease risks to flood events and simultaneously increase resilience within this social-ecological system.

As stated earlier, accelerating urbanization in African cities directly and indirectly impacts the functions and processes of urban ecosystems, which inevitably compromise the ability of ecosystem services to sustain life and functions in urban areas as seen in the case of the Palmiet River catchment. The results of the study confirmed that urbanization caused a disruption to the natural land use/cover which inevitably had impacts on the ability of the Palmiet catchment to provide flood regulating ecosystem services to people (cf. Chapter 4.4). The growth of people in the catchment increased rapidlyin recent years resulting in poor water quality and eroding riverbanks. This resulted in increased risksto the social system, particularly to people residing near the Palmiet River. The various human activities occurring throughout the catchment present different challenges that are not easily addressed in isolation and therefore need a holistic approach. The CoI is a great agent of change in the Palmiet catchment, however, a shortage of human capacity within the municipality is an indicator of the foreseeable challenge facing the municipality: the formation of a CoI is unlikely for each catchment within the city. Therefore, a guideline of the successes and shortfalls of a CoI in catchment management strategies could be useful to address urban river health, with consideration to the possibilities of low-cost ecological infrastructure across the city through a widespread catchment management approach for the entire city. Furthermore, catchments differ in characteristics and people residing within a catchment - despite similar underlying social-ecological challenges. Therefore, approaches to river rehabilitation will differ and various catchment management strategies will need to be researched and applied on a case-to-case basis. Political structures were not included in the study, and therefore it needs to be noted that observed protocols and the delivery of water and

sanitation services are often linked to the political climate per election cycle. Service delivery amongst any social need is understandably prioritized above environmental needs and management in many governmental spaces of South Africa; however, the role of environmental catchment management is becoming more evident through cases such as in the Palmiet river catchment where the linkage between service delivery and environmental management is clearly shown and acknowledged. This is therefore strongly recommended to be strongly reflective and implemented in governmental priorities to sustainably develop the city to accommodate present and future generations. Population growth projections are expected to increase, and therefore the protection and management of ecosystem services will become pertinent to cater for this future growth especially considering worsening climate change impacts.

Physical data availability limited the study to a certain extent but the SES framework by Ostrom (2007) provided a foundation to build upon with existing data through framing knowledge using a non-traditional approach. The SES framework has not been widely used in South Africa as it is an integrative tool that requires a common language between various disciplines. The study of sustainability science in South Africa is still a growing body and has great potential to be applied on urban landscapes. The concentrated amount of information available for the informal settlement in comparison to the entire catchment reflects an SES where many gaps exist yet linkages in understanding a system can still be attempted. The Palmiet river catchment is a sub-system to a sub-system (uMngeni catchment) and one needs the 'bigger' system view to see the overall picture. For the purpose of this study the AoI's were delineated as sub-systems of the Palmiet river catchment to see if there is some intricate information that could add greater value to understanding the social-ecological systems within the catchment.

A finding of this study was that the application of the SESframework revealed that: the lack of rigidity of the framework allowed for methodological determinism which meant that designing an approach that fits the available data within the social andecological systems, which may not always be a true representation of the evolving systems. The social systems encompass behavioural and processes that are not always openly visible (such as cultural and power structures) and thus challenging to present or link to ecological condition. Therefore, social reality may be difficult to capture through research methodologies and can arguablynot sufficiently be depicted in the second-tier categories of the SES framework.

The aim of this study to understand how impacts of flooding determine the resilience of the Palmiet catchment through applying the SES framework revealed that: 1) Flood events are occurring more frequently, and more people are at risk as the influx of people within the catchment increases and the land use/cover changes respectively. 2) A collaborative and equally invested social system with a strong governance unit exists within the Palmiet catchment. This has facilitated conversation for the rehabilitation of the resource system which could thus potentially serve as a viable area for ecological infrastructure investment. 3) The social system has increased resilience within the catchment – however, this may change as flood events continue to increase in intensity and frequency. 4) The SES framework provided a tool to evaluate the social and ecological systems through which to assess the current limitations for the Palmiet river to regulate flood events; and 5) identify ways in which sustainable urban design systems and ecological infrastructure could be used as a part of catchment management strategies to rehabilitate and enhance ecosystem services.

In conclusion, the study achieved its aims and objectives. The findings of the study suggest further exploration into water sensitive urban design and sustainable urban drainage systems in cities to enhance ecosystem services. Moreover, working groups including various stakeholders in societies are the most beneficial and inclusive way to address the needs of people and the environment as proven through the CoI in the Palmiet catchment. It is also suggested that collaboration between government structures, researchers and residents be encouraged through these CoI. The conceptualization of tools to apply social-ecological systems should be interrogated further, especially considering the social systems that exist in African urban systems that are fueled with geo-political contexts that shape many urban catchments.

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APPENDIX A: ECOSYSTEM SERVICES

Appendix A details the classification of important ecosystem services in urban areas. The table below by Gómez-Baggethun and Barton (2013) provides examples of indicators for various example of ecosystem services. Restoring and rehabilitating ecosystems in urban areas is especially necessary with rapidly increasing urbanization and degrading urban rivers. The value of classifying and quantifying ecosystem services has largely been from an environmental standpoint but the benefits to improving the quality of life to people in cities is a value not easily quantifiable yet as important as the economic value.

Table A: Classification of important ecosystem services in urban areas (Gómez-Baggethun and Barton, 2013)

Classification of important ecosystem services in urban areas and underlying ecosystem functions and components.

Functions and components	*Ecosystem service*	*Examples*	*Examples of indicators/proxies*	*References*
Energy conversion into edible plants through photosynthesis	Food supply	Vegetables produced by urban allotments and peri-urban areas	Production of food (tons yr^{-1})	Altieri et al. (1999)
Percolation and regulation of runoff and river discharge	Water flow regulation and runoff mitigation	Soil and vegetation percolate water during heavy and/or prolonged precipitation events	Soil infiltration capacity; % sealed relative to permeable surface (ha)	Villarreal and Bengtsson (2005)
Photosynthesis, shading, and evapotranspiration	Urban temperature regulation	Trees and other urban vegetation provide shade, create humidity and block wind	Leaf Area Index; Temperature decrease by tree cover × m^2 of plot trees cover (°C)	Bolund and Hunhammar (1999)
Absorption of sound waves by vegetation and water	Noise reduction	Absorption of sound waves by vegetation barriers, specially thick vegetation	Leaf area (m^2) and distance to roads (m); noise reduction dB(A)/ vegetation unit (m)	Aylor (1972); Ishii (1994); Kragh (1981)
Filtering and fixation of gases and particulate matter	Air purification	Removal and fixation of pollutants by urban vegetation in leaves, stems and roots	O_3, SO_2, NO_2, CO, and PM_{10} µm removal (tons yr^{-1}) multiplied by tree cover (m^2)	Chaparro and Terradas (2009)
Physical barrier and absorption on kinetic energy	Moderation of environmental extremes	Storm, floods, and wave buffering by vegetation barriers; heat absorption during severe heat waves	Cover density of vegetation barriers separating built areas from the sea	Danielsen et al. (2005); Costanza et al. (2006b)
Removal or breakdown of xenic nutrients	Waste treatment	Effluent filtering and nutrient fixation by urban wetlands	P, K, Mg and Ca in $mgkg^{-1}$ compared to given soil/water quality standards	Vauramo and Setälä (2011)
Carbon sequestration and fixation in photosynthesis	Climate regulation	Carbon sequestration and storage by the biomass of urban shrubs and threes	CO_2 sequestration by trees (carbon multiplied by 3.67 to convert to CO_2)	Nowak (1994b); McPherson (1998)
Movement of floral gametes by biota	Pollination and seed dispersal	Urban ecosystem provide habitat for birds, insects, and pollinators	Species diversity and abundance of birds and bumble bees	Andersson et al. (2007)
Ecosystems with recreational and educational values	Recreation and cognitive development	Urban parks provide multiple opportunities for recreation, meditation, and pedagogy	Surface of green public spaces (ha)/inhabitant (or every 1000 inhabitants)	Chiesura (2004)
Habitat provision for animal species	Animal sighting	Urban green space provide habitat for birds and other animals people like watching	Abundance of birds, butterflies and other animals valued for their aesthetic attributes	Blair (1996); Blair and Launer (1997)

Note: The suitability of indicators for biophysical measurement is scale dependent. Most indicators and proxies provided here correspond to assessment at the plot level.
Source: Own elaboration based on literature review.

APPENDIX B: SOCIAL-ECOLOGICAL SYSTEM FRAMEWORK

Appendix B illustrates the second-tier variables of a social-ecological system adapted from Ostrom (2009). The second-tier variables consist of many variables which aid the understanding of first tier variables and therefore the development of a SES. The selection of second tier variables should be based on the aim of the study in order to understand the interaction of first tier variables leading to the current outcomes of a system.

Table 1. Second-tier variables of a social-ecological system. Source: Adapted from Ostrom (2009:421).

First-tier variable	Second-tier variables
Social, economic, and political settings (S)	S1 – Economic development
	S2 – Demographic trends
	S3 – Political stability
	S4 – Other governance systems
	S5 – Markets
	S6 – Media organizations
	S7 – Technology
Resource systems (RS)	RS1 – Sector (e.g., water, forests, pasture, fish)
	RS2 – Clarity of system boundaries
	RS3 – Size of resource system
	RS4 – Human-constructed facilities
	RS5 – Productivity of system
	RS6 – Equilibrium properties
	RS7 – Predictability of system dynamics
	RS8 – Storage characteristics
	RS9 – Location
Governance systems (GS)	GS1 – Government organizations
	GS2 – Nongovernment organizations
	GS3 – Network structure
	GS4 – Property-rights systems
	GS5 – Operational-choice rules
	GS6 – Collective-choice rules
	GS7 – Constitutional-choice rules
	GS8 – Monitoring and sanctioning rules
Resource units (RU)	RU1 – Resource unit mobility
	RU2 – Growth or replacement rate
	RU3 – Interaction among resource units
	RU4 – Economic value
	RU5 – Number of units
	RU6 – Distinctive characteristics
	RU7 – Spatial and temporal distribution
Actors (A)	A1 – Number of relevant actors
	A2 – Socioeconomic attributes
	A3 – History or past experiences
	A4 – Location
	A5 – Leadership/entrepreneurship
	A6 – Norms (trust-reciprocity)/social capital
	A7 – Knowledge of SES/mental models
	A8 – Importance of resource (dependence)
	A9 – Technologies available
Action situations: Interactions (I) → Outcomes (O)	I1 – Harvesting
	I2 – Information sharing
	I3 – Deliberation processes
	I4 – Conflicts
	I5 – Investment activities
	I6 – Lobbying activities
	I7 – Self-organizing activities
	I8 – Networking activities
	I9 – Monitoring activities
	I10 – Evaluative activities
	O1 – Social performance measures (e.g., efficiency, equity, accountability, sustainability)
	O2 – Ecological performance measures (e.g., overharvested, resilience, biodiversity, sustainability)
	O3 – Externalities to other SESs
Related ecosystems (ECO)	ECO1 – Climate patterns
	ECO2 – Pollution patterns
	ECO3 – Flows into and out of focal SES

APPENDIX C: PALMIET REHABILITATION ACTION PLAN

Appendix C shows images of the excel files that were developed and formed the action plan used bythe CoI. This action plan was comprised of three sections: social, governance and biophysical.

Table B: Action plan formulated by the CoI in 2018

Governance Approach					
G1	**Achieving an integrated approach to catchment management through the development of a governance model for the Palmiet Rehabilitation Project:**				***Mission Critical***
G1a	Develop a Community of Innovators (COI).	BEDS, PRW, CPB, QRW	The CoI focus should be on increasing its effectiveness. Connecting the CoI with municipal and other missing actors should strengthen its effectiveness. This will be ongoing as CPB will keep on engaging with different municipal line functions	ONGOING	
G1b	Develop, adopt and review an appropriate governance model.	CoI	The proposed governance model was adopted during a meeting on 25 May 2016. Critical areas that require urgent attention were also identified.	COMPLETE	
G1c	Development of Memoranda of Understanding between stakeholder groups.	CoI	At the first meeting of the CoI on 25 May 2016, it was agreed that there is no need for a collective MoU. Where projects require a formal contract, this will be addressed.	COMPLETE	
G1d	Develop an implementation plan with time frames and an evaluation of progress •Include EM line functions •Develop list of	CoI	An Action Plan has been finalised and its been updated quarterly based on the activities, but it needs time frames where there are commitments to action, and the gaps need to be filled. The CoI have agreed to prioritse the development of this action plan. The progress report is compiled and disseminated once a year (every September), the latest was done September 2017.	To be done Q3 2018	

	projects, aims, timelines, actors, budget				
G1e	Attracting new critical stakeholders	CoI	Initially eThekwini Conservancy Forum was identified as project implementers in the Palmiet using the TBOR approach. It has been identified that the involvement from the private sector is missing in the action plan. The C40 Sihlanzimvelo water stewardship approach will be used to attract & work in collaborating with the private sector in the quest to develop a community based initiative to clean rivers and remove alien invasive species amongst other benefits. The Palmiet River Watch formed a conservancy, which could attract new stakeholders.	Sihlanzi CFF initiation workshop in Aug 18	
G2	**Attracting missing stakeholder groups to the project:**				***Medium***
G2a	Business/ industry:	BEDS	Little success has been achieved here. The IIPSA project should be used to leverage support in Pinetown.	This will be addressed once the IIPSA is implemented	
G2b	Political leadership and develop political support:	CPB, Councillors, TBOR	CPB has presented the Aller and Palmiet River projects to the Municipality's ECOD committee. Political leadership's suppport has been given. ZK to circulate concept notes with CoI members before presenting to the next TTT with SB at the end of April. SB met with the Ward 23 councillor and plan to meet with other councillors within Palmiet catchment	ZK have circulated concept notes for Ethekwini Water and Sanitation to SB. The meeting was held between SB and representatives from EWS for their participation in COI when necessary.	
G2c	Ward Committees (wards 18, 21, 23, 24, 92):	TBOR, Ward Councillors	No progress has been made here.	Ward Committee meetings will be organised as part of IIPSA project, this likely to be around August 2018	
G2d	Constituency Officers:	Chris Laubscher, Councillors	No progress has been made here.	No target set	
G2e	Private property owners:	TBOR, Palmiet stakeholders	Outreach by PRW has attracted some property owners, but more need to be made aware of the project.	ONGOING	

G2f	Schools and educational facilities (prioritise)	WESSA, TBOR	Cathy has worked with St Mary's at the top of the catchment. As yet, no further progress has been made. Potentially, the IIPSA project could provide a platform.	Part of the IIPSA project is to identify sites for Mini SASSI, that can be used to attract more schools	
G2g	Further environmental agencies e.g. Birdwatch	CPB, DRAP, UKZN, PRW, TBOR	Some notable successes have been achieved here (crowned eagle and maintenance of the Umbilo pipeline, snake monitors in QRW, securing funding through the UEIP.	ONGOING	
G2h	EThekwini line function management	CPB, TBOR, UKZN	Some success has been achieved e.g. Richard Winn participating in the PRP project. Concept notes have been drafted to approach line functions, but it was agreed that we should do this approach through TBOR. Mam Joyce shared details of the meeting with a DSW representative (Nelson) highlighting that 4 community representatives were selected to distribute refuse bags to QRW residents. SB will continue engaging other municipal line functions. A meeting with Human Settlements in being planned.	SB will set meeting with Human Settlement before the end of June 2018, and invite them to participate in some COI meetings when necessary	
G2i	Provincial and National Department officials	CPB	No progress has been made here. SB to ask ZK about presenting the PRP in Central KZN Climate Change to get Provincial interest	SB will engage with ZK about the possibility of presenting PRP in the next CKZNCC meeting before the end of this year.	
G2j	Banana City and other informal settlement committees	Councillor: Ward 23	CS has started working with the Banana City informal settlement, and once IIPSA is implemented more settlements will be reached.	Jan-19	
G2k	South African Police Services	Sergeant Clark	No progress has been made here.	No target set	
G2l	Media	Highway Mail	A number of newspaper articles have been published about the Palmiet (ZK)	Highwall Mail published article on Palmiet Catchment issues, this was organised by Palmiet River watch (June 2016). SOD published an article in the Municipal magazine	
G2m	others		No progress has been made here		

G3	**Improving communication:**				***Medium***
G3a	Develop an improved method of communicating that is effective, simple and not onerous.	WC, UC, Ward Committees, Community leaders, COI	Currently the group communicate to broader stakeholders through email and annual meetings. The CoI communicate through email and Whatsapp. The early warning system is Whatsapp. PRW and BEDS have had a number of articles published in the local press. SOD has published in the Municipal magazine.	SB will investigate the possibility of writing an article and publish it in Municipality paper (Metro Ezasegagasini) newspaper by end of 2018.	
G3b	Develop a mechanism for catchment stakeholders to communicate with the COI - an interactive website and social platform tools could be considered.	CoI	Currently communication is through email.	Email communication is being effective, as it reaches most of the COI members	
G3c	Develop a mechanism for catchment stakeholders to communicate with other stakeholders - use social platforms for reporting environmental crime (e.g. Ecin2Edin)	Palmiet stakeholdrs, PRW	This is currently not being addressed.	No target set	
G4	**Using education and incentives to drive behaviour change:**				***Medium***
G4a	Review existing educational resources, build on and enhance existing education programmes and develop innovative learning opportunities.	COI, ECF, WC, UC, WESSA, CPB, EWS, TBOR	BEDS have worked with St Mary's to implement a stream monitoring programme using Mini SASS. Professor Chris Buckley had an MSc student map the catchment's infrastructure.	SB needs to communicate with Prof Buckley to assess research outputs of this MSc and present it during the COI meeting in December 2018	

G4b	b) Develop an integrated approach to environmental education by relevant line functions in EM.	DSW, DGC, NGOs, EHU, BEDS, TBOR	The TBOR team has already approached a number of municipal line functions to propose collaboration.	ONGOING	
G5	**Addressing inappropriate development, land use management and illegal activities within the catchment:**				***Mission Critical***
G5a	Review status quo of development within the catchment in terms of hardened surfaces and contribution to catchment degradation	SN	At the first meeting of the CoI on 25 May 2016, it was proposed that the status quos should include the DMOSS layer and hardened surface maps, water quality and vegetation assessment. SN has mapped some of the municipal GIS data provided by the CPB to compile an inventory of the impacts observed in the Palmiet Catchment. SN also worked very closely with LD conducting visual observations, walking along the Kingfisher Catchment, Industrial area, Methven Road pump station to Palmiet Nature Reserve and sections around the Wyebank dumpsite.		
G5b	Review key remedial by-laws and legislation.	CPB, BEDS	EThekwini Municipality recently underwent through the process of revising its D'MOSS layer. The process is led by the Biodiversity Planning Branch. Removals of areas within the Aller and Palmiet river catchments were proposed. Six sites were amended to re-instate D'MOSS. The remaining areas have been removed as they have been transformed with loss of biodiversity and ecosystem services. The reviewed DMOSS has been approved by Council.		
G5c	Review of informal settlements in catchment: extent, challenges and potential solutions	CPB, BEDS, TBOR	This has not been done for the entire catchment. Only Quarry Road Informal Settlement has been profiled through CS Mapping project	Palmiet has been identified as a study site for EPIC A implementation, maybe one or two students can look into reviewing the informal settlements (June 2019)	
G6	**Funding challenges:**				***Medium***

G6a	Pursue climate change adaptation funding.	TBOR, CPB, BEDS	i) GCF proposal: EPCPD have developed a Green Climate Fund proposal that seeks to address the issue of informal settlements and landscape planning of natural infrastructure to reduce vulnerability. EPCPD are waiting for SANBI to advertise for concept notes. ii) C40 will work with EPCPD to develop a project proposal to the Flanders Government for an inclusive reslience programme directed towards informal settlement communities and unions. iii) C40 Cities Finance Faciity: This has been approved and an initiation workshop is planned for Aug 2018.	Results of funding applications will be presented during the September COI meeting	
G6b	Other sources of revenue should be investigated.	BEDS, ECF, PRW, CPB	As a contractual clause of the City's investment in the Western Aqueduct system, through the Infrastructure Investement Programme SA, a sum of R5 million has been set aside for investment in ecological infrastructure. The UEIP and DBSA has agreed that this should be used within the Palmiet Catchment. A full tender process is being pursued. The tender advertisement should be out during May/ June 2018	IIPSA likely to commence or implemented end of August 2018	
G6c	Potential for PPP should be investigated.	CoI	No progress has been made here.	No target set	
G6d	Responsible management and use of public funds	CPB	CPB will manage the TBOR project with transparent reporting to its committee. An independent audit will be done on the project upon completion.	This depends on the IIPSA project implementation	
G7	**Develop an understanding of the hydrological and social risks and challenges in the catchment:**				***Mission Critical***
G7a i	Develop a formal, applied science programme: Invite relevant researchers to participate	BEDS, CPB	Formal research from different disciplines is conducted by the UKZN within the catchment. This includes Chris Buckley's Pollution Research Group, and two PhDs (Bahle Mazeka and Patrick Martel). Some research topics will be done through Educational Partnership for Innovation in Communities (EPIC). EPIC will be initiated second semester by working with University of KwaZulu Natal.	EPIC A will be implemented in August 2018 through UKZN.	
G7a ii	Develop a GIS-based geo-database of the Palmiet	BEDS, CPB	Currently there is no database that has been developed for Palmiet,	No target set	

	Rehabilitation Project.				
G7a iii	Review successful global case studies to apply within the catchment		A PRP manuscript is being prepared for submission to a peer-review journal for publication. ZK and CS presented on the Palmiet at an international conference in Norway, and SOD presented at the International Water Assocation conference in October. A session on the Palmiet has been accepted for the IAIA 2018 conference in May 2018.	SB presented Palmiet work in PE Seedbeds conference: The role of Science with Society in achieving the SDG (May 2018). Presentations during the IAIA conference in May 2018.	
G7a iv	Investigate and prioritise research needs in the catchment		EPIC	Aug-18	
G7a v	Provide guidance on solutions within the catchment		EPIC	Aug-18	
G7b i	Develop an informal applied science programme: Coordinate and enhance existing citizen science programme	ECF, BEDS	The Household Mapping Project by BEDS within QRW is addressing this action plan item. These community members have also actively participated and provided input into the Durban's Resilience Strategy.	The Household Mapping Project by BEDS within QRW is done, plans are underway to engage with the Human Settlements on how to use this data (June 2018)	
G7b ii	Encourage catchment stakeholders to participate in catchment research.		The BEDS team has funded and conducted three community workshops in relation to river health and the importance of protecting their surrounding environment as well as the risks associated with the failing ecosystem. PRW organised a learning exchange workshop between the Palmiet, Aller river and Wize Ways Water Care projects.		

Biophysical Approach					
Act #					
B1	**Enhance service delivery in the catchment:**				***Medium***

B1a i	Engage with: Municipal line functions to understand and find solutions to service delivery challenges in the catchment.	CoI, TBOR	SB is engaging with Durban Solid Waste, Water and Sanitation, and Human Settlements to attract them to participate in COI. SB have already secured meetings with these line function to discuss the involvement or what would be their role in Palmiet project	Jun-18	
B1a ii	Communities to understand their service delivery challenges in the catchment.	BEDS, TBOR	The BEDS Team has been working closely with the Quarry Road informal settlement community with some notable successes described in the Project Progress Report (Sep 2017). This is empowering community members to engage with formal municipal process, which is facilitating service delivery. These community members have also actively participated and provided input into the Durban's Resilience Strategy. BEDS team have started working with other informal settlements within Palmiet catchment, i.e. Banana City	ONGOING	
B1 b	Enhance ability of municipality to implement service delivery through capacity building and developing partnerships.	CoI, TBOR	This has been achieved through the BEDS work in QRW.	DONE	
B1c	c) Strengthen conservation and tourism-based activities in the catchment.	PRW	This has not been addressed yet.	No target set	
B1 d	d) Develop WSUD and SuDS solutions for the catchment		No consideration has been given to this yet.	No target set	

B2	**Loss of potable reticulated water:**				***Medium***
B2a	Analysis of infrastructure	CPB, UKZN, PRW	A catchment walk was completed by a PRW student and the infrastructure has been mapped. SB needs to do a follow up to get the data if there was any data collection so it can be used in other projects.	Jul-18	
B2 b	Community reporting responsibility	CPB, UKZN, TBOR	Some success has been achieved with the QRW community reporting challenges.	ONGOING	
B2c	Enhance political leadership to reduce theft	CPB, TBOR	Following the change of political leadership during the last local government elections, the relationship with local councillors suffered. This is now being addressed through higher level support. SB needs to engage with the elected councillors within the area to get their buy in and they can also participate in COI meetings when required.	Aug-18	
B3	**Solid waste:**				***Medium***
B3a i	Develop a waste collection programme: Within Quarry Road informal settlements (immediate)	i)BEDS, DSW, QRW	a) The UKZN Research Team engaged the Wildlands Conservation Trust to initiate a recycling program to help address the waste management challenge, and provide participating community members with some income. A recycling pilot project was initiated on 23rd September 2016. Ten women from the community are employed within the recycling project.	The Wildlands Conservation Trust came to an end but there are initiative planned for waste collections within QRW	
B3a ii	General: throughout catchment		Waste management is huge challenge for Quarry Road (QRW) settlements and their surroundings. Waste that attracts rats is believed to be the root cause of the high number of snakes. Through the litter programme, Mr Nick Evans has removed a number of venomous snakes, and a snake monitoring programme was initiated. The community now understands solid waste attracts rates and snakes, so has put up signs to prevent illegal dumping at the settlement.	DONE	

B3 b	Deploy litter traps.		Removal of solid waste in QRW by the municipality commenced at the beginning of February 2017. A commitment from the Durban Solid Waste Unit (DSW) and the community is an essential component to ensure that waste collection is implemented efficiently in an area like the informal settlement. SB engaged with DSW to revatalise waste collection, this is still in the initial stage and difficult to access whether its working or not.	Meeting with DSW discussed how waste will be collcted from QRW, four community representatives selected to distribute waste plastic bags. DONE	
B3c	Better integration of litter collection and effective enforcement		The CoI has also proposed the "Sihlanzimvelo" stream cleaning model as a suitable programme for QRW community.	Aug-18	
B4	**Industrial Pollution:**				***Medium***
B4a	Improve efficacy of Identifying and educating polluters.	EWS	eThekwini Water & Sanitation (EWS), Pollution and Environmental Branch (PEB) samples licensed companies to issue compliance certificates as part of their operational services. The technicians work closely with the water quality officers. They support industries to apply for trade effluent permits. Despite this, numerous reports of pollution are made by PRW. This indicates that the current monitoring regime is not effective enough. BEDS have a researcher reaching out to industry in Pinetown.	SB needs to invite someone from EWS Pollution and Environment Branch in one of the COI meeting so they can engage with COI members and come up with potential solutions. July 2018. Dr. Cathy Sutherland's student can come and	

				present the findings of the project during the COI meeting	
B4 b	Reporting industrial pollution through improved communication s mechanism.	PRW, TBOR	PRW monitors and reports water pollution on regular basis. (awaiting full report from LD)	ONGOING	
B4c	Enforcement	EWS	PEB attends to pollution incidents by tracing pollution to determine the source of pollution. They serve notices and fines to the perpetrators. EWS also continuously ensure that companies are permitted and compliant in accordance with the eThekwini Sewage Disposal Bylaws	ONGOING	
B5	**Wastewater Pollution:**				***Medium***
B5a	Analysis of Municipal wastewater (sanitation) systems and repair.	EWS, UKZN	The findings from the PRG river walk should be used to investiage this through EPIC.		
B5 b	Reporting on status of sewer system and proactive maintenance programme	EWS	The programme has had some productive engagement with EWS (e.g. crowned eagle maintenance event), but nothing formal is established.	No target set	
B5c	Improved call centre training to prioritise	EWS	Again, this has not been addressed yet.	No target set	

	calls (Municipal, Private Business)				
B6	**River course erosion:**				***Medium***
B6a i	Implement soft engineering solutions identified in G7v: Alien species removal and rehabilitation	EPCPD, TBOR	The project is still at an early stage of developing working partnership with various stakeholders and identifying the main challenges within the catchment. The outcome of all the studies conducted within the Palmiet will provide guidance and solutions to be applied to address these challenges. Suitable rehabilitation solutions will therefore be implemented. The implementation of TBOR will start this process.	No target set	
B6a ii	Wetland restoration	TBOR, CSCM, CPB	The CoI has identified a number of strategic interventions that it considers critical to address the challenges in the catchment and ecological infrastructure, Water Sensitive Urban Design and Sustainable Urban Drainage Solutions approaches have been highlighted as key solutions.	No target set	
B6 b	Review and address malfunctioning natural infrastructure	EPCPD, UKZN, TBOR	A study needs to be conducted in the catchment to identify areas of biodiversity importance, and in terms of providing climate protection as part of the catchment analysis. This can be done by one or two students as part of the EPIC	No target set	
B6c	Monitor performance of soft engineering solutions	CSCM, UKZN	this will only be addressed once projects have been conceived and a baseline assessment is started.	No target set	
B7	**Habitat and Biodiversity Loss:**				***Medium***
B7a	Conduct an assessment of the state of ecosystems within the catchment.	EPCPD, UKZN, TBOR	SN and LD are conducting visual observations, walking along the river to assess the status quo of the catchment. A draft with partial results from SN in place .	Aug-18	
B7 b	Develop an action plan to rehabilitate critical	EPCPD, CFF	This will be addressed after the catchment analysis.	No target set	

	biodiversity systems.				
B8	**Health risks:**				***Immediate***
B8a	Conduct a health risk assessment within the catchment	UKZN	This will partly be addressed by the QRW mapping exercise, but a substantially bigger response is required.	DONE through the Household Mapping Project by BEDS with QRW	
B8 b	Understand the cause of the pest problem to determine a solution	UKZN, DSW, TBOR	Rats have been identified as one of the major pest infestations resulting from the accumulation of waste and illegal dumping within the QRW settlement and surrounds. Various invasive alien plants have been observed within the catchment and are competing with the indigenous vegetation. The loss of ecological infrastructure may have exacerbated the extreme flooding events experienced by the QRW community in 2016 and 2017.	ONGOING	
B9	**Enforcement:**				***Medium***
B9a i	Engage with enforcement organisations to address illegal activities including: Enforcement of EIAs and land use planning-related by-laws and sewerage disposal by-laws	EPCPD, SAPS, PRW, PEB, TBOR	The Biodiversity Impact assessment and Municipal Compliance Branch continuously Enforcement of EIAs and land use planning as and when required. PEB serves notices and fines to the polluters. EWS also continuously ensure that companies are permitted and compliant in accordance with the eThekwini Sewage Disposal Bylaws	No target set	
B9a ii	Crime and violence, include	SAPS, TBOR	No progress to report here.	No target set	

	vandalism of municipal infrastructure				
B9a iii	Illegal discharge into Palmiet River	PEB, PRW	PEB continuously monitors illegal discharge by sampling rivers at various points to identify pollution, sewer blockages or overflows. PRW also reports visible events.	ONGOING	

Social Approach					
S1	**Address the high rate of unemployment in Quarry Road West through the establishment of EPWP-type initiatives:**				**Immediate**
S1a	Waste clean-up project in Quarry Road informal settlement.	a) BEDS, DSW, WCT, CPB, QRW, TBOR, CFF	The UKZN Research Team engaged the Wildlands Conservation Trust to initiate a recycling program to help address the waste management challenge, and provide ten participating community members (women) with some income.	DONE in 2016/17 Financial year	
S1b	ECF "Take Back our Rivers" Programme	ECF, CPB, CoI	EThekwini Municipality has secured R5 million for investment in ecological infrastructure. This will be directed into the TBOR programme, which will be called IIPSA, and currently CPB is in the procurement process and the advertisment is likely to be in May/ June 2018 with the appointment of service provider expected to be done before the end of this calendar year.	The project will likely to be implemented August 2018 with the advertisment of the project likely to be finalised mid July 2018	
S1c	Options in Banana City and the other informal settlements	TBOR, BEDS	The CoI acknowledges the need to incorporate the other surrounding informal settlements into the project. in the meantime, QRW informal settlement has been identified for piloting community based work towards river health and pollution reduction through the TBOR approach.UKZN, through BEDS have started working in Banana City.	Dec-18	
S2	**Social facilities:**				**Medium**

S2a	Develop a crèche in Quarry Road informal settlement	BEDS, QRW	A need to develop a crèche for QRW community has been raised in various community engagements. The community has identified a vacant land that may be suitable for constructing a crèche, and there are potential sources of help, but because QRW is considered non-permanent, no municipal spend can be directed towards this action plan. This is likely not to be achieved since informal settlements are not considered as permanent.	No target set and this will likely to be removed from the Action Plan	
S2b	Develop a pedestrian bridge for the safety of children in Quarry Road informal settlement	UKZN, CPB, CSCM, ETA	The CoI engaged with the community to identify the a suitable area where the proposed for the construction of the pedestrian bridge should be constructed. It was discovered that the construction of the proposed bridge was intended to provide easy access to the adjacent section of the informal settlement, which is separated by the river. During the data collection and risk analysis from the "Mapping Project" based on community participation concluded that the contraction of the bridge would be the least of the community priority needs. This will likely not to be achieved and maybe it needs to be taken out from the Action Plan.	No target set and this will likely to be removed from the Action Plan	
S3	**Decrease level of risk in informal settlements (focus on Quarry Road West):**				***Medium***
S3a	Alternative housing solutions for residents	BEDS, QRW, CSCM	One QRW resident's household structure is at high risk of flooding due to a collapsed river bank. The ward council has been engaged to seek permission for the relocation of the family structure to a low risk area within the settlement. The Khumalo family has been allocated a site away from the river. The project has identified an opportunity to work with other stakeholders to design and build a structure that would be a home whilst being resilient to extreme events, including flooding and heat using building material currently available to QRW residents. The Household Mapping Project led by UKZN is aimed to establish a detailed household database and develop a community based map. The committee played a major role in identifying critical attribute data that should be considered for collection. Data has been collected in 931 households. During exercises various risks and hazards were identified. UKZN analysis is yet to be	Meeting between UKZN researchers, QRW residents and EM Human Settlements to discuss results of the Mapping project and seek way forward. The meeting will be organised before end of June 2018	

			finalised and map by the UKZN team.The community has also been affected by numerous fires incidents.		
S3b	Set-backs from river to decrease flooding risk	CSCM, Enforcement	Set-back lines based upon modeling of climate change-affected storm designs is completed. Enforcement is needed to ensure community members do not settle in dangerous areas.	ONGOING	
S3c	Legal electricity supply to community – community / public participation process	EM	The municipality has commenced with the roll out of phased electrification at the Quarry Road West informal settlement. This can only be done for those part of the settlement that are planned as permanent.	ONGOING	
S3d	Establish an early warning system to alert QRW residents of flood risk.	CSCM, BEDS, PRW	The QRW settlement falls within 1:50 year flood and the community is exposed to a flash floods risk. The CoI has established a communication platform, using social media and cell phones to circulate early warning messages. It serves to warn them of possible extreme weather events so that they take necessary precaution measures.	ONGOING	
S4	**Develop partnerships, social learning opportunities and the building of new identities to enhance social capital in the catchment.**				**Medium**
S4a	Establish a snake monitoring programme	BEDS, QRW	After the snake capture it was realised that there's need for community awareness on snakes with the settlement communities. Ten young snake monitors were nominated from the community. The UKZN organised and funded a snake awareness workshop for the community.	DONE in 2016/17 Financial year	
S4b	Pursue support from business through Corporate Social Responsibility initiatives	TBOR, CFF	Pinetown Chamber of Commerce was identified as one of the critical stakeholders, but no support has been received as yet.	No target set	

The screenshots below depict a report of the PRP that was produced during internship with the CPD at Ethewini Municipality.

UMNGENI ECOLOGICAL INFRASTRUCTURE PARTNERSHIP (UIEP):

Progress on the Implementation of Palmiet Rehabilitation Pilot Project

Report produced by: Ms Zama Khuzwayo and Londiwe Dlamini

5th September 2017

1. BACKGROUND

1.1. UIEP

The uMngeni Ecological Infrastructure Partnership (UEIP) is a diverse group of organisations from government, business, academia, and civil society who are committed to finding ways of better integrating ecological infrastructure solutions into water resource management; through collective participation and coordination of activities in the greater uMngeni River catchment. The primary focus of the UEIP is on exploring the role ecological infrastructure can play in improving water security in the catchment.

Three pilot projects are being implemented as proof-of-concept projects under the UEIP. They are the Save the Midmar Dam, Palmiet River Rehabilitation (PRR) and Baynespruit Rehabilitation projects. The Climate Protection Branch in eThekwini Municipality oversees implementation of the PRR Project. This is a progress report for the Palmiet Pilot Project of the UEIP. Actions described within this report are aligned with the PRRP action plan, developed by the broader project stakeholder group.

1.2. Palmiet River Rehabilitation.

The PRRP is an innovative shared-governance approach to catchment-scale ecological infrastructure management with a climate change adaptation focus. The project primarily focuses on conservation, rehabilitation & restoration of natural systems within the Palmiet Catchment to improve community resilience.

The main problems within the catchment are pollution and habitat transformation, which have caused health and flooding issues, and caused the loss of biodiversity. For example, the Palmiet (*Prionium serratum*) after which the river is named, has disappeared. This plant is found only in South Africa (i.e. it is endemic) and is sensitive to changes in water quality, and therefore a good indicator species of water quality problems. Sources of contamination include regular industrial chemical discharge, surcharging manholes, waste from informal settlements and residential suburbs.

Informal settlements built in wetland areas and along the banks of rivers, such as the Palmiet have adverse impacts on the system. The constant flushing of various waste materials directly into water sources has resulted in a deterioration of water quality. Equally, the informal settlements have been negatively impacted by flooding events resulting in fatalities and damage to property.

Another challenge is the increased illegal dumping by non-informal settlement residents, illegal gill netting and sand mining along rivers. Storm water management system failures exacerbate the degree and the frequency of river pollution events. Invasive alien species proliferation compounds the main problems, particular shallow-rooted species that do not stabilise river banks and block drainage systems.

The preliminary implementation stages of the project proved to be difficult because of the fraught relationship between the municipality and the communities surrounding the areas that were earmarked for wetland reconstruction (adjacent to informal settlements near the confluence of the Palmiet and the uMngeni rivers). The retirement of the initial project champion, then Head: EWS, Mr Neil Macleod was also a setback because project funding was not secured at that time.

In a parallel but related process, researchers from the University of KwaZulu-Natal's (UKZN) School of Built Environment and Development Studies were working on a community research project, and had established a close working relationship with the Quarry Road informal settlement leadership. Following the retirement of the Head: EWS, the CPB took over responsibility for the Palmiet Rehabilitation Project and initiated a process to bring a wide range of catchment stakeholders into a catchment management planning process with UKZN. The process presented an opportunity to establish multi-sectoral collaborations to mobilise resources through a shared governance approach and the development of the project concept note.

The communities within the Palmiet River Catchment, including those of the vulnerable Quarry Road West informal settlements became project stakeholders. This arrangement encouraged community engagement and raised awareness on different communities' experiences with the conditions of the catchment. A formal committee consisting of community leaders that provide support to the ward councillor and help disseminate information to the community, is used as a vehicle to the create awareness and bring the project closer to the informal settlement residents. This collaborative approach brought existing catchment champions like the Palmiet River Watch and municipal line functions into a shared governance framework that opened communication channels to collate existing data, prioritised actions and helped avoid duplication of effort.

Following the stakeholder engagement process and the development of a concept note, prioritised action items to address challenges within a project action plan were developed and endorsed. The action plan identified project actors, and roles and responsibilities for the proposed solutions to catchment issues. The identified issues are spread across three broad themes: governance, social and biophysical approaches.

1.2.1. Aims and Objectives

The project aims to address multiple challenges within the catchment to improve governance processes along with physico-chemical, ecological and socio-economic conditions within the Palmiet Catchment with following objectives:

- Construction of artificial wetlands. Strategic positions along the Palmiet River were required to be identified to construct artificial wetlands aimed at restoring watershed services along the river. The artificial wetlands will emulate the features of natural wetlands and act as bio-filters, removing or trapping sediments and pollutants before entering the uMngeni River system.
- Extensive clean-up of the Palmiet River to remove solid waste and debris before construction of the artificial wetlands.

- Removal of alien plants and re-vegetation of the Palmiet River banks with indigenous plants to stabilise the riparian zones.
- To address human behaviour. Conduct awareness campaigns and develop educational materials on illegal dumping to the communities living along the river banks.
- To monitor, and reduce water pollution and its impact of the river.

2. PROJECT IMPLEMENTATION AND PROGRESS

Through the project stakeholder participation process, and prioritised list of actions were developed and multiple stakeholders have committed towards the implementation of the actions. Through these commitments a number of milestones have been achieved and positive outcomes have been recorded. This section of the report provides an outline of progress that has been made in implementing the project action plan within its three themes: governance, biophysical and social.

2.1. Governance Approach

The shared governance approach seeks to achieve an integrated response to catchment management through the development of a Community of Innovation (CoI) as prescribed by the action. The CoI effectively forms a working group of core actors in the Project. The CoI convenes quarterly to monitor the progress and outcome of the stakeholder activities towards the implementation of the project action plan. These meetings are also used as the platform to collate and relay information to the informal settlement community via their representatives in the CoI. The CoI is represented by:

- The Climate Protection Branch (CPB) of eThekwini Municipality, who acts as Secretariat producing minutes and manages the Take Back Our Rivers project in the catchment.
- The Pollution and Environment Branch of eThekwini Municipality's EWS, which engages with the project in the monitoring of environmental pollution around the catchment.
- The University of KwaZulu-Natal, School of Development Studies, who have engaged closely with the QRW informal settlement community and conducted research.
- Palmiet River Watch (PRW), an non-profit organisation that monitors pollution along the River. The NGO also plays a role in stakeholder's mobilisation to create awareness and promote integrated approach to a healthy river.
- Quarry Road West informal settlement community representative committee. These community representatives provide the project with a direct link to engage with, identify and understand challenges within these communities. Their involvement in the project enables an open channel of communication and working relationship with the municipality which was not possible previously.
- EThekwini Conservancies Forum, a river network and supporting non-profit organisation that provide insight on "Take Back our Rivers" program implementation. The "Take Back our River" model has been identified as a possible approach that is relevant to the Palmiet River

Rehabilitation Project. The Forum, engages with the project to share their best practices, which can be replicated in Palmiet Rehabilitation Project.

The project has also created awareness and support through stakeholder engagement processes. The process will be used to strengthen cooperation between municipal line functions, leveraging the Durban Research Action Partnership to secure more sustainable practices in the municipality's infrastructure maintenance program. It has begun to open a channel of communication to guide municipal line functions on biodiversity and conservation practices. This mutual cooperation between the Palmiet stakeholders and municipal line functions facilitated the delay of scheduled maintenance on municipal EWS infrastructure upon which crowned eagles (*Stephanoaetus coronatus*) were nesting. The maintenance was delayed to avoiding disturbing these birds (which could have resulted in them abandoning the egg) until the chick fledged. Improved governance has had a positive impact on biodiversity protection through line function awareness and sensitivity around wildlife issues whilst engaging with daily work activities.

Relationships with communities have been continuously fostered to guide them on how to engage with municipal operational processes. Quarry Road community members are provided with support to correctly channel their service delivery related matters, and progress in resolving these matters is monitored. The UKZN team has funded and conducted three community workshops in relation to river health and the importance of protecting their surrounding environment as well as the risks associated with the failing ecosystem. During one of the workshops that was convened on the 9th February 2017, the community members, through the committee expressed their gratitude for some of the observed positive initiatives brought by the project.

The Household Mapping Project by UKZN has brought capacity building and some income to 21 map makers. The project was aimed to establish a detailed household database and develop a community based map. The committee played a major role in identifying critical attribute data that should be considered for collection. The "map makers" were exposed to four training sessions on data collection as well as the use of the GPS coordinate units, amongst other elements and other research ethics requirements. Following data collection activities in 931 households, the mappers were trained to capture data on excel. In addition to training, the mappers received several stipends. They have since realised the value of their input, by participation in shaping the project. These community members have also actively participated and provided input into the Durban's Resilience Strategy.

Through project implementation, it is hoped that collaborative efforts will realise an improvement in conditions within the Palmiet Catchment. The project has fulfilled one of the key objectives of the action plan (Governance Approach) by achieving an integrated approach to catchment management through the development of a governance model for the project. However, the project needs to work harder to attract the private sector and other municipal line functions to commit action to support the project.

2.2. Biophysical Approach

This approach assesses the ecological and physical health of the system. Solid waste, industrial, domestic and waste water pollution, the proliferation of alien invasive species, inappropriate formal and informal development and hydrological changes are some of the major challenges within the catchment. The distribution and the severity of catchment challenges still needs to be established. This section seeks to understand the root causes, the contributing factors and the solutions to biophysical challenges in the Palmiet Catchment.

Waste

Littering and the lack of a solid waste management program have been the major root cause of excessive waste in the informal settlement areas and along the river. Waste has attracted pests like rats, which are believed to have attracted a high number of snakes. The snakes have been identified as a risk to the community, especially following a report of a fatality that was supposedly due to a snake bite. Mr Nick Evans, a herpetologist, was approached by the UKZN team to remove a 3m black mamba *(Dendroaspis polylepis*). The snake was caught along the busy pedestrian walk next to an illegal dump site, adjacent to settlement homes on 5th May 2016. An urgent need to educate the community about the risks of the accumulating waste, rats and the awareness of snakes emerged.

Ten young snake monitors were nominated from the community during the workshop which was coordinated by the UKZN team in partnership with Mr Evans. The workshop created an understanding of the relationship between excessive waste, rats and the apparent increase in snake numbers. It also created awareness of the important role played by snakes in controlling rat numbers and how the snake monitors should approach snakes. A further aim of the training was to reduce the unnecessary killings of non-venomous snakes and to better inform community members of which snakes were dangerous. Through this interaction, the community has recognised that solid waste is a major problem and has discouraged their residents from littering. The communities are also discouraging and closely monitoring illegal dumping by non-residents. In this action there is a clear change in community behaviour which contributes towards addressing solid waste, a mission critical priority.

A commitment from the municipality to implement a waste management proposal has been pursued since 2015 with the 2016 local government elections adding further delays. The Wildlands Conservation Trust was engaged to assist with the initiation of a recycling program to help address the waste management challenge, and provide an opportunity for the participating community members to earn an income.

A recycling pilot project was initiated on 23rd September 2016. Through the project's continuous interaction with the community on waste management issues, ten women from the community expressed their interest in the recycling project. The UKZN team assisted the women with the development of a project business plan. Wildlands Conservation Trust trained these women on recycling waste collection and provided recycling storage bags for paper and plastic collection. The

women were also provided with protective gloves and gumboots as well as refuse bags to collect the material. The Wildlands Trust collects the recycling material in exchange for money, according to the waste material and its mass. Challenges were experienced in the initial phases of the project, but the women have now received payments from their several collections. Establishment of green economy initiatives, based on the Community Ecosystem-based Adaptation (CEBA) approach using innovative funding models is one of the fundamental goals for climate adaptation in the City. The CPB has engaged Wildlands Trust to facilitate a workshop for the recycling project participants to help improve implementation of the project.

Removal of solid waste by the municipality commenced at the beginning of February 2017. This program was once initiated but was soon halted following disagreements between the municipality and the community. This time around the communities have welcomed the services of the municipality. A commitment from the Durban Solid Waste Unit (DSW) and the community is an essential component to ensure that waste collection is implemented efficiently in an area like the informal settlement. Waste collection is currently implemented in a provisional state, which has led a couple of challenges and interruptions. These include the distribution of black refuse bags to households; identification of common collection zones; as well as the lack of consistency on the collection days. A waste collection program needs to be systematic and requires proper guidelines and systems to be put in place and needs to be well communicated to the communities. Hence the need for area specific support" from DSW to be engaged through the PRP was then identified. The CPB has identified and secured a representative from DSW who is a Customer Liaison Officer for Quarry Road West and Clare Estate informal settlements. Mr Mqanjelwa Mabika has agreed to be the DSW point of contact and a representative at the CoI meetings to improve the waste program challenges.

Following the capture of the snake, the nomination of the ten young snake monitors and the waste initiatives there have been no further reports of snake related problems.

2.2.1. River pollution

The Palmiet River is continuously being subjected to pollution events. The Palmiet River Watch (PRW) monitors and reports water pollution on a regular basis and it reported 120 cases during 2016. These cases include industrial and household pollution as well as contamination by failures in the sewage system. The eThekwini Water & Sanitation's Pollution and Environment Branch (PEB) has been struggling with capacity to closely monitor these incidents and to deal with their source. The PRW has a close working relationship with local media to raise awareness on river pollution and work done by the NGO to address it, and several articles have been published.

Notable successes have been achieved; however the impact of these achievements is limited. Consequently, the action plan implementation progress evaluation by CoI points out that the stakeholders have been dealing with the symptoms and not with the source of identified problems. The identified challenges require the attention of the responsible municipal line functions. Key

projects addressing mission critical action items have been aligned with the relevant municipal line functions and stakeholders identified in the action plan. From that, several concept notes have been developed that the CoI will use to engage the relevant or affected line functions to invite them to engage with the projects. These projects are being developed as work packages as part of a work plan for implementation following the securing of funding from eThekwini Municipality. The purpose of the concept notes is to extend an invitation to line functions to engage as members of the CoI specifically to drive interventions in the Palmiet Catchment to extend the ability of the Municipality to provide service delivery and adapt to the impacts of climate change. During the project's stakeholder engagement process, a number of key challenges which negatively impact on water quality have emerged, threatening the long term ecological health of the Palmiet system and the health and safety of catchment communities, and which increase the risks of damage to private and public property.

The CoI has identified a number of strategic interventions that it considers critical to address the challenges in the catchment and ecological infrastructure, Water Sensitive Urban Design and Sustainable Urban Drainage Solutions approaches have been highlighted as key solutions. The CoI seeks an opportunity to present the concept notes at the eThekwini Municipality Disaster Management Advisory Forum to secure administrative leadership support, as well as the political committees for political support. It is envisaged that a long term plan to address these challenges can be agreed upon.

2.3. Social

The QRW communities are a direct link to some of the challenges in the catchment. Their involvement in the project enables an open channel of communication and working relationship with the municipality and the other stakeholders, in understanding issues within the informal settlement. The UKZN team has conducted household surveys- to determine the relationship between the river and the informal settlement community and a research paper is under a peer-review process.

2.3.1. Socio-Economic Upliftment

The Palmiet project aims for initiatives that bring multiple co-benefits, like job creation and poverty alleviation, to improve community resilience to climate change. The recycling pilot project represents the thin end of a wedge that will be used to address the high rate of unemployment in the informal settlement. The establishment of Expanded Public Works Programme (EPWP) and "Sihlanzimvelo" type initiatives will be key approaches in the improvement of the socio-economic status of the households within the informal settlement, while the rehabilitation of ecological infrastructure is planned for the catchment. The municipality will require funding to establish and sustain such programs.

2.3.2. Community Vulnerability

The QRW settlement falls within the 1:50 year floodline and the community is exposed to a risk of flash flooding. The CoI has established a communication platform, using social media and cell

phones to circulate early warning messages of possible extreme weather events, as published by the South African Weather Services, so that they take necessary precautionary measures. During the May and August 2016 extreme rainfall events, communities were affected by floods due to burst riverbanks and overwhelmed storm water drainage systems. Informal houses were washed away and a fatality was reported during the latter incident. This fatality by drowning was due to the volume of sheet water flowing through a section of the QRW informal settlement towards the river, rather than the river bursting its banks. It heralds a not hitherto seen level and type of water movement in the catchment. The eThekwini disaster management team assisted the affected families with communal tents, food parcels and blankets. The CoI remains vigilant and continuously monitors the river flow during the rainfall events. Circulation of early warning messages via WhatsApp to communities remains a valuable and potentially life-saving tool.

One QRW resident's household structure is at high risk of flooding due to a collapsed river bank. The ward council has been engaged to seek permission for the relocation of the family structure to a low risk area within the settlement. The Khumalo family has been allocated a site away from the river. The project has identified an opportunity to work with other stakeholders to design and build a structure that would be a home whilst being resilient to extreme events, including flooding and heat using building material currently available to QRW residents.

Illegal electricity connections in the formal settlement remain a challenge for the city. The community has also been affected by numerous fire incidents. The municipality has commenced with the roll out of phased electrification at the Quarry Road West informal settlement. This project was implemented shortly after a child succumbed to a fatal electrocution.

The CoI has limited social input to the project. The community had identified a crèche and a pedestrian bridge for the safety of their children. The CoI engaged with the community to identify a suitable area proposed for the construction of the pedestrian bridge. It was necessary for the CoI to understand the needs and associated risks that precede a request to construct a bridge. The construction of the proposed bridge was intended to provide easy access to the adjacent section of the informal settlement, which is separated by the river. The community has retained access to the adjacent informal settlement by using an exposed storm water pipe to cross the river. However, this has been discovered to be nearly impossible and of high risk to people particularly during flood events. Furthermore, the community is forced to extend their walk around the informal settlement during periods of turbulent and high river flows. The extended walk was found to have no significant impact on travel time, safety or community wellbeing. During data collection and risk analysis from the "Mapping Project" based on community participation, the community concluded that the construction of the bridge would be low in the list of the community's priority needs. The CoI does not have a mandate to take decisions and implement some of the proposed solutions. In addition to lack of funds, there are guidelines from legislation and municipal polices that need to be followed. The project requires financial commitment and the commitment from the various relevant line functions, as well as the political leadership for its social aspect to be fulfilled.

3. Way Forward

Stakeholder's collaborative learning through each milestones has been a fundamental output in the implementation and the progress to the project. The CoI are collaborating on a peer-review publication evaluating the progress of the project. The UKZN research team will also embark on a community based mapping and Geographic Information systems (GIS) which will profile each household and provide an integrated output to the project.

EThekwini Municipality has acquired loan funding through the Integrated Infrastructure Programme of South Africa (IIPSA) to the value of R700 million as well as a grant of R93 million towards the Northern and Western Aqueduct projects that aim to address water-related challenges where the existing bulk water supply infrastructure has reached the limit of its capacity. In addition to having secured this funding, the city has a contractual condition to address land use management practices. Section 5.5 and 11.16 of the Facility Agreement between eThekwini Municipality and the Development Bank of South Africa stipulates that the City as a grant recipient should invest at least R5 Million on the integrity of the ecological infrastructure within the Municipality. The outcome lessons should be shared with the Grantor and its associates like the South African National Biodiversity Institute, which is a major stakeholder of the UEIP. During a recent UIEP coordination committee meeting (14th November 2016 and 18th May 2017) it was resolved that the PRP, as a pilot proof of concept project for the value of ecological infrastructure would be ideal to pilot a community-based rehabilitation of the catchment's ecological infrastructure. The funds were then transferred from eThekwini Municipality Water and Sanitation Unit to the EPCPD which has a global reputation for pioneering the Community Ecosystem-Based Adaptation (CEBA) approach that includes ecological infrastructure-related work and is the PRP coordinator. The CoI have identified a project approach that aligns with the project action plan and are busy with securing a service provider for implementation.

This funding will not be able to address all of the required interventions in the catchment. The project will consider pursuing additional funding to seek an integrated rehabilitation of the entire catchment. Engagements with the line functions to commit to the project may also be the key to unlock some of the financial and capacity challenges.

In the next quarter, the PRP Secretariat will develop an evaluation process to measure success with implementing the prioritised action plan. This will be report in the CoI meetings, and in subsequent progress reports.

APPENDIX D: IMAGES OF THE PALMIET RIVER

The Palmiet River has been a degraded system for a few years now and the images presented below are of the lower catchment within the informal settlement where the Palmiet passes through before entering the uMngeni River. The source and dates are included with each image.

Source: Lenesh Sukhlala (EWS), 22 June 2018

Source: Lenesh Sukhlal (EWS), 22 June 2018

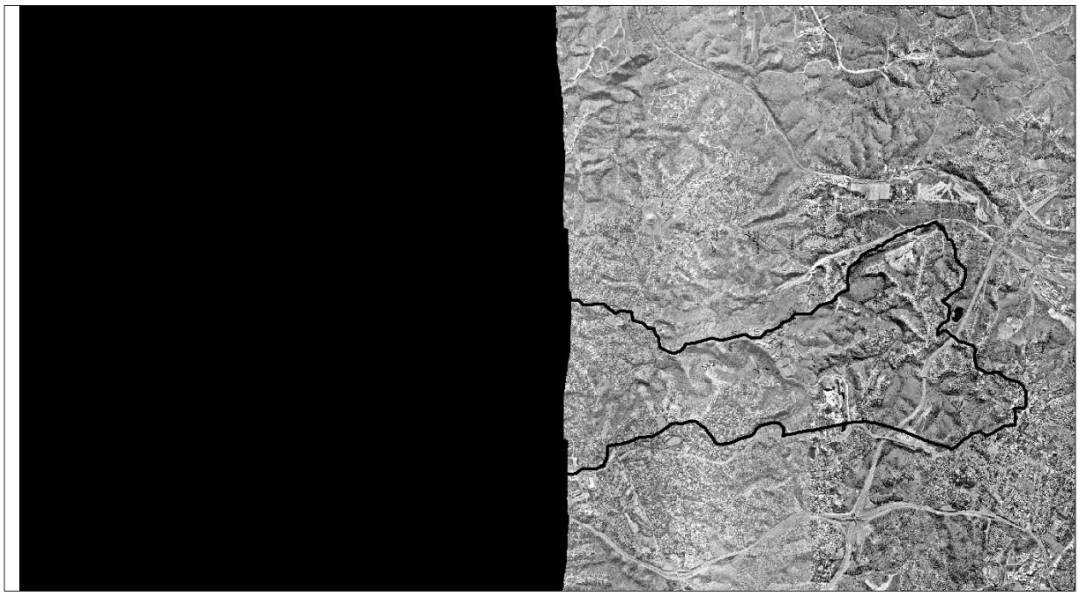
Source: Lenesh Sukhlal (EWS), 22 June 2018

Source: Lenesh Sukhlal (EWS), 26 June 2018

Source: Lenesh Sukhlal (EWS), 23 September 2016

Source: Lenesh Sukhlal (EWS), 23 September 2016

Pinetown/New Germany Industrial area in 1981



Pinetown/New Germany Industrial area in 1999